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Bari, 2-5 September 2024

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a cura della Società Geologica Italiana

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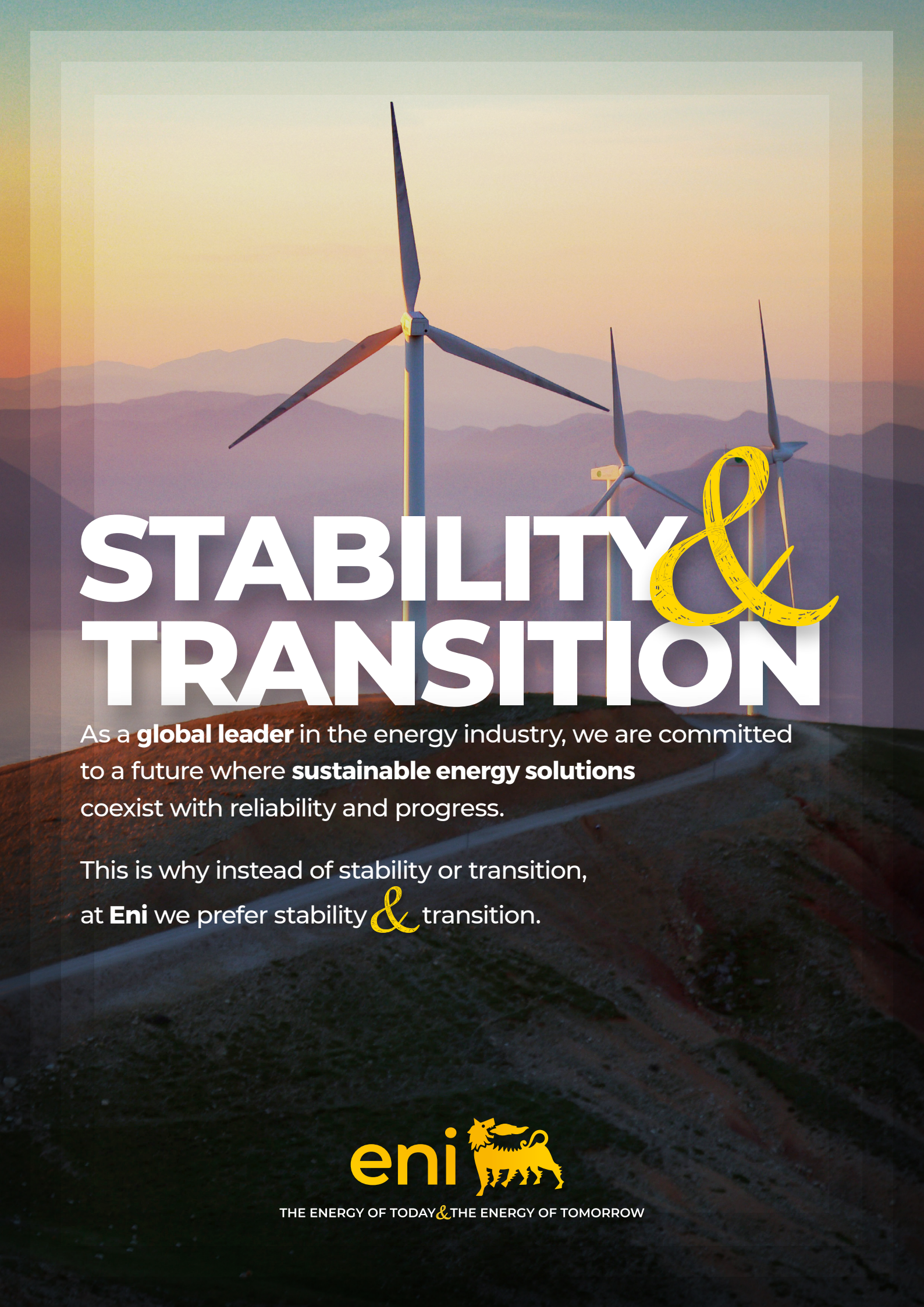
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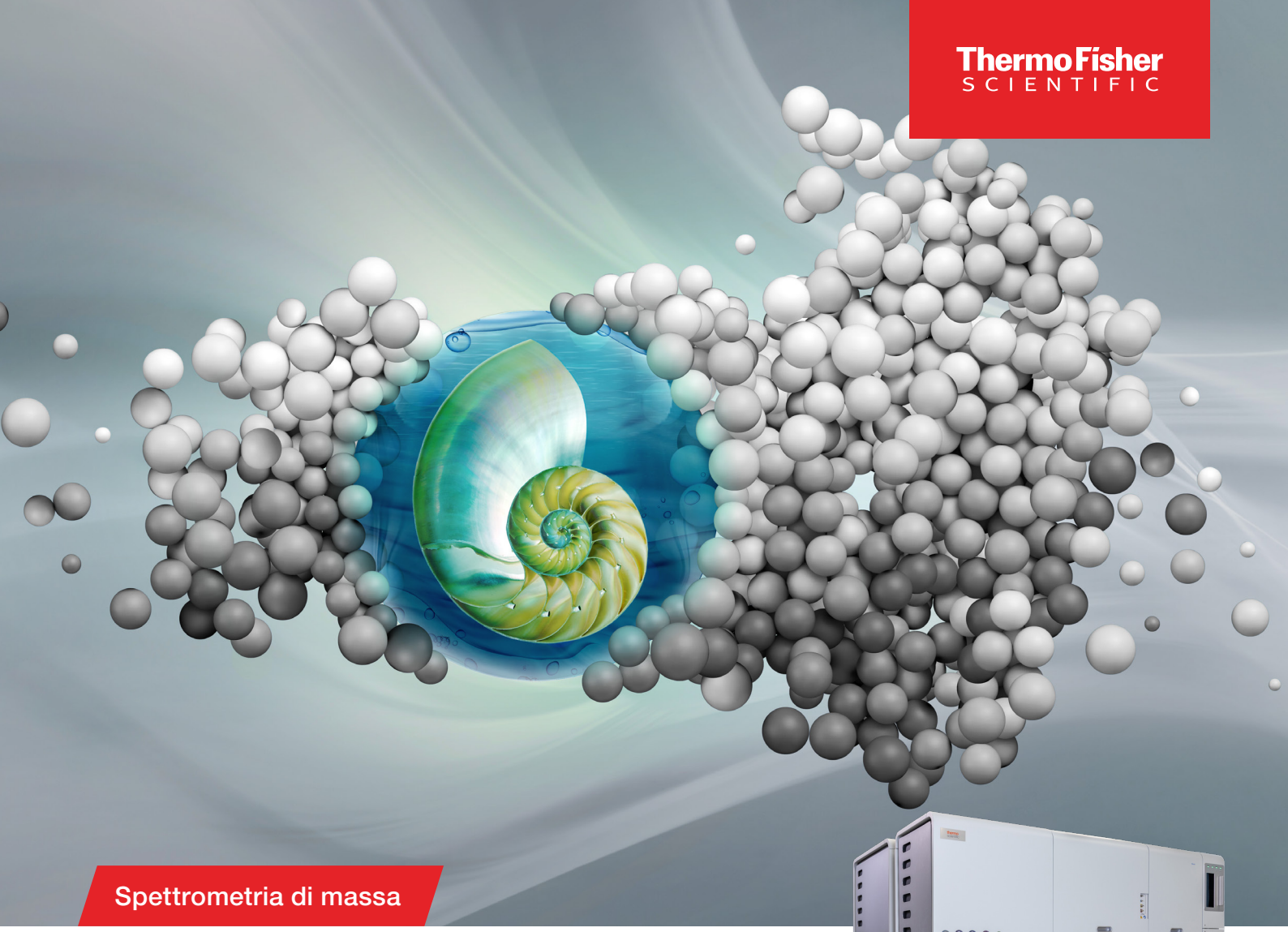

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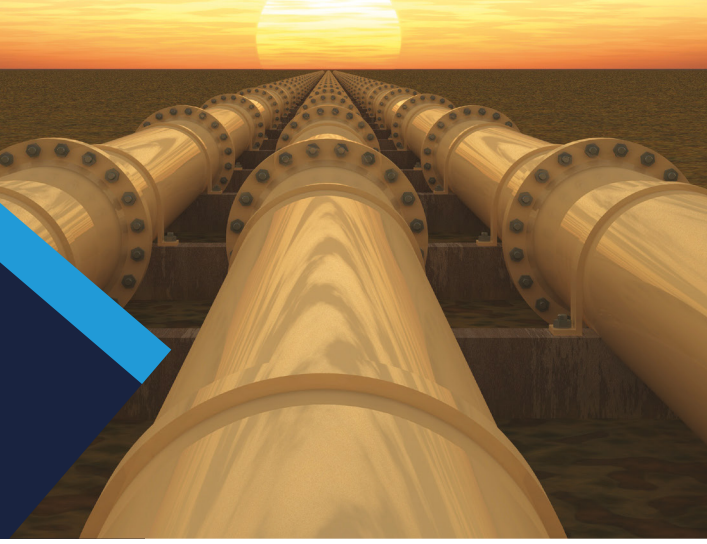

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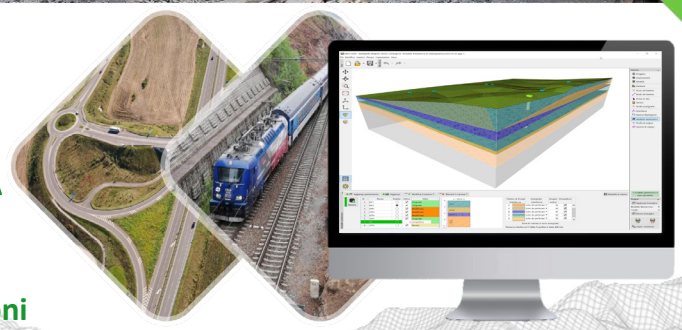

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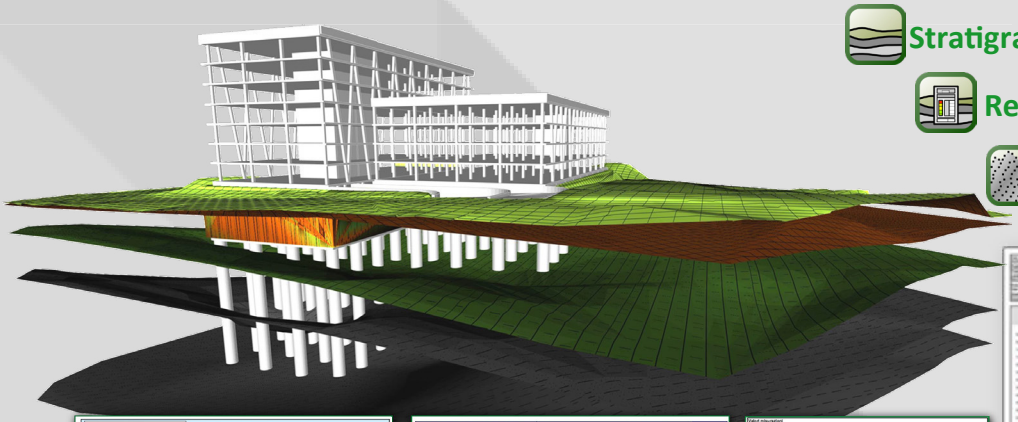

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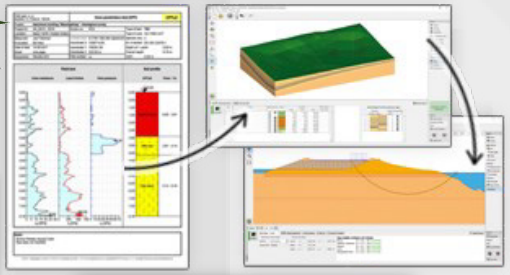

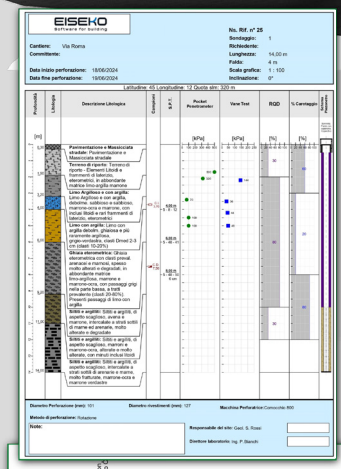

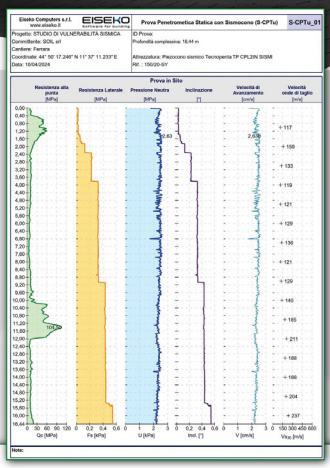

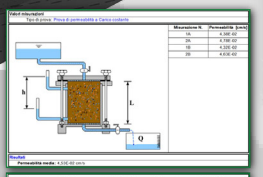

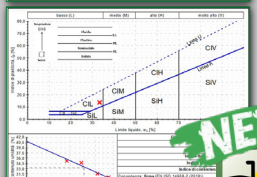

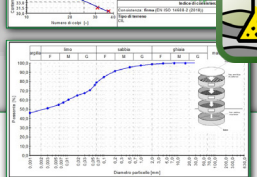

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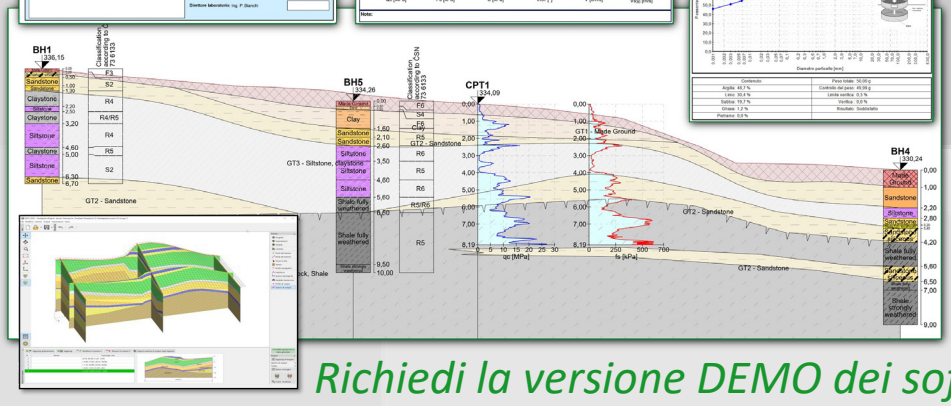

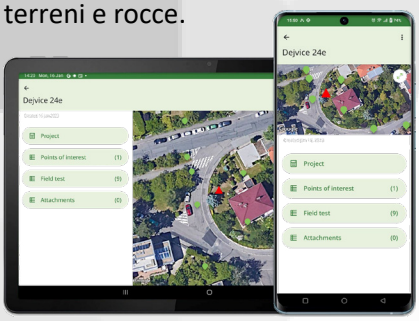

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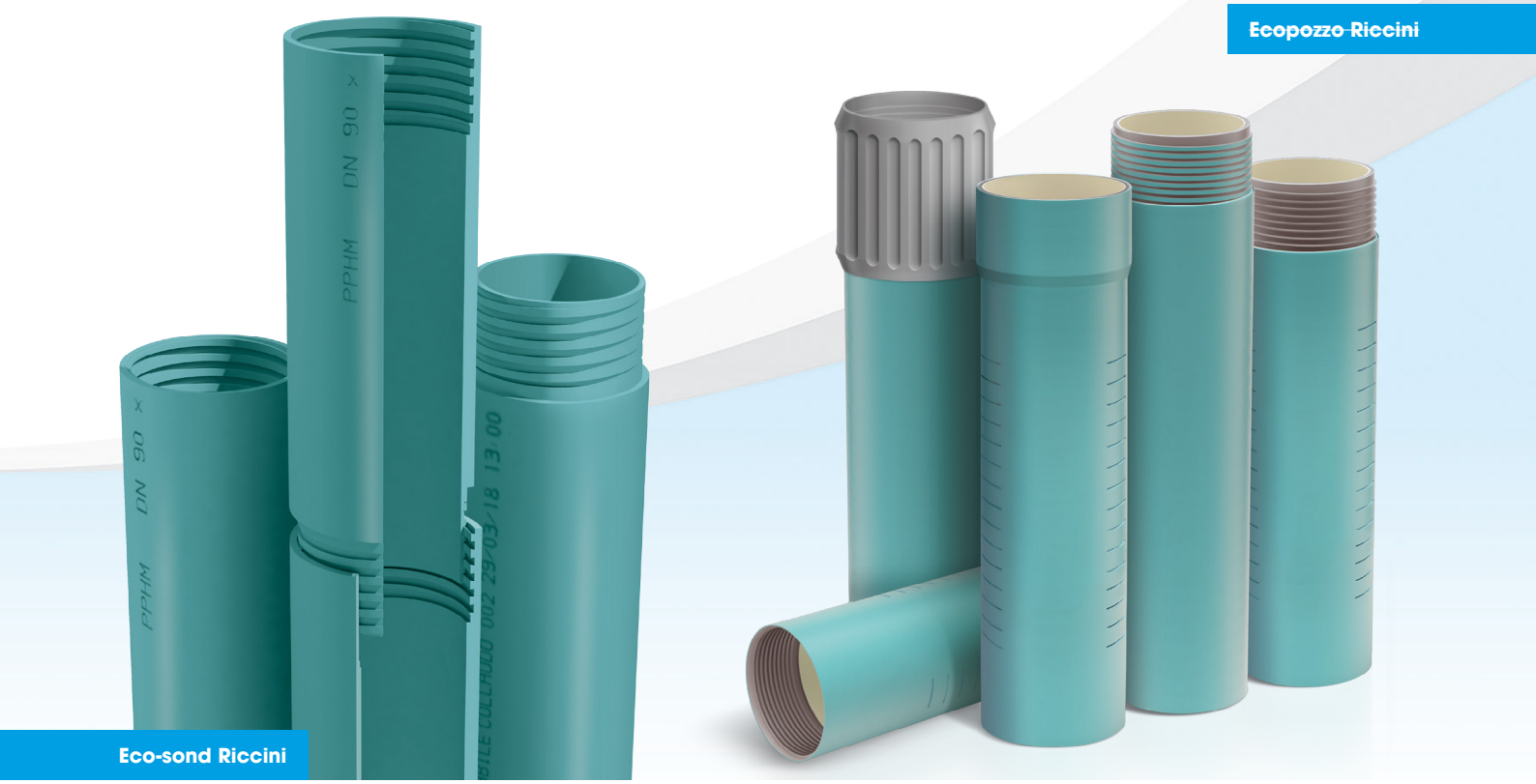

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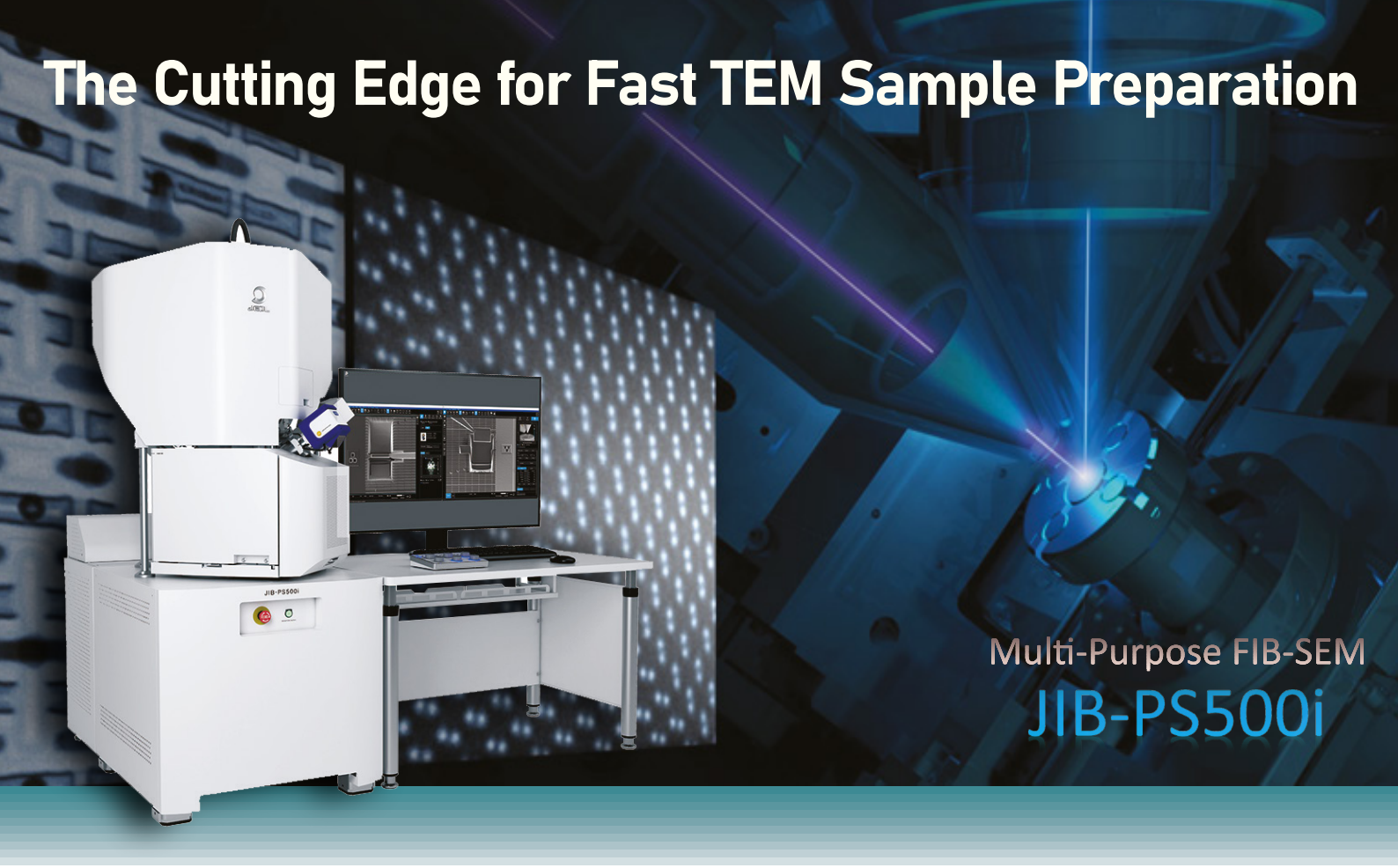

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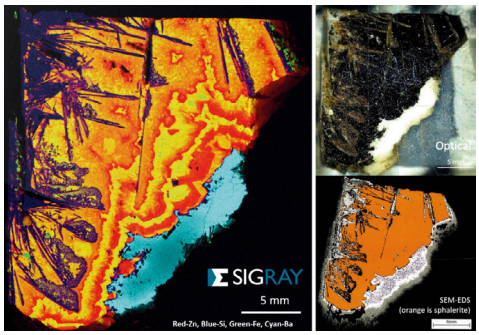

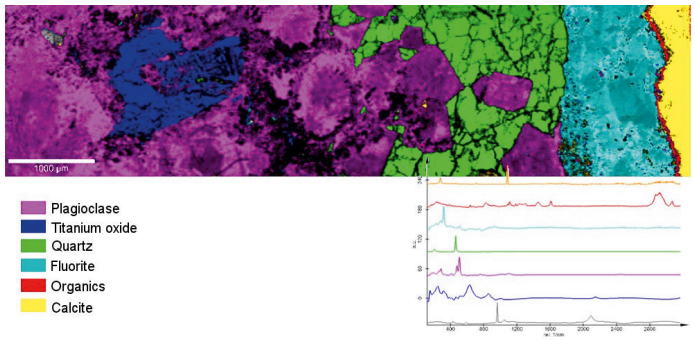

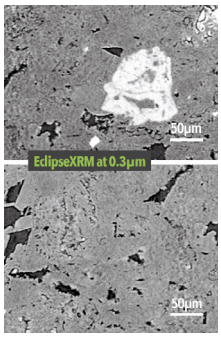

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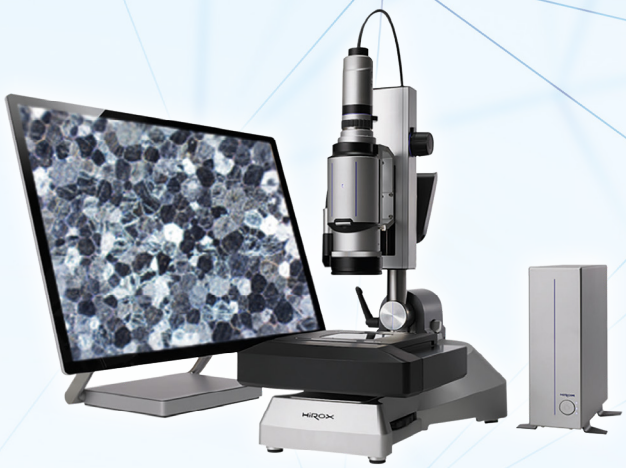

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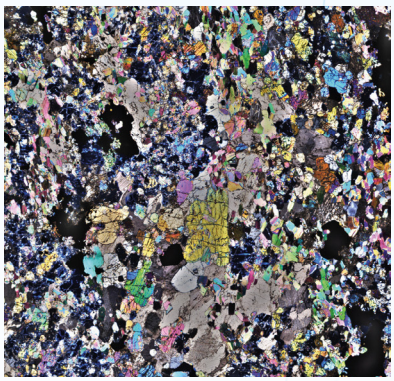

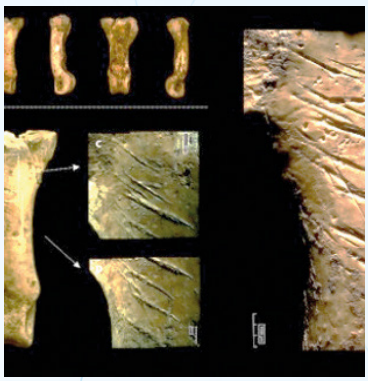
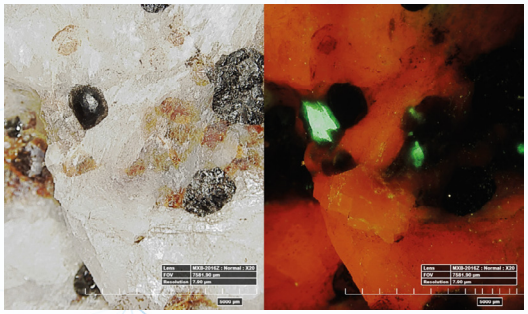
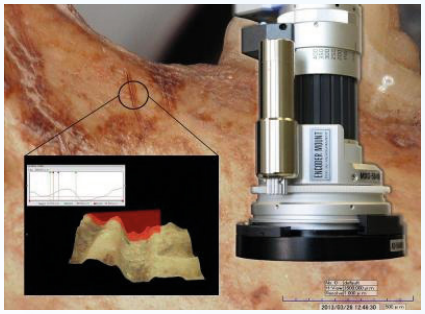
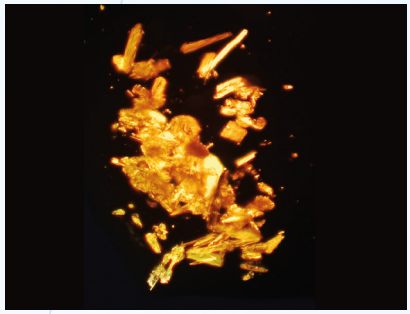

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Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Università degli Studi di Bari Aldo Moro

Workshop nell'ambito della Cerimonia di Apertura

2 settembre 2024, ore 17:00

Aula Magna Attilio Alto - Politecnico di Bari
Campus Universitario Ernesto Quagliariello - Bari

La geologia per la società: l'importanza della comunicazione, così difficile, così necessaria

Christopher Jackson
(BBC)
Geoscience Communication During the Energy Transition

Özlem Adiyaman Lopes
(UNESCO)
Geology and the Sustainable Development Goals

Luigi Bignami
(FOCUS)
Geologia: quanto bella e affascinante...ma quanto difficile raccontarla

Emilio Casalini
(RAI 3)
Raccontare la bellezza per imparare a riconoscerla e a condividerla

Progetto Euroseeds UNIBA S63 - Patrimonio naturalistico e turismo culturale ed escursionistico in aree protette (pa.na.c.e.a.)

Divulgazione dei concetti
di "sviluppo sostenibile"
e di "conservazione e gestione
della geo/bio-diversità"

HORIZON EUROPE SEEDS

OPENING CERIMONY

Geoscience Communication During the Energy Transition

Jackson C.A-L.

Department of Earth Science & Engineering, Imperial College, London

Geological issues related to the Earth's subsurface increasingly intruding on the everyday lives of ordinary people. Whether it is the subsurface injection of water for geothermal power, the deep storage of waste such as CO_2 or spent nuclear material, or the storage and recovery of H_2 and O_2, the global public are being confronted with complex, often controversial, and yet critical (in terms of tackling the linked issues of global warming and lower-carbon energy provision) geological interventions beneath their homes. Communicating these complex scientific and technical issues is made more challenging by the general public's unfamiliarity with the geological realm, with cognitive studies highlighting that the public is anxious about what they perceive as tampering with nature. Relatively recent events have shown that this anxiety is not misplaced, given geothermally- and fracking-induced seismicity, and mine tailings dam failures.

The natural response of scientists is to assume that technical rigour and the simple conveyance of facts will allay the public's concerns and gain them 'licence to operate'. However, values and beliefs may trump data, particularly when filtered through the lived experience of individuals who not only have limited understanding of the Earth beneath their feet, but who have also experienced poor conduct by companies. Shaping public perspectives on controversial geoscientific issues are thus challenging, yet it is critical that companies are prepared for these discussions. With a growing recognition that it is social rather than technical factors that stir public unease and fuel community outrage, geoscientists need to develop new strategies to engage the sometimes-hostile public, underpinned by a culture change in geocommunication from conveying 'matters of fact' to brokering 'matters of concern'.

In this talk I will review several studies with the intent of how we might better communicate "contested geoscience"!

Geology and the Sustainble Development Goals

Adiyaman Lopes O. & Sabo R.

Section on Earth Sciences and Geoparks, Division of Ecological and Earth Sciences, Natural Sciences Sector, The United Nations Educational, Scientific and Cultural Organization (UNESCO)

Geology, with its quiet wisdom, reveals the connection of all life, showing that sustainable development is rooted in humans' mutual relationship with the Earth. UNESCO recognises that neglecting to understand our planet's geological framework could undermine 2030 the Sustainable Development Goals (SDGs). UNESCO, which holds the unique United Nations mandate for geoscience, directs a global network of geologists and sites working on projects related to the SDGs through its International Geoscience and Geoparks Programme (IGGP).

Geoscientists Unite for Planetary Challenges: The International Geoscience Programme (IGCP)

In collaboration with the International Union of Geological Sciences (IUGS), the IGCP programme harnesses the intellectual capacity of a worldwide network of geoscientists to lay the foundation for our planet's future, highlighting the importance of SDG 17: Partnerships for Goals amongst other. The IGCP supports projects under six themes: Earth resources, global changes and the evolution of life, geohazards, hydrogeology, geodynamics, and geoheritage, addressing global challenges and sustainable development. The programme also supports female scientists, youth, and those from developing countries.

As an illustration, IGCP project 767: Environmental Dynamics of Western Rwanda focus on SDG 3: Good Health and Wellbeing. This project conducts a comprehensive study of the Mount Nyiragongo region in Rwanda to understand potential health risks to inhabitants, particularly regarding volcanic emissions, soils, and lakes.

Geological Heritage for Everyone: UNESCO Designated sites and geosciences

UNESCO designated sites, World Heritage, Biosphere Reserves and Global Geoparks (UGGp), aim to protect our heritage, which is deeply connected with geology. Italy is home to the largest number of world heritage sites, with 59 inscribed properties, all of which relate to the geoheritage of Italy.

Humans have always been connected to Earth, and the 213 UNESCO Global Geoparks across 48 countries, as of 2024, uniquely embody this connection. Geoparks empower local communities to understand and nurture their territories. A UGGp integrates the protection and promotion of geological heritage with sustainable local development, focusing on conserving geological heritage alongside other heritage types to enhance community living conditions. Thus, the three pillars of a UGGp are geoconservation, education, and local sustainable development (Fornaro & Fernandes, 2018).

Concerning sustainable development, geoparks implement projects that benefit local communities through a "bottom-up" approach, which is demonstrated in the 11 UGGps in Italy (2024) . For example, Rocca di Cerere's UGGp in Italy, established a Local Development Strategy focusing on enhancing the area's sustainability by improving local environmental and cultural heritage, as well as agricultural resources. In the short term, it aims to improve residents' quality of life and social inclusion, while long-term goals include preventing depopulation and strengthening the social fabric.

UNESCO Global Geoparks make geology accessible to all and highlight the importance of connecting with local geological features for sustainable development.

Geology: as fascinating as difficult to describe

Bignami L.

Journalist and science communicator

The history of mankind is tied to the history of the Earth. The birth of our Planet, its evolution, the ongoing geological processes have allowed and allow the Planet to be alive and host life. Yet we know very little about what happened during Earth's 4.5 billion years of life, and we know even less about what lies beneath the surface. While all this is fascinating, the lack of knowledge of many geological processes makes it difficult to explain geology to non-geologists.

Luckily, sometimes nature comes to our aid: this is the case of Calabria, for example, where tectonic thrusts have bent the "layers" of the Earth by 90 degrees. It's as if instead of having a book to read page after page, you had a vertical book that allows you to see all the pages from above, from the first to the last one. Crossing Calabria from east to west across the verticalized layers, it is possible to walk from the rocks that were at the transition between crust and mantle up to the more superficial rocks of the crust. An example of how anyone can travel down to the depths of the Earth's structure while standing on its surface.

But explaining geology is also difficult because we are not used to imagining in three dimensions what is under our feet. And this is fundamental because the layers of the Earth are not always parallel to each other, and their chronological order is often reversed. In fact, buried "folds", "faults", and "thrusts" could have folded everything and brought very old rocks on top of younger rocks. The trained eye of a geologist can sometimes picture all this complexity, but for the layman things become simply too complex to understand. It takes knowledge and imagination, and a good dose of interpretation and creativity to properly convey the beauty of geology. In this way, a good geology communicator can show how, in addition to being useful, geology can lead to see the "beauty" of our Earth.

If geological dissemination can achieve this ambitious goal, it will lead us on the right path to understanding why the beauties of the Planet sometimes become destructive for mankind. Especially if and when mankind is unable to read the geological clues around us.

The storytelling of natural beauty to learn how to recognize and share it

Casalini E.

Journalist, writer, radio and television host

Italy, this privileged country where we are surrounded by beauty since our birth. And perhaps for this reason our eyes have become accustomed to absorbing all this beauty while our hands, words, actions, thoughts are less used to it.

Art, museums, archaeological areas, religious and civil buildings which made our cities, towns, villages with their amazing historic city center and squares like hearts. They are part of the incredible cultural heritage that we share with the world. This is the reason why people land here from every part of the world. And we can add music, speeches, culture, food and wine, craftsmanship, including fashion. All this, and much more, is the opera of human beings.

But also nature it's an absolute protagonist of our story. Even if we forget about it and it's a shame, because it has so much to tell.

In stones which gave substance to all architectures designed over the centuries and of which we are rightly proud. From Carrara marble that provides the material for Jago and Michelangelo's artworks, to the raw materials used to make the colors that filled our imagination. Like the most famous fresco in the world, the Last Judgment of the Sistine Chapel, whose blue has reached us with that intensity because it is made with lapis lazuli, a mineral extracted for 7 thousand years in Afghanistan's mines of Sar-e-Sang. And getting it there cost an arm and a leg and only a Pope could afford it.

So, the storytelling of that wonder becomes much richer if there is also the voice of a geologist in addition to the one of an art expert.

Thus our landscapes, our lands, from Sienna to the small spheres of Is Arutas' beach in Sardinia, become the reason for a trip. Better appreciated if told in any aspect.

To discover the beauty hidden within the mineral life that surrounds us.

PLENARY SESSIONS

Digital classroom for petrology and mineralogy

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Carl Zeiss S.p.A.

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Keywords: digital classroom, connected microscopes, interaction.

Teaching is the art of passing knowledge of the few on to the many. For this you need a good overview of all the learners, a deep insight into the individuals, and the option of networking them all together. A digital classroom with connected microscopes is a valuable tool in teaching today. It enables endless opportunities to create hands-on, customizable learning experiences and build deep understanding in the classroom. Students learn easily from each other and experience learning successes in a playful way. Connected microscopes offer an interactive, digital platform which increases attention and motivation, and also gives freedom to the teacher. During the education, larger groups of students are required to spend several days per week in a microscopic lab. Learning time is always limited and the course leader often needs to set-up and dismantle the systems in shortest time. The microscopes must be robust and easy-touse. A digital classroom is a major benefit to course leaders it allows them to use microscopes that are connected to each other, and digital tools to support and enhance teaching and learning. The images and videos can be shared directly with students. This allows open discussion and the explanation of the visible components. Fast acquisition, taking notes and annotating, saving and sharing the results are necessary. Direct access to each student's microscopic live image for the course leader makes the classroom more interactive. Students, as well as course leaders, should be inspired and have fun.

How Geoscientists can make the difference in industrial carbon storage projects

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ENI SpA.

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Keywords: CO_2 storage, basin geology, geological modeling, structural geology.

The underground storage of CO_2 is considered one of the most effective strategies to mitigate climate change by removing CO_2 from the atmosphere, with special reference to the so-called 'hard-to-abate' industries. The search for a safe pore space is a huge problem for any company interested in reducing their emission profile. Subsurface knowledge and understanding are therefore key factors in finding suitable sites which must be able to store a significant amount of CO_2. To be effective, an industrial storage project must tackle a series of geological issues which are more complex than the traditional O&G workflows. Therefore, the Geoscientist has a key role in designing effective storage solutions, from regional screening to site monitoring, providing the scientific basis for regulatory frameworks and public assurance.

The birth of the modern ocean and its first 180 million years of crises, speciations and extinctions

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Keywords: ocean ecosystems, coccolithopores, Mesozoic, biodiversity, resilience.

Along with diatoms, cyanobacteria and dinoflagellates, coccolithophores are responsible for primary productivity, energy transfer, export of biogenic particles, and exchanges with the atmosphere. Coccolithophores are the most abundant calcifying organisms in the oceans, and their fossils are key for tracking global climate-ocean changes.

The rise of coccolithogenesis is a profound ecological innovation in the ocean ecosystem. Early Triassic nannofossils from South China help understand the circumstances prompting (or allowing) phytoplankton to mineralize calcite, marking the birth of the modern ocean. Coccolithophore origination shortly after the Permian mass extinction reset marine ecosystems, forcing biota to adapt to extreme climatic and chemical conditions and novel niches. The onset of coccolithogenesis began a long and successful evolutionary trajectory that influenced oceanic ecosystem dynamics, biochemical processes, and sedimentation. The geological history of coccolithophores indicates Mesozoic evolution characterized by increasing diversity, punctuated by speciations, extinctions, and turnovers that led to 25 coccolith/nannolith families and 5 groups Incertae sedis, peaking before the end-Cretaceous mass extinction.

Times of accelerated rates or drops in nannofossil diversification correlate with global changes in the geosphere, hydrosphere, and atmosphere, linking evolutionary patterns to environmental perturbations. Significant events in Mesozoic nannoplankton evolution align with changes in CO_2 concentrations, nutrient availability, ocean chemistry, and climate. Global environmental changes are interconnected with geological processes, and biosphere evolution should be linked to the Earth's interior. However, it is challenging (and contentious) single out causes triggering coccolithophore evolution and calcification; a combination of environmental changes likely drives evolutionary innovations and stability.

Mesozoic coccolithophore biodiversity and calcification patterns can assess their resilience: calcareous nannoplankton as a whole showed high resistance to global disturbances maintaining diversity, while individual taxa varied in resilience. Calcification patterns reveal moderate to lowered resilience, with species-specific sensitivity and resistance: timing, magnitude, and recovery dynamics aids understanding the impacts of current global changes and thresholds leading to ecological crises. Improved chronology of paleobiological and geological events is crucial for understanding evolutionary processes.

L'analisi qualitativa e quantitativa del rischio geomorfologico e la sua gestione tramite sistemi di allertamento lungo le infrastrutture ferroviarie

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Keywords: rischio geomorfologico, sistemi di allertamento, analisi quantitativa.

La mappatura del rischio geomorfologico è fondamentale per la valutazione di innesco di eventi e delle relative conseguenze. L'analisi può essere affrontata con approcci qualitativi, volti alla prioritizzazione delle strategie e degli interventi, e approcci quantitativi basati sulle curve di probabilità e l'analisi delle conseguenze. I sistemi di valutazione del rischio necessitano, inoltre, dell'integrazione con i Sistemi di Allertamento (EWS) per l'innesco di eventi pluvio indotti consentendo anche una gestione in tempo reale del rischio quantitativo. Nella relazione sono illustrate tecnologie all'avanguardia per l'acquisizione di dati lungo le infrastrutture (ARCHITA) e algoritmi di calcolo che permettono l'analisi a diverse scale e livelli di dettaglio, integrando l'approccio qualitativo e quello quantitativo tramite (MIRETS, modulo di Mappatura Idrogeologica).

Contourites and mixed depositional systems: a paradigm for deepwater sedimentary environments

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Keywords: contourites, mixed depoositional systems (turbidite-contourite), deepwater depositional systems.

Along-slope bottom currents and a series of secondary oceanographic processes interact at different scales to form sedimentary deposits referred to as contourite and mixed (turbidite-contourite) depositional systems. Recent proliferation of both academic and industry research on deep-marine sedimentation documents significant advances in the understanding of these systems, but most non-specialists remain unaware of the features in question and how they form. Contourites and mixed depositional systems represent a major domain of continental margin and adjacent abyssal plain sedimentation in many of the world's oceans. They also appear in Palaeozoic, Mesozoic and Cenozoic stratigraphic sections. The growing interest in these systems has led to a refined but still evolving understanding of them. In addition to resolving their exact origins and evolutionary trajectories, research must also continue to ascertain their role in deep-sea ecosystems, geological hazards, environmental policy and economic development. Key gaps in understanding persist regarding their formation, their function in oceanographic systems and their evolution over time.

This Plenary Session summarises current conceptual paradigms for contourite and mixed depositional systems, lists global geographic examples of these systems and discusses their identification and interpretation in terms of diagnostic features as they appear in 2D and 3D seismic datasets and at sedimentary facies scale. It also considers the role that bottom currents play in shaping the seafloor and controlling the sedimentary stacking patterns of deepwater sedimentary successions. The growing interest in, and implications of, contourite and mixed depositional systems demonstrates that these systems represent significant deep-marine sedimentary environments. Combined efforts of researchers, industry partners and policy-makers can help advance understanding and responsible stewardship of deepwater depositional systems.

Sustainable mining of critical raw materials: opportunities and obstacles for geoscientists

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Keywords: mineral resources, CRMs, sustainability.

The 'green' energy transition away from carbon-based fuels is driving a resurgence in mining because Earth materials are needed in renewable technologies such as battery-driven vehicles, solar panels and wind turbines. These technologies require specialist materials, many of which are known as critical raw materials (CRMs). CRMs have high economic importance and a high supply risk. Variable CRM lists have been defined by different countries and regions (US, EU, Canada, Australia, etc.) but the lists often include metals such as Li, Co, REE and tungsten, and materials such as graphite and fluorspar. Globally, significant exploration and development of CRM deposits is in progress, with the aim of mining many of these to increase the supply of CRMs. To reduce the negative aspects of mining, and to respond to pressures from consumers, many companies have adopted a 'sustainable mining' policy to undertake mining that is profitable and maximises the flow of resources into circulation while protecting the environment and human rights and health. This presentation outlines opportunities and obstacles for geoscientists with respect to sustainable mining of CRMs. Opportunities include developing geomodels for previously understudied CRM orebodies and working in multidisciplinary teams to deliver innovation technologies and procedures along the whole mining value chain for the industry. Time constraints and integration of natural, engineering and social science research are some of the obstacles that will be discussed. Overall, geoscientists have a major leading role to play in the global sustainable mining of CRMs.

Carbon isotope analyses on dissolved inorganic carbon of seawater samples: sample preparation and analysis using the GasBench Plus system

Pellegrini M.* & Fischer M.

Thermo Fisher Scientific

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Keywords: $\delta^{13}C$ analyses, sample preparation, GasBench Plus System.

The $\delta^{13}C$ isotope composition of the dissolved inorganic carbon (DIC) content of natural water samples helps to better understand carbon cycling and gas exchange in various hydrogeological systems. The biggest challenges of the $\delta^{13}C$ analysis of DIC samples are often connected to sample storage and sample preparation before the analysis with the IRMS and this is based on the fragility of the carbonate balance in water samples.

Extraction and analysis of $\delta^{13}C$ of DIC water samples can be done using the Thermo Scientific™ GasBench Plus universal on-line gas preparation and introduction system that features TriPlus™ RSH SMART Autosampler which enables automatic helium flushing and sampling. Two sample preparation procedures were tested on DIC water samples to investigate their effect on the $\delta^{13}C$ results: method A) Acid-Flushing-Sample and method B) Sample-Flushing-Acid. The selected DIC water samples comprised authentic seawater (spiked with $HgCl_2$). Here we present GasBench Plus System overview and features supporting an optimized workflow for achieving high precision carbon isotope data of DIC in water samples.

S1.

Geobiological and geochemical approaches in the study of bioconstructions and microbe-mineral interactions: new tools for modern and ancient environmental reconstructions and bio-remediation

CONVENERS & CHAIRPERSONS

Mara Cipriani (Università della Calabria)

Mario Borrelli (Università della Calabria)

Carmine Apollaro (Università della Calabria)

Adriano Guido (Università della Calabria)

Daniela Medas (Università di Cagliari)

Marcello Natalicchio (Università di Torino)

Mine tailings characterization and potential pychoremediation

Balzano S.[1], Ghani J.[2], Bettinelli A.[1], Zhao Y.[4], Guo L.[4] & Funari V.*[2-3]

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Keywords: mine tailings, characterization, nannochloropsis sp.

Mine tailing soils pose a potential threat to the environment due to their long-term disposal with toxic metal pollution and adverse eco-toxicological impacts (Chen et al., 2023). The present study aimed at characterizing four samples of mine tailings from different active mining sites in China, by X-ray fluorescence (XRF) and assess elemental recovery after aqua regia digestion (ARD) followed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) determinations. Total elemental contents by XRF showed relatively high Co, Cr, Ni, V, Zr, and REE concentrations in all samples. ARD results showed potentially toxic elements in all samples can be mobile. In the context of minimizing environmental impacts through sustainable decontamination options, we tested phycoremediation using *Nannochloropsis oceanica* strain CCMP1779 in the four mine tailings samples. The mine tailings treated with *N. oceanica* led to a slight increase in metals (Pb, Cr, Ni, and Zn) concentration compared to the control experiment. After four days incubation, microalgal growth was observed in gold- and iron-based mine tailings whereas no growth was observed in the copper- and lead/zinc-based mine tailings. The successful biomass growth and microalga ability to perform leaching showed promises in environmental-friendly phycoremediation of contaminated sediments, with twofold benefit of high biomass-to-bioenergy conversion potential, which is seen as an asset in process sustainability (Kholssi et al., 2023).

Chen X. et al. (2023) - Selected rhizobacteria facilitated phytoremediation of barren and heavy metal contaminated gold mine tailings by Festuca arundinacea. Chemosphere, 337, 139297, https://doi.org/10.1016/j.chemosphere.2023.139297.

Kholssi R. et al. (2023) - Microalgae as a sustainable energy source: Growth and lipids production of Nitzschia sp., Nannochloropsis sp., and Tetraselmis sp. from Mediterranean seawater. Biocatal. Agric. Biotechnol., 50, 102720, https://doi.org/10.1016/j.bcab.2023.102720.

Microbial signatures in the Early Jurassic phosphatic sandstones of the External Rif (Northern Morocco)

Borrelli M.*[1], Kairouani H.[2], Micheletti F.[3], Zaghloul M.N.[2], Fornelli A.[3] & Perri E.[1]

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Keywords: phosphorites, microbialites, carbonate fluorapatite.

In the early Jurassic Prerif succession of the External Rif chain (Northern Morocco), phosphatic-carbonate sandstone deposits were for the first time recorded. These latter are represented by moderately to well sorted fine-grained mixed arenites with sub-angular to well-rounded clasts cemented by sparitic to microsparitic calcite. The phosphatic grains represent ca. 25-30% of the total, whereas the remaining are dominantly made up of carbonate (mostly micritic grains and foraminiferal tests) and secondarily by siliciclastic grains (primarily quartz and secondarily feldspars). The phosphatic grains can be grouped into two main classes: phosphatic peloids in majority and phosphatic bioclasts (as fish bone, representing less than 5% of the total). XRD data revealed the presence of a complex mineralogical assemblage composed by: calcite, present as cement, bioclasts (e.g. formainifera tests) and micritic peloids; quartz, as dominant terrigenous clasts; and phosphate, made by carbonate fluorapatite (CFA). The phosphate grains host multiple witnesses of a precursor biogenic relationship with the mineral structures. In particular, all the phosphate grains result characterized by the densely packed and compressed aggregation of minute nanospheres (ca. 30 - 40 nm in diameter), forming most of the volume of the phosphate grains, except for isolated and sparse zones where these latter gradually aggregates to form assemblages of rod-shaped crystals (ca. 4- 5 μm in length and ca. 1 μm in diameter). The rod-shaped crystals are present both as single and as geminate with a bi-radial structure commonly showing the presence of relicts of small central voids. Both the nanospheres and the rod-shaped crystals are closely associated to organic matter relicts that commonly appear as planar and sheet-like membranes (< 1 μm thick) and rarely as filamentous. Very common microborings with both a spherical up to filamentous unbranched morphology also occur. These latter centripetally penetrate into the bioclasts showing a mineralized dense phosphate rim and an internal hollow structure sparsely filled by acicular phosphate crystals that still leave central internal voids. The microborings can greatly alter or up to completely destroy the original structure of the precursor grain. Understanding the main mechanisms or phosphate deposition and microbial bioerosion can have significant implications for palaeoenvironmental and taphonomic reconstruction, up to possibly define correlations with the Jurassic-Palaeogene large phosphogenic province extending from Middle East to North Africa.

Role of microbes in the the Pliocene giant cold-seep system of the Crotone Basin

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Keywords: cold seep, conduit, pavement.

The giant Pliocene cold seep system of the Crotone Basin (South Italy) represents a key-site for dimension, outcropping exposure and quality. It is composed by a large carbonate (calcite) body (350 m long, 100 m wide, 40 m thick), and characterized by a conduit facies made of authigenic calcite interpreted as previously active gas/fluid escape pipes and by a pavement facies, depicted as the surrounding early calcite-cemented bioclastic and siliciclastic sediments. Pavement facies are commonly colonized by chemosymbiotic and non-chemosymbiotic macrofauna (Lucinids and Solemyids bivalves, gastropods, serpulids). The conduit microfacies is characterized by the inward accretion of dark micritic laminae alternating with whitish sparitic layers. The micritic laminae show a microbial peloidal to dendrolitic fabric, which commonly incorporates planktonic foraminifera and coprolites, whereas the crystalline layers are made of microsparitic and sparitic crusts of prismatic zoned calcite crystals. The pavement facies shows more variability, as it is typified by laminated microbial boundstones, chemosymbiotic-bivalves packstone, foraminiferal packstone/wackestone and hybrid arenites. The stratigraphic constrain coupled with the foraminiferal assemblage (planktonic taxa) suggests a deep-water setting occasionally affected by siliciclastic sedimentary flows. The pavement facies also shows common brecciation features, suggesting the establishment of post-depositional overpressure conditions due to the early cementation of the conduits, which triggered localized rock failure. Stable isotopes analysis of the different facies reveals overall negative $\delta^{13}C$ values (-6.8 to -37.4‰ VPDB) indicating the presence of a complex mixture of methane with other hydrocarbons consumed microbially via anaerobic oxidation of methane. Whereas δ18O is relatively positive (0.0 to 3.4‰ VPDB) suggesting the possible dehydration of clay minerals and/or destabilization of gas hydrates. This study, besides helping in the definition of the migration pathways and modality of accumulation of hydrocarbon-rich fluids, can also help in building more and more realistic models for the complex genesis of cold seep carbonates.

ROV-based sampling as tools for geobiological determination of recent marine bioconstructions

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Keywords: bioconstructions, sampling, technological innovation.

Mediterranean Sea hosts a wide range of biogenic "reefs" originated by the growth and stabilization of several organisms. They are distributed in different marine settings, from shallow to deep water and from open to confined sectors (especially vermetid reefs, sabellariid build-ups, polychaeta/bryozoan biostalactites from submarine caves, coralligenous build-ups and deep-sea cold-water corals) and constitute important archives of recent environmental and climate changes. Among these, the coralligenous habitat represents an important "hot spot" of biodiversity (Ballesteros, 2006) characterized by a low accretion rate and a high sensitivity to natural and anthropic impacts, including the ongoing climate change (Basso et al., 2022).

During the project "CRESCIBLUREEF" and according to principles of the Europe Blue Growth Strategy, a ROV-based innovative technology for minimally invasive sampling of marine bioconstructions has been developed and tested. This underwater coring device is characterized by three main modules: (i) core drilling head, (ii) anchoring system and, (iii) tool change mechanism. Moreover, it is driven via a specifically designed control interface which contains information such as core rotation speed, drilling depth and tool magazine positioning.

Using the protocol proposed by Cipriani et al. (2024), coralligenous core samples, collected from off Marzamemi (Sicily, Italy), are characterized from a geobiological perspective and compared with data obtained from coralligenous build-ups sampled in the same area by scuba-drives the method of Bertolino et al. (2014).

This comparison will assess core-samples obtained with ROV-based technique as representative of the entire bioconstruction. If representativeness is confirmed, the new tool would be used for sampling marine bioconstructions, with minimal invasiveness and preventing unnecessary damage to these slow-growing and delicate ecosystems.

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Cipriani M. et al. (2024) - Origin and role of non-skeletal carbonate in coralligen

Authigenic carbonate and native sulfur formation in Messinian (Upper Miocene) marine sediments: sedimentological, petrographical and geochemical constraints

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Keywords: authigenic carbonates, elemental sulfur, lipid biomarkers.

Carbonate concretions accompanied by elemental sulfur were found in an early Messinian (Late Miocene) marine succession of NW Italy. The rocks were studied with an integrated approach including sedimentological, petrographical, stable isotope (carbon, oxygen, and multiple sulfur isotopes), and lipid biomarker analyses. Unlike other examples from Messinian strata of the Mediterranean area, the studied carbonate and sulfur concretions did not derive from the diagenetic replacement of sulfate minerals. Three lithofacies were distinguished: a) laminated lithofacies representing aphotic carbonate stromatolites enclosing fossils of filamentous sulfide-oxidizing bacteria; b) brecciated lithofacies deriving from the brecciation of carbonate stromatolites by mud injections; c) sulfur-bearing lithofacies deriving from the precipitation of thin laminae of elemental sulfur at or close to the sediment-water interface. The carbon and oxygen stable isotope composition of authigenic carbonate minerals and lipid biomarkers indicate that the initial formation of the laminated lithofacies was favored by organoclastic sulfate reduction in the shallow subsurface close to the sediment-water interface, producing sulfide that sustained dense microbial mats of sulfide-oxidizing bacteria at the sea floor. Calcification of the mats and consequent formation of stromatolites were possibly favored by nitrate-driven sulfide oxidation at the sea floor. The subsequent brecciation of the stromatolites was apparently the consequence of sulfate-driven anaerobic oxidation of methane (SD-AOM) in an underlying sulfate-methane transition zone (SMTZ). Focused fluid flow from below, possibly resulting from destabilization of gas hydrates, was not only responsible for the brecciation of the stromatolites, but also for the delivery of bicarbonate ions and the consequent precipitation of additional, 13C-depleted calcite (d13C values as low as -52‰). Along with bicarbonate, also hydrogen sulfide was produced by SD-AOM at the SMTZ and was transported upwards. The oxidation of hydrogen sulfide at or close to the sea floor promoted the formation of elemental sulfur characterized by higher d34S values and lower D33S values than coeval seawater sulfate.

Biomineralization of As-schwertmannite in acid mine drainage

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Keywords: As-schwertmannite, biomineral, acid mine drainage.

Iron and arsenic extraction occurred at the San Blasio mine, near the village of Caulonia (Southern Calabria, Italy), until it was finally abandoned in the XIX century. A whitish/orange muddy precipitate was identified where acid water, showing pH ca. 3 and main ions (mg/L) SO_4 590, Ca 140 and Fe 55.3, outflows from the mine. This precipitate is mainly composed of amorphous As-schwertmannite (FeO 69%, SO_4 14%, As_2O_5 11%), and in very minor amount of hematite. Amorphous As-schwertmannite mineral nanoparticles (<10 nm) represent the most common basic mineral structure, which form roughly homogeneous mineral aggregates, or, more commonly, subspherical nanospheres in the range of 100-300 nm in diameter. Nanospheres are mostly hollow with a solid mineral wall ca. 30 nm thick in average, appearing like single elements or coalescing to form more complex clusters. Furthermore, mineral nanofibers (100-300 nm in length and 5-30 nm in width) can cover the outer portion of the nanospheres with a radial orientation, while the inner part can be filled with homogeneous mineral nanoparticles.

A microbial community, mainly consisting of prokaryotes cells (mainly streptobacilli and filaments, and less spirochete) commonly enclosed within the extracellular polymeric substance (EPS), occurs, strictly associated with all types of mineral precipitates. In fact, mineral nanoparticles nucleate on the external cell walls or inside the EPS mass, up to replacing the whole organic structures. Moreover, abundant bacterial outer membrane vesicles (OMVs), consisting of spheroidal bodies with diameter of ca. 100-200 nm, and characterized by a double-layered wall have been also observed. OMVs appear partially to totally mineralized, being, most likely, the organic substrate replaced by the As- schwertmannite to form the nanospheres.

In the light of what has been said so far, the San Blasio mine case can represent an interesting site of research, since less is known about the mechanisms involved in As-schwertmannite biomineralization. Finally, the understanding of the microbial communities and the biotic processes that mediate the biomineralization of this mineral phase, could drive to the possible development of water treatment plants, finalized to avoid toxic elements dispersion in the environment.

Heavy metal-minerals microbial mediated coprecipitation in mine tailings drainage

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Keywords: biomineral, hydrozincite, mine tailings.

The Rio Roia Cani (Southern Sardinia, Italy) is a seasonal stream draining mine tailings and residues of the Montevecchio mine. Along a limited sector (ca. 300 m) of the stream through the mine dump, water chemistry composition (sampling November 2023), is characterized by a circumneutral pH, and a roughly constant mean amount of the main ions: (mg/L) SO_4 = 730, Zn = 132, Ca = 130, and HCO_3 = 55. Moreover, a variable number of other metals is present in the short upstream part (µg/L): Mn = 370, Pb = 81, and Cd = 1580; and in the downstream part: Fe = 550, Mn = 1350, Pb = 490 and Cd 990, as the influx of sunk water.

Along the stream course, three distinct biomineral phases have been observed, strictly associated with microbial biofilms: hydrozincite $Zn_5(CO_3)_2(OH)_6$ in the upper stream part and Mn-Pb hydroxides associated with Fe-Mn-Pb oxides in the downstream part.

Hydrozincite is present as whitish/ochreous soft to hard crusts forming small relief barriers, transversal to the water flow, with small upstream pools and downstream lobes. The crust exhibits a stromatolitic fabric, characterized by sub-millimetric thick, cryptocrystalline laminae, variably covering the streambed, rock clasts and river plants. The mineral is covered by a widespread living microbial biofilm, and the lamination is due to the alternance of solid mineralized laminae with less dense ones, characterized by disperse globular crystal aggregate. Both types of laminae are rich of well-preserved to fully mineralized microbial cells and Extracellular Polymeric Substances (EPS) that formed a biofilm community, which are particularly abundant in the less dense laminae. Hydrozincite mineral nanocrystals constitute the basic mineral structure, forming roughly irregular particle or fibrous crystals aggregates tens of nm in size. Nanocrystals nucleate along the external cell walls or inside the EPS, sometimes replacing the entire organic tissues.

As the water composition downstream varies, hydrozincite almost disappears, while two new distinct amorphous biominerals precipitate. One is represented by a reddish mud mainly composed of a Fe-Pb-Mn oxide phase (hematite?) with minor amount of hydrozincite, characterized by 30 to 200 nm nanospheres. The second amorphous biomineral consists of a dark mud, frequently found underneath the reddish mud or streambed clasts, composed of a Mn-Pb hydroxide (ranciéite?). The basic mineral structure of this precipitate consists of fibrous nanocrystals (ca. 20 nm thick) which aggregate to form clusters. In both cases, mineral nucleation and growth is again associated with the biofilm components, such as diatoms, bacteria, and EPS, implying their biologically mediated origin.

Microbial activity involved in aluminosilicate mineralization in an arsenopyrite mine

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Keywords: biomineralization, aluminosilicate, bacteria.

The mechanisms underlying eukaryotic biosilicification have been intensively investigated. By contrast, prokaryotic biosilicification has been less studied. It is known that bacteria are involved in the formation of siliceous deposits through both extracellular and intracellular biosilicification with passive and active processes respectively (Ikeda, 2021). Considering the extremely wide variety of bacteria and archaea, it is plausible that more prokaryotes could be involved in silicate precipitation than those already recognized. In the frame of this topic here we investigate the possible role of bacteria in aluminosilicate mineralization.

Aluminosilicate biomineralization is a complex process that involves different stages of metal–microbe interactions, metal substitution, and crystallization (Sánchez-España et al., 2018). Depending on water chemistry and the bacterial species involved in the biomineralization process, aluminosilicate of bacterial origin can show different morphologies, from amorphous to submicron or nanometric in size, and exhibits a variable composition (e.g., kaolinite-like, halloysite-like, nontronitic, and chloritic). These so-called biosilicate form under both experimental and natural conditions, but until now they are not described forming bioconstruction-like bodies.

Here we describe unusual dendritic fabric forming in natural environment, inside the Macariace arsenopyrite mine, near the Mammola village (Southern Calabria, Italy). These fruticose structures develop in a decimetric fracture of the cave wall characterized by sub-photic conditions. They appear white and formed by an intricate frame of millimeters convolute tubular structures. The set of micromorphological and biogeochemical/mineralogical data of optical microscopy observations, SEM and TEM electron microscopy characterization, XRD analyses, EDS microanalyses, thermal analysis and UV-Epifluorescence observations, confirm the aluminosilicate nature of these structures and suggest unusual biomineralization processes involved in their deposition. Whether this mineral precipitation is a process influenced by EPS taphonomy or represents an induced mechanism linked to specific metabolic processes is currently unknown, but the chemical characteristics of the water system, characterized by low pH values (up to 4.8) and Ca-SO_4 compositions suggest the possible role of acidophilic communities involved in the biomineralization processes.

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GIS-based protocol for benthic habitat mapping of Coralligenous build-ups (Isola Capo Rizzuto, Calabria, Italy)

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Keywords: underwater habitat mapping, multibeam echosounder, coralligenous.

In temperate waters of the Mediterranean Sea, calcareous red algae (CCA) form endemic algal reefs known as Coralligenous build-ups, which represent a major hot spot of biodiversity in the Mediterranean basin. Coralligenous has a prominent role in submarine landscape formation and demise through geological times, producing various morphotypes on the seafloor. Based upon the nature of the substrates, Coralligenous have been categorized mainly in two groups: banks and rims. Furthermore, Bracchi et al. (2017) proposed a new categorization for Coralligenous morphotypes on sub-horizontal substrate: tabular bank, discrete relief and hybrid bank.Although Coralligenous bioconstructions are present along almost all Mediterranean continental shelf, their distribution is still underestimated and has been mapped only in few areas. In addition, Coralligenous is a fragile and threatened habitat (Cipriani et al., 2024), characterized by a low accretion rate and a high sensitivity to natural and anthropic impacts, including climate changes (Basso et al., 2022). For these reasons, acoustic instruments, such as Multibeam Echosounder (MBES), represent optimal tools because they allow to quickly recognize and identify the extension of benthic habitats on the seabed and thus map their regional distribution without perturbation of this delicate ecosystem.

In this work, a semi-automated GIS-based protocol for benthic habitat mapping were proposed and tested in shallow coastal water of Capo Bianco, within the Isola Capo Rizzuto Marine Protected Area. This method firstly combines high resolution bathymetric and backscatter data obtained by Multibeam Echosounder with geomorphological and geomorphometric indices (es. slope, profile curvature, topographic position index, terrain ruggedness index, etc.) to develop innovative approaches for eco-geomorphological and geobiological studies. The obtained results provide a powerful instrument, with centimetric resolution, capable not only of discriminating coralligenous bioconstructions from Posidonia oceanica meadows and surrounding seascape, but also of quantitatively define the 3D distribution of build-ups in terms of area, volume and heigh relative to the substrate from which they develop.

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Minerals & microorganisms, a possible relationship: an awareness project of GEOMICROBIology

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Keywords: geomicrobiology, microbe-mineral interactions, geobiology dissemination.

The growing awareness of the strict interconnection between minerals and microorganisms has largely impacted the geosciences in the last decades. Microorganisms have been recognized to play a fundamental role in aquatic and terrestrial biogeochemical cycles that results in the precipitation of minerals (i.e. "biomineralization and organomineralization"; sensu Dupraz et al., 2009) and in the formation of peculiar rocks (e.g. microbialites, stromatolites) that punctuate the geological record. Moreover, the Earth history has been characterized by episodes of massive accumulation of biogenic material on the ocean floors resulting in the formation of biogenic deposits (i.e. biosiliceous and carbonate oozes) that represent natural archives of paleoenvironmental and paleoclimatic information (Berger & Wefer, 2009). Finally, the rapid growth of minerals can act as a trap for microorganisms that can be perfectly preserved within the crystal lattice or fluid inclusions for millions of years (Lowenstein et al., 2011)

Such strict connections between the geosphere and the biosphere are mostly unknown to the general audience, although the impact of microbial (microorganisms) and nanoscopic (viruses) life is emerging more and more in our society.

The GEOMICROBI project aims at showing the microbial life enclosed in minerals and rocks, elucidating its role in the modification of the natural environments in the geological past and nowadays. Improving people awareness about the role of microorganisms in shaping the Earth will contribute to understand the importance of life as a "geological force" (Westbroek, 1992). The project GEOMICROBI will contribute to raise such awareness throughout imaging (mostly by SEM photomicrographs) the "invisible life" hidden within minerals and rocks. Main targets of the project are the creation of a photographic exhibition accompanied by informative conferences on the theme "Minerals & Microorganisms". This presentation is intended to attract the attention of the geological community on this dissemination initiative and to look for amazing, high-definition images on mineral-microorganism interactions.

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From bioleaching to biomining: learning from geomicrobial processes in mining areas

Onnis P.*[1], Calandrelli T.[1], Alisi C.[2], Dore E.[1], Fancello D.[1], Frau F.[1], Marras P.A.[1], Medas D.[1], Musu E.[1], Pisano B.[3], Podda F.[1] & De Giudici G.[1]

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Keywords: goethite, metals, siderophores.

Microorganisms interacting with the surrounding environment may mediate the precipitation of biominerals, bioaccumulate metals, and promote bioleaching processes favoring mineral dissolution. In the last decades, key mechanisms ruling geomicrobial processes received increased attention with a particular focus on their applications to environmental remediation strategies and sustainable mining, such as biomining.

Metal-mining areas in SW Sardinia (Italy), dismissed in the last decades of the last century, keep reaching the public audience due to i) the presence of critical raw metals and their potential extraction from mining wastes, ii) environmental pollution, and iii) the naturalistic and archaeological industry beauty of strong interest to local and regional communities. These areas are extreme environments with high concentrations of contaminants in waters, sediments, and wastes. At Rio Irvi (Montevecchio Mine), drainage outflow from Casargiu Gallery connects underground mining to riverine water with an estimated output of 900 kg/day Zn into the Mediterranean Sea. Variation of redox and pH (4-6) conditions generates precipitation of non-crystalline Fe(III)-(oxy)hydroxides and sulfate-bearing green rust (Frau et al., 2015). Here, Fe biogeochemistry and the role of microorganisms in its mobility were investigated to understand mineral stability and potential biomining applications. Microbiological investigations isolated and identified the indigenous bacteria *Pseudomonas protegens* FeIIC1 able to extrude siderophores and chelate Fe^{3+}. Laboratory experiments studied the bacteria capability to mobilise Fe^{3+} from nano to microscale crystals of synthetic goethite α-FeO(OH). The bacteria were added to a Fe-deficient medium, and after reaching a growth plateau, goethite was added with a 1 mg to 2 ml ratio. The bioleaching was observed for three weeks by monitoring i) Fe concentrations in the medium, ii) siderophore production, iii) bacteria colony formation unit, iv) pH and redox parameters. Scanning electron microscope images showed biofilm on mineral surfaces. The monitoring of Fe concentrations in the medium highlighted a continuous bio-mediated dissolution and maximum concentrations towards the end of the experiment, with an apparent recovery of about 20%. Preliminary output encourages applications to mining wastes often bearing other metal(loid)s, namely Zn, Cd, As, and Ni. Understanding the naturally occurring bio-mechanism ruling metal leaching and precipitations in mining areas will shed light on microorganisms' potential as environmental remediation or metal sourcing from wastes.

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Microbial micritic cementation in a Late Pleistocene (MIS 5.5) mid-latitude shallow-water calcarenite (Gulf of Taranto, central Mediterranean)

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Keywords: MIS 5.5, microbial micrite, central mediterranean.

Higher sea level and sea surface temperature than at present are inferred for the Last Interglacial (MIS 5.5, 135-116 ky), which is considered a good analogue for Earth's climate response to global warming in near future. The MIS 5.5 deposits cropping out along the Gulf of Taranto are mainly composed of few meters thick bioclastic calcarenite layers, representing a locally vegetated shallow sandy seabed, with relatively high energy conditions (Santagati et al., 2023). These deposits are affected by limited post-depositional diagenesis, allowing the study of early cementation processes. The clasts are composed of medium-coarse sandy skeletons and fragments deriving from a varied biota, including large molluscs that lived in the sediment, and of a negligible quantity of siliciclastics.

Most bioclasts are variably micritized, and micritic cements are common and show various micromorphologies and textures: non-isopachous aphanitic and filamentous rims, aphanitic micro-mounds, vacuolar peloidal meniscus, and aphanitic matrix filling the porosities. All these microbial mediated cements consist of submicrometer anhedral or nanospheroidal crystals of low-Mg calcite, mixed with a smaller amount of irregular plate-like crystals of saponite. All cement fabrics are rich in mineralized filamentous, tubular, and subspherical bacterial bodies, evidencing the occurrence of an epilithic to endolithic biofilm-forming microbial community, that stabilized the mobile sediment and mediated early cement precipitation.

The process of microbial mediated early cementation led to the formation of a relatively hard substrate, which allowed the settlement of cemented epilithic taxa, such as *Spondylus gaederopus*, oysters, and minor serpulids and barnacles, which represent a minor component of the paleocommunity. However, as testified by the dominant presence of burrowing molluscs, the process was not pervasive, or was volumetrically limited along the sediment column.

Similar processes of microbial micritic cementation are common in modern tropical carbonate platforms (Diaz & Eberli, 2022), whereas are substantially absent in the modern Mediterranean. Their occurrence in the MIS 5.5 central Mediterranean deposits confirms warmer water temperatures, estimated at +2°C than today (Santagati et al., 2024), and suggests that such process of early cementation of shallow-water sediments could become more widespread in response to the global warming.

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Capo Colonna (Crotone Basin – Southern Italy) MIS 5 calcareous bioconstructions: an association of algal, metazoan, and microbial framebuilders

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Keywords: biocostructions, late pleistocene, microbial micrite.

The Last Interglacial (MIS 5) transgressive-regressive deposits of the marine terrace of Capo Colonna (Crotone Basin) provide a good fossil example of infra/circa-littoral environments of the central Mediterranean, characterized by low-relief bioherms and biostromes dominated by calcareous red algae, analogous to the modern coralligenous and mäerl habitats respectively (Nalin & Massari, 2009; Bracchi et al., 2014).

The primary framework of the bioherms consists of laminar to massive encrusting red algae that act as the main bioconstructors, with secondary bryozoans, foraminifera, and serpulids. The tabular mäerl bed is composed of free-branched coralline red algae rudstones. A variable amount of sandy bioclastic sediment is laterally interbedded with the bioconstructions and is trapped in their cavities and pockets.

All bioconstruction sedimentary subfacies and associated sediments are rich in microbial-mediated syn-sedimentary autochthonous micrite, with aphanitic, peloidal, clotted peloidal, and filamentous fabrics. Microbial micrite can also trap and bind variable amounts of grains or be a secondary component of detrital sediment with micritic rims enveloping the clasts. All these early lithified micrites show the typical nanostructure of microbial-mediated primary carbonates, rather than of an accumulation of detrital mud particles, since they are made up of nanospheres that coalesce into subhedral microcrystals, replacing and mineralizing both the microbial cells (present with different morphological types) and extracellular substances (e.g., Perri et al., 2012).

This implies the widespread presence of lithifying microbial biofilms that colonized both the cavities of the bioconstruction frameworks and the intergranular space of the associated sediment. These microbial communities, thanks to the metabolic processes of the microorganisms that induced the precipitation of carbonates, contributed significantly to the early cementation of all the studied deposits.

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Nanoscale biosignatures in native-Cu and sulphides from the Wadi Tayin ophiolite, Oman

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Keywords: serpentinisation, nanoscale, geochemistry.

Hydration of ultramafic rocks (serpentinisation) is a low-temperature, low-pressure process driven by water-rock interaction and changes in variables such as H fugacity ($fH_{2,aq}$). Serpentinisation starts at low water-rock ratios, where Fe released from olivine and pyroxene oxidises, to form abiogenic $H_{2,aq}$ and reducing conditions (Frost, 1985). $H_{2,aq}$ can react with C and water to form methane, carbon dioxide and organic acids (Templeton et al., 2021). Therefore, serpentinisation may have facilitated the initiation of early life (Cardace & Hoehler, 2009) but few studies have investigated the availability and cycling of nitrogen in serpentinising environments. The present work investigates natural systems where conditions were sufficiently reducing to form native metals and, potentially, biogenic or abiotic hydrogen.

This work used nanoscale techniques, such as Atom Probe Tomography (APT) and Time of Flight-Secondary Ion Mass Spectroscopy (ToF-SIMS), to search for evidence of biotic activity in sulphides and Cu-alloys from the Wadi Tayin ophiolite, Oman. Mineral assemblages and nanoporosity suggest that native-Cu formed during serpentinisation, and we speculate that the nanopores acted as fluid traps and hosted microorganisms. ToF-SIMS maps show that native-Cu and partially dissolved magmatic chalcopyrite are enriched in cyanide-complexes, offering insights into the nanoscale nitrogen cycle.

APT analyses show Ag segregation along grain boundaries in native-Cu, consistent with literature reports of transfer of Ag from magmatic sulphides to alloys and native metals during serpentinisation (Lawley et al., 2020). This previously undocumented concentration of Ag in defects provides new insights into mechanisms of Ag transfer. Taken together, the results suggest that Cu acts as an electron acceptor during early serpentinization and supports the idea that early life may have thrived in serpentinising environments.

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Integrated Geochemical/Geobiological approach for the identification of environmental proxies in Coralligenous bioconstructions

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Keywords: geochemistry, biomineral, environmental proxies.

Coralligenous is the most important marine ecosystem in the Mediterranean Sea because of its extent, complexity and heterogeneity (Basso et al., 2022; Bracchi et al., 2022). Moreover, it is a prominent geobiological system and a unique hot spot of biodiversity (Cipriani et al., 2024), object of special interest by the UNEP RAC/SPA and considered among the priority habitats for monitoring and conservation by the European Community.

Since the last century, coastal ecosystems have been increasingly threatened by human activities due to the discharge of contaminants which leads to an overall deterioration of the environmental quality. Several studies have been conducted to demonstrate the relationships between metal contents (physico-chemical parameters of seawater) and the occurrence of aberrations in marine organisms. However, these researches focused mainly on the incorporation and effect of major, minor, and trace in the soft tissues of recent taxa (e.g., foraminifers, brachiopods, molluscs and algae). To date, only a few studies (see Deias et al., 2023) have investigated possible correlations between the composition of skeletal and non-skeletal components of marine bioconstructions with the chemistry of the surrounding seawaters. The research suggests that biominerals can serve as good proxy for environmental studies, capable of recording short- and long-term variations in the geochemistry of marine environments.

Here, an integrated geochemical/geobiological approach has been utilized to investigate the balance between reef status and environmental parameters and to identify possible proxies for short- and long-term environmental studies. This multidisciplinary approach showed an evident relationship between chemical composition of the carbonate minerals and the waters in which coralligenous forms. Positive anomalies in heavy metals were found in bioconstructions and surrounding seawaters. Such enrichments could result from pollutants introduced into the marine system by human activities and recorded by the components of the bioconstructions. These data, although preliminary, allow to consider coralligenous build-ups as environmental database that continuously record environmental disturbance (both natural and anthropic), enabling temporal reconstruction of the marine environment over time.

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Petrography of stromatolites from the summit of the Pelel Formation in the Walidiala valley (Madina Kouta Basin, Kédougou, Senegal)

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Keywords: Madina Kouta basin, petrography, stromatolites.

These structures are described for the first time in the Madina Kouta basin (Walidiala valley) on the hill of Pélel in the vicinity of the Nandoumari flat (10 m) where it is overlain by the clay-sandstone deposits of the Dindéfélo Formation and at the base of the Tanagué hill (40m), unconformably overlain by the Neoproterozoic glacial formations (Youm, 2019). These are algal bioconstructions, made up of greyish-white stromatolites, centimetric to decimetric, linked by a strongly ferruginous carbonate matrix and very weakly sandstone, which caps the Pelel Formation. There are allochthonous debris of algae (*Algal limeclasts*), oncoids in irregular nodules with convex and concave contours, large pelloids (>2 mm), simple and composite ooliths, sometimes in fragments, multiform concentric stromatolitic structures, more or less associated.

Microscopically, the presence of stromatolites is distinguished by a stacking of thick hemispherical layers, nested together in a very clear manner. Two types of layers alternate more or less regularly: i) clear and limpid layers, most often made up of sparitic carbonate crystals. They are generally the most developed; ii) grey, dark, more intensely pigmented layers (clays or organic matter or iron), sometimes reduced to a single dark line or curved lenses of micritic carbonates, associated with detrital quartz, feldspar debris, zircon and mica flakes. The phenomena of recrystallization and dolomitization (sparite, calcite and dolomite) are very extensive, which sometimes completely masks the structures. Stromatolites are very often pellet and oolith traps. The bonding phase is a carbonate matrix of micrite, dolomicrite, microsparite and quartz of very small size as well as a sparitic and ferruginous cement (sparite or dolosparity and iron oxides). The texture is packstone-like (Dunham, 1964) with sparite recrystallization fractures. These are ferruginous stromatolite reefs or ferruginous stromatolite limestones with oncoliths and pellets. As carbonates are very little studied, sometimes even omitted in the descriptions, this work will allow a better understanding of the stromatolite emplacement processes and will be the outline of a more in-depth study of bioconstructions, particularly in the Madina Kouta basin and in Senegal, since other levels of stromatolites have already been identified but not yet studied.

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S2.

The global challenge of plastic pollution: causes, impacts and solutions

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Response of benthic foraminifera to plastic pollution

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Keywords: plastics, marine pollution, foraminifera.

Plastic pollution poses a significant threat to oceans and marine life globally. Microscopic plastic particles entering aquatic environments can disrupt benthic communities by altering their distribution and activity. Despite the undoubtedly harmful long-term effects on microbiota, the impact of microplastics, chemicals, and synthetic molecules on marine microorganisms remains poorly investigated (Baztan et al., 2018; De Sá et al., 2018). Benthic foraminifera are crucial components of marine ecosystems, playing key roles in ecosystem functioning and biogeochemical cycles. Their sensitivity and rapid response to environmental stress make them effective environmental indicators of past and present changes. To better understand the effects of emerging pollutants on oceans and their interaction with marine organisms, we studied the impacts of plastics and bio-accessible plasticizers (specifically DEHP, bis(2-ethylhexyl) phthalate) on selected benthic foraminiferal species using μ-FTIR (Fourier Transform Infrared) spectromicroscopy.

Our analysis revealed the following key findings: i) certain foraminifera species (*Cibicidoides lobatulus*, *Rosalina bradyi*, and *Textularia bocki*) can grow on plastic remnants; ii) plastic-related molecules and debris can be incorporated into the cytoplasm and tests of foraminifera, altering biomineralization processes; iii) DEHP can be incorporated into the cytoplasm of calcareous foraminifera cultured in vitro (*Rosalina globularis*), potentially entering biogeochemical cycles (Birarda et al., 2021).

We hypothesize that plastic waste and associated additives may affect the biomineralization process in foraminifera, compounding the effects of ocean acidification and potentially reducing their biogenic carbon (C) storage capacity.

Furthermore, we conducted experiments exposing benthic foraminifera to high concentrations of DEHP over three months in sediment cores from the Santa Gilla lagoon (Cagliari, Italy) and comparing them with the foraminifera from other cores that were left in natural conditions. After the experiment, surviving benthic foraminifera were cataloged. Gas chromatography coupled with mass spectrometry was used to identify and quantify plastic pollutants in the lagoon sediment.

Next steps will involve the study of the incorporation of plastic pollutants into foraminiferal tests and the possible modifications in foraminifera shell (e.g., changes in density) using Scanning Transmission X-ray Microscopy, Low Energy X-ray Fluorescence, and X-ray computed microtomography. These analyses will validate foraminifera as reliable proxies for monitoring ongoing human-generated pollutants. The presence of associated molecules in foraminiferal shells (such as total particulate matter and plastic) could provide insights into anthropogenic pollution history spanning several decades, given foraminifera's ability to fossilize.

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Integration of microplastic gravimetric separation protocol considering sediment texture and composition

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Keywords: microplastics, coastal environments, sediment analysis.

Coastal-lagoon environments are highly vulnerable and subject to multiple stressors, among which marine litter (ML) is a serious global issue. The predominant category of ML recorded along coasts mainly consists of artificial polymeric materials (Le et al., 2024). In the environment, macro-ML degrades into smaller items due to photo-thermo-oxidative degradation: Large Micro Plastics (LMP, 5 - 1 mm), Small Micro Plastic (SMP, 1 mm – 20 μm), nano Plastics (nP, ≤ 20 μm). These microplastics are defined as secondary. However, primary microplastics can also be found in the environment, which are produced in microscopic sizes for specific purposes and various applications (Saeedi, 2024).

Many protocols have been developed to study and quantify the presence of SMP in various types of coastal environments. Quantifying SMP along the sandy coasts of the northern Adriatic Sea remains challenging due to the very fine dimensions of the sediments in which microplastic items are trapped. Therefore, the gravimetric separation of microplastics from sediments using non-toxic and cost-effective saline solutions presents some practical difficulties. The protocol conventionally used in the Adriatic area for sampling and analysis of SMP (Palatinus et al., 2015) suggests adding 200 mL of saturated NaCl solution (density 1.2 g/cm^3) to 50 mL of sampled sediment. This mixture is then stirred for 2 minutes to suspend the microplastic items embedded in the sediments. According to the protocol, a waiting time of 4 minutes is required for sediment precipitation, and then the supernatant can be collected and filtered in order to collect the microplastics on borosilicate glass fiber filters (Whatman® microfiber filetrs GF/D, mesh size 2,7 μm).

However, the mentioned protocol does not provide information correlating sediment grain size with an optimal waiting time to perform this procedure. From various tests conducted by our team, it has been observed that the indicated waiting times are not sufficient to achieve the complete settlement of non-plastic particles, particularly for samples containing an average of 69% fine sediments, rich in muddy fraction (d < 0.250 mm).

With this work, we suggest a possible integration to the protocol based on preliminary tests useful for verifying the optimal waiting times for collecting the supernatant to be filtered, in relation to the textural and compositional characteristics of the sediments. This integration helps to avoid both the deposition of a compact solid matrix on the filter, which could mask the presence of the microplastics to be observed, and the damage to the equipment used for vacuum filtration.

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Investigation of the efficiency of several TiO_2 microstructures for the photocatalytic degradation of nanoplastics

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Keywords: photocatalysis, nanoplastics, TiO_2 microstructure.

Nanoplastics in the environment represent one of the emerging problems of our time, with widespread and harmful impacts on global aquatic ecosystems. These plastic particles, less than 1 μm in size, derive from various sources, including improper disposal of plastic waste and spoilage of synthetic articles. Their ubiquity in aquatic environments and their persistence and bioaccumulation ability raise severe issues for human health and the marine ecosystem (Arif et al., 2024). Growing awareness of the widespread of nanoplastics and their harmful effects has prompted the search for innovative solutions to address this particular pollution. Among various proposed strategies, photocatalysis emerges as a promising option for the degradation of nanoplastics, exploiting the ability of photocatalysts to activate advanced oxidation reactions under the irradiation of sunlight (Llorente-García et al., 2020). However, the need for highly selective and efficient photocatalysts remains a critical challenge in converting this technology into practical solutions. In this context, we investigated the efficiency of several TiO_2 microstructures for the photocatalytic degradation of nanoplastics. Our methodology focuses on the controlled hydrothermal synthesis in 5M, 6M, and 7M HCl of TiO_2 (Zhou et al., 2011) to obtain at least three different microstructures (spheres, nanoflowers) able to degrade nanoplastics. The results showed that performing the hydrothermal synthesis at 150°C and different HCl concentrations led to three different microstructures, such as two types of spheres and nanoflowers. All microstructures are composed of rutile TiO_2 and present different surface area values, which correlate with their differences in the efficiency of the nanoplastics photocatalytic processes. The results of this work show that photocatalysis can significantly contribute to solving nanoplastic pollution environmental challenges.

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Identification of microplastics in human tissues and fluids: a pilot study

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Keywords: microplastics, microscopy, micro-Raman spectroscopy.

Plastic uses increased more and more in the last decades, thanks to its characteristics (malleability, lightness, durability, and versatility). In fact, it is the third material produced by the man on Earth, after steel and concrete. Nevertheless, in the last years academic and non-academic people are worried about the destiny of these materials because their chemical, physical, and biological degradation leads to the dispersion of microplastics (MPs). These particles are little fragments with dimensions reaching up to 5 mm, that can potentially accumulate in the environments and in the organism tissues, man included. MPs have been identified in different human tissues, as lungs, blood, placenta, urine, breast milk. Their accumulation can trigger physical and biological effects, that are responsible of damages to cardiovascular, digestive, and respiratory systems. In fact, their toxicity depends on different biological mechanisms (e.g.: absorption and distribution processes inside the human body, metabolism, and excretion ways) and physical factors (e.g.: morphology, dimensions, surface charge, concentration, and their ability to bond themselves to organic and inorganic pollutants).Biomonitoring is a method utilized to evaluate human exposure to different environmental pollutants; it is carried out characterizing a determined chemical substance, its metabolites, or transformation products in biological samples. This evaluation considers the combination of the potential contaminated elements (e.g.: air, food, water, industrial products) with the different exposure pathways (inhalation, ingestion, skin contact). MPs absorption evaluation inside human tissue is made difficult because of the data lack about both population exposure and MPs distribution and dynamic in the human tissues. Moreover, scientific demonstration about MPs presence and the correlation with different diseases and the research of possible exposure sources are still at an early stage. In this work, a MP evaluation by optical microscopy and micro-Raman spectroscopy inside different human media (serum, urine, and tissues) will be presented. The patients involved in this study are people living in Alessandria province (Italy) and admitted to the Azienda Ospedaliero-Universitaria SS. Antonio e Biagio e Cesare Arrigo and to the Santo Spirito Hospital of Casale Monferrato, Italy. The enrolled population will include different patients (e.g.: pregnant women, hemodialysis patients) to determine whether microplastics are detectable inside their fluid or tissues and if there is any difference in MPs presence depending on where patients live and their lifestyles or considering different times during the therapies (e.g., levels before and after hemodialysis sessions, in order to assess extraction). The chemical analyses will be coupled to exposure questionnaires to investigate possible exposure sources.

Extraction of microplastics from marine environmental matrices: density separation protocol validation

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Keywords: microplastic, density separation, protocol validation.

Microplastics (MPs) differently concentrate within marine sediments depending on transport and accumulation agents as well as chemical-physical properties of plastic compounds (Chaukura et al., 2021). When MPs occur within marine sediments they can be utilized by agglutinated organisms, as Sabellariid polychaets, to build arenaceous reefs, thus MPs can also accumulate in bioconstructed substrates. Heterogeneity of MPs accumulated in different environmental matrices, rising interest in the last years but the lack of standardized guidelines for extraction brought us to a widespread inconsistency of data due to different recovery and quantification protocols.

Size, shape, floating behavior and density of plastic particles are handful information to correctly recognized true MPs from other grains in environmental matrices. Particularly, density of plastic materials, ranging from ~0.8 to -1.4 g cm^3, makes MPs lighter then sedimentary grains made of lithic fragments, minerals and biogenic remains (Ruggero et al., 2020) allowing a density separation. The aim of this work is to validate the extraction protocol using Sodium Iodide (NaI) brine solution (Kedzierski et al., 2017) applied to two types of environmental matrices: coastal marine sediments (mainly sands) and arenaceous bioconstructions built by the honeycomb worm *Sabellaria spinulosa* (Leuckart,1849). Extraction efficiency of NaI brine solution was compared with the extraction efficiency of sodium chloride (NaCl). The comparison was applied to both sediment and bioconstruction samples also using two different quantities (10 g and 40 g). Moreover, each sample was previously added with microplastics of known quantity and type: plastic particles with sizes from 250 µm to 500 µm, made of plastic compounds commonly produced by industry in a wide range of densities, such as polyethylene terephthalate PET (1.38 g cm^{-3}), polypropylene PP (0.855–0.946 g cm^{-3}), and polyvinyl chloride PVC (1.1–1.35 g cm^{-3}). Manipulated samples were put in 200 ml solution of NaI and NaCl, mixed and sonicated. After 6-12 hours, the obtained solutions were filtered through a 0.23 µm membrane for MPs isolation. Identification and quantification of MPs on the filters were performed under a stereomicroscope. Results documented a higher quantity of recovered MPs for the samples treated with NaI, confirming the higher extractive capability of this salt. On other hand, there were no statistically significant differences in tested sample quantities (40 g vs 10 g) nor in the number of extracted MPs with respect to the type of analyzed matrix (bioconstruction and sediment), indicating that the proposed protocol correctly works for different environmental matrices also using very small quantity of material.

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Evaluation of microplastics in coastal and marine sediments of the Ionian Sea (Southern Italy)

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Keywords: microplastics, Ionian Sea.

Microplastics (MPs) have become a complex problem in coastal areas in terms of pollution, human health and risk for marine flora and fauna ecosystems. The majority of MPs found in coastal areas are produced in terrestrial environments. A lot of activities are responsible for their production and their direct or accidental dispersion into environmental matrices. MPs arrive to marine environment carried by wind, rainy events and water bodies (like rivers or aquifers), to be retained in marine sediments.

Pino di Lenne is a beach located near the mouth of the river Lenne. On the one hand it holds great value due to its rich fluvial biodiversity and uniqueness. On the other hand a river is one of the means that most contributes to the transport of MPs from land to sea. Therefore this location was chosen for our research for the specific position near the river mouth. The aim is to understand how the presence of a river can influence the concentration of MPs.

A series of sediments samples were collected along the backshore locations, at each step of the morphological profile, and in offshore locations, selected after preliminary analysis of the marine substrate.

The evaluation of MPs in coastal and marine samples was carried out following the international standard procedure. Sediment grain-size analysis were conducted for sediments with fraction up to 63 μm, coulter analysis were performed for sediments with fraction < 63 μm. The MPs were separated from sediments and classified by shape, size and color. A new innovative method was applied for the automatic identification of microplastics with size smaller than 10 μm and automatic characterization of polymers. μ-FTIR and μ-Raman techniques were employed to evaluate the origin of polymers.

The distribution of MPs contamination was assessed to determine what is the river mouth influence on it, and how the distribution changes in relation to the location.

Imaging of microplastics in bio-engineered marine substrates: a neutron tomography approach

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Keywords: microplastic, Mediterranean reef, neutron imaging.

Microplastics (MP) are an ubiquitous pollutant that can be considered a planetary boundary threat. The persistence and durability of this synthetic material in the environment allows MP to easily enter the food web and the sedimentary record. Several freshwater (e.g Trychopteran insects) and marine benthic species, such as Sabellariid polychaetes, rely on natural occurring materials as biogenic fragments and sandy grains to build their agglutinated cases. Particularly, Sabellariid polychaetes build arenaceous reefs in the intertidal and subtidal zone along the temperate Atlantic and Mediterranean European coasts. The reef consists of a myriad of arenaceous packed tubes made up of sandy particles mobilized by waves. Sabellariid reefs are dynamic engineered habitats that constitute nutrient and sediment storage (Lisco et al., 2017), thus they play a crucial role increasing local biodiversity and enhancing coastal protection.

Recently MP abundance within Sabellaria spinulosa (Leuckart, 1849) reefs from Mediterranean Sea has been investigated (Lo Bue et al., 2023), but the applied method has required a destructive approach: the arenaceous tubes forming the bioconstruction have been digested in hydrogen peroxide and MP particles have been separated from the arenaceous matrix by density. As a result, MP quantification was provided as number of particles per gram of dry sediments. Unfortunately, information on MP distribution within three-dimensional bioconstruction samples was irremediably lost.

This work aims to perform neutron tomography, combining non-destructive X-ray and neutron imaging, on two portions of S. spinulosa reef. A similar approach had been previously utilized to identify microplastics (MP) in sediment samples (Tötzke et al., 2021). During our study, small reef portions, collected from the Torre Mileto bioconstruction (Gargano promontory, Southern Adriatic) were placed in two laboratory tanks: the first sample was manipulated with the addition of MPs at known concentration and size (up to 2 mm); while the second one, utilized as a control, was not manipulated.

After one month of exposition, both reef samples were analyzed at ICON, the cold neutron imaging facility at the neutron spallation source, Paul Scherrer Institut (Kaestner et al., 2011).

Results showed that most of MP agglutinated within the samples were easily identifiable, but the real content was probably overestimated. Unfortunately, our bioconstruction samples showed additional complexity with respect to sediments previously observed with a similar technique. The agglutinated grains forming the bioconstruction are bounded by an organic glue used to aggregate the tubes. Furthermore, remains of the worm organic tissues could persist partially filling the tube cavities. As additional beamtime has been obtained at PSI facility, further analyses addressed to refine the analytical procedure will allow us to overcome this problem.

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Lo Bue G. et al. (2023) - First attempt to quantify microplastics in Mediterranean Sabellaria spinulosa (Annelida, Polychaeta) bioconstructions. Mar. Pollut. Bull., 196, 115659, https://doi.org/10.1016/j.marpolbul.2023.115659

Tötzke C. et al. (2021) - Non-invasive detection and localization of microplastic particles in a sandy sediment by complementary neutron and X-ray tomography. J. Soils Sediments, 21, 1476-1487, https://doi.org/10.1007/s11368-021-02882-6.

Microplastic dynamics in the littoral reefs created by Sabellariid Polychaetes in the Southern Adriatic Sea

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Keywords: microplastics, Mediterranean reef, arenaceous tubes.

The Mediterranean Sea stands out as a semi-enclosed basin with high density of population who lives along the coastlines: this implies a high concentration of microplastics (MPs) originating from land sources. For this reason it can be considered a "Plastic Soup" (Suaria et al., 2016), with marine sediments playing the role of primary MPs sink.

The impact of MPs extends beyond their presence in the sedimentary record and their effects on marine life are still largely unknown: for example, the recent record of MPs incorporated into the arenaceous bioconstructions of sedentary marine worms (Sabellariid polychaetes) has arisen interest (Mancin et al., 2022; Lo Bue et al., 2023).

Sabellaria spinulosa (Leuckart, 1849) reefs, thriving in subtidal littoral environments, are formed bya myriad of packed arenaceous tubes, meticulously built using agglutinated sand particles. This engineered substrate not only serves as a vital habitat for the polychaete and associated biota, but also plays a crucial role in the coastal ecosystem dynamics as a nutrient and sediment storage (Lisco et al., 2017). In this context, this works aims at understanding the dynamics of MPs interactions within the seafloor environment associated with Sabellariid reefs, and specifically to assess the accumulation of MPs within the largest known Mediterranean *S. spinulosa* reef in the South Adriatic Sea. Samples of sea-floor sediment and bioconstruction (36 replicates in total) were collected along six transects from the Torre Mileto reef (41◦55045.3" N; 15◦37012.37" E) to compare the abundance of MPs in both substrates. MPs were extracted by density difference and submitted to census count using a stereomicroscope equipped with a UV light. Suspected MPs and other anthropogenic particles sized 2µm to 5000µm were identified based on morphology, colour, fluorescence, and physical response (for example to a hot needle). Quantitative data were reported as number of particles per gram of dry sediment; MPs were classified into size classes and morphological categories. Furthermore, µRaman spectroscopy was performed on twelve samples (33% of the total samples) to obtain validated data on MPs composition.

Results document MPs presence in all the collected samples, with fibers more abundant than fragments. The absolute abundance of MPs resulted comparable between sediment and reef substrates. Data suggest a mutual influence between the reef and the neighbouring sediment: the peculiar dynamic status of the larger Sabellariid reefs, characterized by an alternation between growth and erosion phases during the year, can control the abundance of MPs in the associated sediment. In particular, while the ancient, more stable portion of the reef are acting as sinks, the younger unstable one can become source of sediment and MPs.

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Plastic accumulation on a marine protected area: the case study of the Giannutri Island in Tuscan Archipelago

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Keywords: plastic dispersion, protected areas, plastic colonization.

Following the report of an accumulation of waste on the seabed of the island of Giannutri by divers working in Tuscan Archipelago zone, a multidisciplinary project to study this peculiar accumulation was born, involving institutes of the CNR, ENEA, INGV, University of Pisa and Toulon. The accumulation, noted for several years, is in a circumscribed area at a depth of 15 meters, in front of the island of Giannutri, Tuscan Archipelago. In August 2022, the conspicuous presence of anthropogenic material, mostly of polymeric type (bottles, vials, etc.), was verified. In November 2022, in collaboration with the CNeS (Nautical and Diving Center of the State Police of La Spezia), an underwater photographic mapping and geophysical characterization were performed, video/photographic footage taken and samples retained for subsequent laboratory analysis. In July 2023, the intervention of CASTALIA fleet allow the removal and disposal of all the material, except for a number of retained samples. On all the November and July samples we identified different species of bryozoans and benthic foraminifera, and we analyzed the degradation and aging of the polymeric matrix, in collaboration with Pisa PolyGreenLab group of CNR-IPFC, involved since years in these kind of studies (De Monte et al., 2022).

The first results did not reveal the presence of NIS species among those found in the bottles, and instead confirm that all detected species belong to the ones living in Posidonia prairies, suggesting the local origin of these concretions. This would lead to the assumption of an arrival of the material by sea from other areas, their subsequent sinking there (probably due to fouling resulting in a change in the density of the object) and then colonization by local species (Zettler et al., 2013). Interestingly, there was a low taxonomic homogeneity and the presence of a dominating species shown by each of the analyzed bottles; this introduces potential danger, as if bottles leave the Gulf of Spalmatoio of Giannutri and join a larger current to be transported far from the accumulation area, this could lead to some species being carried into uncolonized areas, inducing competition with other species and leading to what is known as a bio-invasion phenomenon (Kiessling et al., 2015). To test this hypothesis, in parallel with the chemical/physical state of the recovered objects, a study of the dynamics of the currents in the area is being conducted through Lagrangian models to understand what forcing factors led to the presence of such an accumulation. In the next few days (April 6 - 10) a campaign will be conducted to check, about 10 months after removal, whether any finds are present in the area again, and quantify them, and at the same time dispersal experiments will be carried out using specially made drifters that have already been tested for the study of surface movements of marine litter in coastal areas (Merlino et al., 2023).

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Microplastics characterisation in shallow waters of the Arno River (Central Italy) and its discharge into the Mediterranean Sea: the main impacting role of the smallest size particles

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Keywords: microplastics, Arno river, urban impact.

Crossing anthropized inland areas, riverine systems undergo the addition of a wide array of contaminants. Among them, microplastics (MPs), defined as plastic particles of 1-5000 µm in size, are ubiquitous and worthy of interest due to their potential health risks and impact on ecosystems (Thompson et al., 2004). Here, the Arno River (Central Italy) was investigated to evaluate MPs contributions from urban landscapes (2.5 million inhabitants live in the area) and to estimate the MPs discharge from the river to the Mediterranean Sea. Shallow river waters were collected in April and July 2022 at seven sites located upstream of the main pollution sources (i.e., urban centres) up to the river mouth. Differently from most studies, a specific protocol (sampling, extraction, analysis) was developed to allow the investigation of almost all MPs sizes (5-5000 µm). Samples containing MPs > 60 µm and MPs < 60 µm were simultaneously collected and analysed by µ-FTIR and fluorescence microscopy (Nile red dye), respectively. River flow rates were also recorded to allow calculations of MPs fluxes. By far the most abundant material were MPs < 60 µm, representing >99% of particles found all-river-long and reaching concentration peak (5×10^4 items/L) across the city site of Florence. Pre-urban sites displayed concentrations of 1×10^4 items/L, while the lowest concentrations were observed at the river mouth (1 to 3×10^3 items/L). Among MPs < 60 µm, an inversely proportional relationship between size and abundance was observed; the fraction 5-15 µm (61-70%) was the most abundant, followed by 16-30 µm (18-30%), 31-45 µm (6-8%), and 46-60 µm (3-4%).

MPs > 60 µm (<0.5% of total) were mostly classified as processed fibers of cellulose (68%) strictly connected to textile products (i.e., garments) (Islam et al., 2020). Synthetic polymers (32%) were associated with textiles (i.e., PET, PA, PAN), automotive and building components (i.e., Neoprene rubber, ABS, PMMA).

The yearly average discharge of MPs (MPs > 60 µm plus MPs < 60 µm) into the Mediterranean Sea was estimated to 4.6 quadrillion ($4.6\pm1.3\times10^{15}$) Items/year.

Compared with rivers worldwide (Kumar et al., 2021), the Arno River waters are affected by a significant MPs contamination, mainly associated with domestic-industrial laundry effluents from urban areas, and mostly characterized by MPs smaller than 60 µm. The latter micro-litters represent a risk for fluvial and marine ecosystems being the most bio-accessible (Lehtiniemi et al., 2018) and easily transported fraction to the sea, where it may persist for a long time. The methodological approach developed in this research allowed i) to identify the key role of the smallest MPs to assess the Arno River water quality and, ii) to quantify MPs discharges into the Mediterranean Sea. To avoid relevant underestimation, the quantification of plastic particles belonging to the whole range size of MPs is strongly recommended in similar studies.

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Hotspots of microplastic accumulation at the land-sea transition and their spatial heterogeneity: the Po river prodelta (Adriatic Sea)

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Keywords: microplastics spatial heterogeneity, Po river delta, processes.

Deltas are the locus of river-borne sediment accumulation, however, their role in sequestering plastic pollutants is still overlooked. By combining geomorphological, sedimentological, and geochemical analyses, which include time-lapse multibeam bathymetry, sediment provenance, and μFT-IR analyses, we investigate the fate of plastic particles after a river flood event providing unprecedented documentation of the spatial distribution of sediment as well as of microplastics (MPs), including particles fibers, and phthalates (PAEs) abundances in the subaqueous delta. Overall sediments are characterized by an average of 139.7 ± 80 MPs/kg d.w., but display spatial heterogeneity of sediment and MPs accumulation: MPs are absent within the active sandy delta lobe, reflecting dilution by clastic sediment (ca. 1.3 Mm3) and sediment bypass. The highest MP concentration (625 MPs/kg d.w.) occurs in the distal reaches of the active lobe where flow energy dissipates. In addition to MPs, cellulosic fibers are relevant (of up to 3800 fibers/kg d.w.) in all the analyzed sediment samples, and dominate (94%) concerning synthetic polymers.

Statistically significant differences in the relative concentration of fiber fragments ≤ 0.5 mm in size were highlighted between the active delta lobe and the migrating bedforms in the prodelta. Fibers were found to slightly follow a power law size distribution coherent with a one-dimensional fragmentation model, thus indicating the absence of a size-dependent selection mechanism during burial. Multivariate statistical analysis suggests traveling distance and bottom-transport regime as the most relevant factors controlling particle distribution. Our findings suggest that subaqueous prodelta should be considered hot spots for the accumulation of MPs and associated pollutants, albeit the strong lateral heterogeneity in their abundances reflects changes in the relative influence of fluvial and marine processes.

Source-to-sink propagation of marine plastic and accumulation in seafloor sediments: the role of sedimentary gravity flows

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Keywords: plastic, submarine canyons, sedimentary gravity flows.

Plastic litter is nowadays ubiquitous in all environmental compartments of the world's oceans and sequestration in deep-sea sediments is considered its long-term sink. However, several knowledge gaps exist about the processes driving the dispersion and the ultimate fate of this pollutant in the marine environment. Since the physical processes that control the distribution of sediment and water masses in the oceans have a prominent role also on the transport and deposition of plastic, the source-to-sink approach applied in sedimentary research could bring significant advances to elucidate land-to-sea linkages of marine pollution, to identify pathways and plastic accumulation hotspots. Submarine canyons, acting as preferential conduits connecting shallow to abyssal depths, are widely recognized as main vectors for plastic transport from land to the deep sea, and are also focal points for accumulation of plastic litter derived from fishing gears. While the occurrence of fishing-related plastic is linked to fishing activities, which can be quite intense in and around canyons due to the high productivity often associated with these features, the accumulation of plastic along canyon axes can be related to different transport mechanisms, encompassing enhanced bottom currents, dense water cascading and especially sediment gravity flows. The efficient transfer capacity of sedimentary gravity flows is supported by ongoing evidence of large litter piles at great water depths and seems to be influenced by the proximity of canyon heads to shore and to riverine inputs, recognized as main entry points for plastic at sea. Along with the transport of plastic at great depths, sediment gravity flows can also determine its burial, as demonstrated by the recovery of plastic items enclosed within coarse-grained turbidite deposits at 2.5 m below the seafloor in a core retrieved from a prodelta channel. Overall, the paucity of studies relating plastic distribution to transport and depositional processes and the paucity of data from deep sea-setting, such as the lower reach of canyons, which may represent main depositional areas for land-based plastic, strongly limit our capability to assess the real extent of plastic accumulation on the seafloor. This, along with the lack of specific devices and strategies for the reckoning of buried plastic, raise the quest on the magnitude of the plastic storage on and within seafloor sediments, which may represent the largest plastic depocenters in the oceans.

Litter distribution in marine and coastal environments: highlights from ongoing research projects

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Keywords: coastal monitoring, beach litter, microplastics.

This study illustrates ongoing research activities carried out in the frame of the "RETURN" Project (funded by the National Recovery and Resilience Plan) and "Riparti" Project (funded by the Apulia Region) and focused on the assessment of beach litter (BL) distribution on sandy beaches and microplastics (MPs) in sediments. BL analysis is performed by applying both standard in-situ procedures and innovative methods, which are based on the exploitation of UAVs aero-photogrammetric surveys and the application of both manual and automatic imaging classification approaches, (Sozio et al., 2023). Such analyses are integrated with the evaluation of the predominant morphodynamical processes (coastal erosion and/or accretion), to support the identification of coastal zones affected by the accumulation and burial of BL items. For what concerns the MPs analyses, tailored sampling procedures are applied. Following the European guidelines, beach samples are collected at different points along the backshore while marine sediments are sampled at different depths in the shoreface and offshore. MPs classification is performed through both standard and innovative approaches. The latter are based on the exploitation of hyperspectral imaging (HSI) working in the short-wave infrared range (1000-2500 nm) (Fiore et al., 2022).

Test sites are located in the Apulia region along the Adriatic and the Ionian coast. BL monitoring activities have been carried out in 100 m long beach sectors at Torre Guaceto (Brindisi) and Capitolo (Bari); the first site is included in the Marine Protected Area and for this reason, it is not subject to scheduled cleaning activities due to the lack of tourist and recreational services; the second site is an important touristic destination, especially during the summer season. Sediment samples for MPs analyses have been collected at Torre Guaceto beach, in the Gulf of Taranto, and offshore the city of Bari. Results show BL density values ranging from 0.04 to 0.47 items/m^2 and plastic represents the most abundant material identified along the investigated beaches. BL items tend to accumulate in the upper part of the backshore, along the embryo/foredune limit, where density reaches a value of 1.24 items/m^2 (Rizzo et al., 2023). MPs concentration in marine sediment samples ranges from 1246 to 209 MPs/kg. The results of the μ-FTIR and μ-Raman analyses revealed that a large proportion of MPs in marine sediments derived from textile fibers (Cofano et al., 2023). Finally, different HSI-based procedures were developed. A ground-based hyperspectral system has been used at Torre Guaceto to evaluate the recognition of different types of plastic BL directly in situ. Regarding the sediment samples collected at Torre Guaceto and in the Gulf of Taranto, two effective laboratory-scale protocols have been developed to identify and classify the different polymers constituting the MPs directly on the matrix surface without the need for their preliminary extraction.

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Fiore L. et al. (2022) - Classification and distribution of freshwater microplastics along the Italian Po River by hyperspectral imaging. Environ. Sci. Pollut. R., 29(32), 48588-48606, https://doi.org/10.1007/s11356-022-18501-x.

Rizzo A. et al. (2023) - The Use of UAV Images to Assess Preliminary Relationships between Spatial Litter Distribution and Beach Morphodynamic Trends: The Case Study of Torre Guaceto Beach (Apulia Region, Southern Italy). Geografia Fisica e Dinamica Quaternaria, 45, 237-250, https://doi.org/10.4461/GFDQ.2022.45.12.

Sozio A. et al. (2023) - Comparing Meanshift/SVM and Mask-RCNN algorithms for beach litter detection on UAVs images. In: 2023 IEEE International Workshop on Metrology for the Sea; Learning to Measure Sea Health Parameters (MetroSea), 483-487, https://doi.org/10.1109/metrosea58055.2023.10317158.

Effect of plastics on marine ecosystem: preliminary findings of Phthalates (PAEs) on Gromiids

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Keywords: marine pollution, DEHP, benthic organisms.

Plastic pollution is one of the human-created severe threats on marine and coastal systems. Phthalates (PAEs) are a class of chemical compounds widely used in the manufacturing and processing of plastics (plasticizers) which are employed in a wide variety of industrial and consumer products (i.e., personal care products and food).

As PAEs do not form a covalent bond with polymers, they are easily released into the environment from such commercial products. For these reason, PAEs can either be absorbed by suspended particles that can sink to the bottom of aquatic ecosystems and build up in the sediments, or they can become readily available to marine organisms. Marine sediments can also act as an uptake source by benthic microorganisms in these ecosystems.

Among PAEs, di(2-ethylhexyl)phthalate (DEHP) is the most widely produced and used, as well as the most persistent phthalate found in seawaters and many studies have recently reported its negative effects on acquatic species.

This study examines the potential impact of DEHP on Gromiids, unicellular heterotrophic protozoa which are a common component of benthic marine communities. These organisms are characterize by the accumulation of a significant volume of stercomata (waste pellets), together with mineral grains and other extraneous particles, within the cell. In fact, they play a key role in benthic food webs by feeding on detritus and recycling nitrogen and carbon.

A chronic toxicity assay was carried out to assess the impact of this pollutant in the gromiids physiology and behavior. Contaminated colture were exposed and monitored for up 4 weeks, and at the end of the experiment all the live individuals were analysed by steomicroscopy and μ-FTIR (Fourier Transform Infrared) spectromicroscopy.

Under the microscope, some individual showed a discernible decrease in cellular turgor, which was most likely caused by sediment loss and cell membrane breakdown. Meanwhile, FTIR results revealed the presence of synthetic material inside the cell.

FTIR data allowed to answer the question whether there are any noticeable biochemical differences in the proteinaceous shells and the cytoplasm depending on the exposure of the cell organism to this bio-accessible plasticizers. As observed in other unicellular organisms related to gromiids, such as foraminifera, DEHP can induce similarly oxidative stress and protein aggregation. Additionally, this plasticizer can be assimilated into the gromiids cytoplasm, thereby entering biogeochemical cycles.

In summary, gromiids could be a good proxy of on-going emerging pollutants, highlighting the possibility that plastic pollution could enter the marine sedimentary record providing a unique signal that is unequivocally attributable to human activities.

It is essential to understand the mechanisms behind the interactions between plastic pollution and marine organisms, to develop effective mitigation strategies to safeguard marine biodiversity and ecosystem health.

Microplastics analysis from sediment samples collected at Capitolo Beach (Apulia, Italy)

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Keywords: microplastics, coastal pollution, beach monitoring.

In the last twenty years, several scientific studies have been focused on the identification of microplastics (MPs) in marine ecosystems, particularly in marine sediments which turn out to be a collection point for them, thus defining a global environmental problem (Alomar et al., 2016). Based on this, different methodologies aimed at the extraction of MPs from sediment samples have been tested. These techniques differ mainly based on the efficiency and type of material used during separation, and some, such as density separation techniques, are very effective and capable of separating the most common polymers, but results are expensive and harmful to the environment and humans (He et al., 2021). Following the approach proposed in Scopetani et al. (2020), in this contribution we present preliminary results obtained using oil to separate MPs from sediments, taking advantage from the oleophilic properties of plastic. This method turned out to be fast and efficient and, at the same time, with low health and environmental risk.

Study area is located on the Adriatic side of Apulia region (Capitolo Beach), which is a popular tourist destination hosting recreational facilities (bathhouse), especially during the summer season. Due to its high anthropogenic exploitation, Capitolo Beach is prone to be affected by plastics and microplastics pollution along the beach and within the sea sediments.

Sand samples were collected along the backshore following the procedures indicated by the European guidelines (Galgani et al., 2023). Then, samples were dried at 50°C to perform granulometric analysis. Before the oil-based separation phase, it was necessary to perform organic matter digestion on all samples using a hydrogen peroxide (H_2O_2) solution. Finally, MPs were analyzed in order to define their predominant characteristics and polymer-composition.

The results of such activities allow to evaluate the distribution of MPs in the beach sediments and to distinguish primary or a secondary origin of MPs, supporting the assessment of the environmental quality of the investigated beach.

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He D. et al. (2021) - Methods for separating microplastics from complex solid matrices: Comparative analysis. J. Hazard. Mater., 409, https://doi.org/10.1016/j.jhazmat.2020.124640.

Scopetani C. et al. (2020) - Olive oil-based method for the extraction, quantification and identification of microplastics in soil and compost samples. Sci. Total Environ., 733, https://doi.org/10.1016/j.scitotenv.2020.139338.

Multidisciplinary approaches for the analysis of Beach Litter distribution in coastal environments

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Keywords: coastal monitoring, beach litter analysis, machine learning.

The ever-increasing presence of pollutants and waste in the coastal environment has become one of the significant issues affecting marine-coastal areas worldwide, especially considering the continuous increase in the concentration of artificial polymers in environmental matrices (i.e., water, sediments, etc.) and the trophic chain. The effects they have on coastal environment are multiplied because of the combined action of meteo-marine processes and human activity. In this context, the Mediterranean basin is considered a "hot spot" for plastic pollution due to its peculiar hydrodynamic and geomorphological conditions. The presented study, which was carried out in the frame of the RIPARTI Project funded by Apulia Region, presents the results of the Beach Litter (BL) distribution analysis by applying different methodological approaches. In detail, standard in-situ surveys (Galgani et al., 2023) were coupled with indirect analyses performed by exploiting high-resolution images obtained from Unmanned Aerial Vehicles (UAVs) photogrammetric surveys and Machine Learning (ML) tools. Orthomosaics were used for manual screening in a GIS environment, and computer vision algorithms were employed to automatically detect BL items. The investigated sites are located along the Adriatic coast of the Apulia Region (Southern Italy). They include Torre Guaceto Beach (in the Marine Protected Area of Torre Guaceto, Brindisi) and Capitolo Beach (Monopoli, Bari). Results of the in-situ surveys show that the most abundant BL items measured at Torre Guaceto were represented by artificial polymers (32%), with a density of 0.5 item/m2 (Rizzo et al., 2021) as well as the case of Capitolo beach, where the artificial polymers represent the 90% of total items and with a density value of 2.5 item/m2. The manual screening also yielded similar results. At the Torre Guaceto site, plastic fragments were found to be the most abundant items, with a total of 336 out of 534 items. At the Capitolo site, 100 plastic items were identified out of a total of 143 BL items. The automatic identification and classification performed using the ML algorithm were conducted according to three classes of BL categories: "bottles", "worked wood", and "nets" (Sozio et al., 2023). Results show an underestimation of the total amount of only 45 items detected at Torre Guaceto beach and 63 items detected at Capitolo beach. The overall accuracy for both sites was 0.27 (mAP@IoU). This novel multidisciplinary approach comprehensively assesses the BL distribution and identifies the main accumulation zones. This information is crucial for designing tailored coastal management actions. Moreover, a specific flight protocol will be proposed to conduct aero-photogrammetric surveys to assemble datasets for automatic detection algorithms. Our future work will focus on improving the detection algorithm and expanding the classification classes, further enhancing the practicality and usefulness of our findings.

Galgani F. et al. (2023) - Guidance on the Monitoring of Marine Litter in European Seas An update to improve the harmonised monitoring of marine litter under the Marine Strategy Framework Directive. Technical report of the Join research Centert (JRC), Publications Office of the European Union, Luxembourg, 200 pp., https://doi.org/10.2760/59137.

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Autonomous underwater vehicles (AUVs including gliders) for the characterization and monitoring of environmental conditions in fresh and marine waters

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Keywords: underwater vehicles, water characterization, monitoring fresh and marine waters.

Fresh and marine waters pollution has emerged as a significant environmental concern over the past decade, also affecting marine sediments, due to potential and demonstrated negative effects on organisms, including humans. The present research aims to use and develop specific devices for autonomous underwater vehicles and underwater gliders to characterize and monitor the environmental conditions of fresh and marine waters. The investigation and sampling are performed to the full depth of the water column, in terms of microchemistry (e.g., dissolved oxygen), conductivity, temperature, pressure, pH, irradiation, acoustic/hyper-acoustic emissions, microplastics, micro-particles, sediments and further extended also to the biological content. The most employed techniques for sampling and subsequent laboratory analysis are discussed (e.g., Rickerby et al., 2000; Moro et al., 2021). This research also delves into the limitations and potential future developments of in-situ sampling techniques for micro-particles and microplastics. Traditional sampling methods, while effective, can be time-consuming and may not cover a sufficiently broad area to provide a comprehensive understanding of micro-particles and microplastics distribution. In response to these challenges, in this work we present a research that develops and uses innovative systems such as autonomous underwater vehicles, including ocean gliders (Helal et al., 2023; Helal et al., 2024), to sample and monitor the water column, both in fresh and marine waters, for a comprehensive 3D characterization (physical, analytical and biological) of its environmental conditions.

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Helal K.M. et al. (2024) - Effectiveness of ocean gliders in monitoring ocean acoustics and anthropogenic noise from ships: A systematic review. Ocean Eng., 295, 116993, https://doi.org/10.1016/j.oceaneng.2024.116993

Moro D. et al. (2021) - Thermal, X-ray diffraction and oedometric analyses of silt-waste/NaOH-activated metakaolin geopolymer composite. J. Compos. Sci., 5, 269, https://doi.org/10.3390/jcs5100269.

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S3.

Antarctica and the Arctic: unveiling the geological past and future evolution of polar regions

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High-resolution mineralogical and petrographic analysis of marine sediments in Antarctica: from silt to gravel

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Keywords: heavy-minerals, petrography, provenance.

In glaciated regions, marine sediments represent a unique archive to infer the geology of source rocks, often hidden below thick ice or sparsely outcropping in the Antarctic continent interior. Clast distribution and composition are commonly used for provenance studies in Antarctica (Zurli et al., 2022). We present the preliminary results of the study of clast and sediment textural and high-resolution mineralogical and petrographic analyses, performed on marine sediment samples collected in 2022 by the PNRA19_00022 COLLAPSE project, in the continental slope and rise off the Cook and Ninnis glaciers. The study area preserves a record of environmental changes occurred during the recent past glacial and interglacial climate cycle in the offshore of one of the largest subglacial basin of the East Antarctic Ice Sheet. The method proposed consists in analysing sediments, from silt to sand to gravel, applying laboratory protocols described by (Andò, 2020), and optical identification analysis coupled with a Raman spectrometer (Andò & Garzanti, 2013). Mineral chemistry of single species in rock fragments was studied analysing olivine, amphiboles and feldspars. Most common rock fragments identified, indicate very low to medium grade metamorphic source rocks. Volcanic clasts are derived from Cenozoic volcanic centres of the West Antarctic Rift System rather than from the Jurassic Ferrar Large Igneous Province and are concentrated in sedimentary facies characterised by coarser grain size, IRDs and Diatom assemblages typical of warm environmental conditions. Heavy-mineral (HM) analysis on 12 samples show a higher concentration of HM in this sedimentary facies, that is preliminary interpreted as contouritic and deposited during the transition from glacial to interglacial conditions. The samples collected in the offshore of the Cook glacier are dominated by volcanic sources, with abundant clinopyroxenes (67-79%), minor garnets, amphiboles, apatite, tourmaline and trace of zircon, rutile, titanite and orthopyroxenes and reveals a sharp increasing in corrosion feature of amphiboles and pyroxenes in the surficial samples, indicating a possible influence of brine as weathering factor in this area. The samples collected in the offshore of the Ninnis glacier are dominated by volcanic sources, with less abundant clinopyroxenes (43-70%), minor garnets, amphiboles, tourmaline, apatite, epidote, titanite and trace of zircon, rutile, Al-silicates and orthopyroxenes. Further analyses are ongoing on the isotope composition of the silt fraction and on the biogenic component to better constraint the preliminary interpretation. These preliminary results show the high value of the data set and the importance of a multidisciplinary approach to understand past oceanographic and climate changes. This study presents the first paleoceanographic record in the offshore of the Cook and Ninnis glaciers that will provide new insights into their past dynamics since MIS5.

Andò S. (2020) - Gravimetric separation of heavy minerals in sediments and rocks. Minerals, 10, 273, https://doi:10.3390/min10030273.

Andò S. & Garzanti E. (2013) - Raman spectroscopy in heavy-mineral studies. In: Scott, R. A., Smyth, H. R., Morton, A. C. & Richardson, N. (eds). Sediment Provenance Studies in Hydrocarbon Exploration and Production. Geo. Soc., London, Sp. Pub., 386, 395-412, http://dx.doi.org/10.1144/SP386.2.

Zurli L. et al. (2022) - Data report: petrology of gravel-sized clasts from Site U1521 core, IODP Expedition 374, Ross Sea West Antarctic Ice Sheet History. In: McKay R.M. et al, Ross Sea West Antarctic Ice Sheet History. Proceedings of the International Ocean Discovery Program, Volume 374, https://doi.org/10.14379/iodp.proc.374.201.2022.

Multi-proxy single-grain provenance analysis to tackle growth and retreat of West Antarctic Ice Sheet: insights from apatite and zircon U-Pb dating coupled with fission-track age and geochemical analysis of apatite

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Keywords: provenance, glaciomarine sediments, Antarctic ice-sheets.

In recent years the advance in geochronological technique applied to provenance studies allowed better exploring the flux of glaciomarine sediments in polar regions and in turn to highlight events of increase and retreat of the Antarctic ice sheets.

In particular, the coupling between the classical thermochronological method of fission tracks in apatite with the less common U-Pb dating by LA-ICP-MS in the same apatite grain provides a powerful tool to constrain the rock source of the sediments. Moreover, during U-Pb dating through LA-ICP-MS it is possible to determine the major and trace elements (including REE) for the single double-dated apatite that can be statistically compared (O'Sullivan et al., 2020) to provide an affinity to the lithology source providing a further provenance discrimination factor.

We recently applied this multiproxy method on samples coming from two legacy DSDP drill cores (DSDP271, 272, 270) that cover a stratigraphic time window from the Oligocene to Present and are located close to latitude 180◦, considered the location of the present-day confluence between ice fed mainly by the EA and WA, respectively (Olivetti et al., 2023; Balestrieri et al., 2024).

Coupled with zircon U-Pb analysis, our multi-proxy study turned out to be a robust tool for the modeling of ice sheet volumes and ice drainage patterns from late Oligocene to Present.

Balestrieri M. L. et al. (2024) - Recurrent E-W oscillations of the ice flow confluence of the East and West Antarctic ice sheets in the central Ross Sea, Antarctica, from the Middle Miocene to the present day. Palaeogeogr. Palaeocl., 633, 111885.

Olivetti V. et al. (2023) - Ice volume variations and provenance trends in the Oligocene-early Miocene glaciomarine sediments of the Central Ross Sea, Antarctica (DSDP Site 270). Global Planet. Change, 221, 104042.

O'Sullivan G. et al. (2020) - The trace element composition of apatite and its application to detrital provenance studies. Earth-Sci. Rev., 201, 103044.

GRETA (CoolinG oveR thE VicToria LAnd (GRETA)): resolving the Ross Sea response to continental climate change during the last two millenia

Battaglia F.[1], Torricella F.[1], Belt S.[2], Capotondi L.*[3], Colizza E.[4], Colleoni F.[5], Di Roberto A.[6], Langone L.[1], Giordano P.[1], Mollenhauer G.[7], Pochini E.[8] & Tesi T.[1]

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Keywords: Antarctica, Ross Sea, IPSO25.

Ice cores have significantly improved our knowledge of short-term climate variability in Antartica over the last two decades and indicate an abrupt cooling event along the Victoria Land (western Ross Sea, Antarctica). However, no information isyet available from marine sediment. GRETA proposes to fill this knowledge gap by investigating the ocean response to a cooling event over Victoria Land (ca 1.3-1.9 ky CE). We present a new high-resolution sediment sequence collected in the western Ross Sea (JOIDES Basin), comparing the new data with existing data collected in Wood Bay and Edisto Inlet (Mezgec et al., 2017; Tesi et al., 2020; Battaglia et al., 2024). We are using a multidisciplinary approach that includes micropaleontological analyses (diatom assemblages), geochemical analyses (biomarkers such as IPSO25 and PIPSO25, organic carbon and stable isotope analyses, TEX86-L/RI-OH') and sedimentological analyses (grain size analyses and sortable silt determination). The ultimate goal of our project is to reconstruct sea ice dynamics, water mass properties (sea surface temperature, water mass circulation, upwelling) in the western Ross Sea during the last 2,000 years and its relationship with corresponding continental climate events. Finally, we will merge the information obtained from the marine domain with ice core and model data to provide new insights into the sub-millennial variability of atmosphere-ocean interactions.

Battaglia F. et al. (2024) - The discovery of the southernmost ultra-high-resolution Holocene paleoclimate sedimentary record in Antarctica. Mar. Geol., 467, 107189.

Mezgec K. et al. (2017) - Holocene sea ice variability driven by wind and polynya efficiency in the Ross Sea. Nat. Commun., 8(1), 1334.

Tesi T. et al. (2020) - Resolving sea ice dynamics in the north-western Ross Sea during the last 2.6 ka: From seasonal to millennial timescales. Quaternary Sci. Rev., 237, 106299.

Paleoclimatic reconstruction of the past 30.000 years through analysis on calcareous nannofossil assemblages on the west Spitsbergen margin

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Keywords: Weichselian glacial stage, deglaciation, Arctic.

The analysis of calcareous nannofossil (CN) assemblages has been proven to be a reliable approach for reconstructing paleoclimatic conditions along Arctic margins, given the high sensitivity of nannoflora to changes in water column parameters (e.g. temperature, insolation, and nutrient availability). The piston core GS191-01PC was collected from the Bellsund Drift crest on the west Spitsbergen margin during the PREPARED cruise (Lucchi et al., 2014). It was drilled at a water depth of 1647 meters and it consists of 19.67 meters of sediment characterized by a complex stratigraphy. This included bioturbated and laminated sediments, with sparse to massive Ice Rafted Debris, oxidized layers, and two tephra layers. Caricchi et al. (2019, 2022) have extendedly investigated the GS191-01PC core, establishing a robust age model for the region.

The CN assemblages were investigated in a 13.90 m bsf segment of the core, covering the last 30,000 years BP (140 samples at 10 cm intervals). The analysis focused on the distribution of species *Emiliania huxleyi* and *Coccolithus pelagicus*, alongside reworked specimens and data on total nannofossil abundance (number of specimens/10 mm^2). The *E. huxleyi/C. pelagicus* ratio (H/P; Carbonara et al., 2016) was calculated to investigate oscillations between the warmer West Spitsbergen (H/P > 1) and the cooler East Spitsbergen (H/P < 1) Currents. During the Late Pleistocene, the distribution of *E. huxleyi* and reworked specimens evidenced the onset of Heinrich (3, 2, 1) and the Melt Water Pulse-1A abrupt events. Throughout the Younger-Dryas and Holocene epochs, fluctuations in total nannofossil abundance and the overall assemblage composition provided insights into events such as the Holocene Thermal Maximum, and the 8.2, 4.2, and 2.8 cooler episodes.

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Soft- and hard-shelled foraminiferal assemblages to assess the vulnerability of Foraminifera to climate change in Kongsfjorden, Svalbard

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Keywords: foraminifera, melting ice, Arctic.

Arctic regions are highly affected by global climate change because of polar amplification. Recent studies have demonstrated that Svalbard fjords are changing more quickly than most other marine environments due to continuos climatic changes. The key elements influencing sea ice coverage and the lengthening of the ice-free summer season in the Svalbard region are atlantification, and the increase in air temperature and precipitation.

Situated at 79°N 12°E near Ny-Ålesund, the Kongsfjorden is an essential site for studying environmental climate change in the Svalbard archipelago. Its noteworthy alterations over the last 10 years, especially the dramatic decline in the extention of winter sea ice, have attracted a great deal of attention. This phenomenon is partly attributed to the increasingly prolonged annual presence of Transformed Atlantic Waters (TWA), which are intermediate water masses originating from warmer Atlantic Waters (AW). Furthermore, this retreat of land-terminating glaciers in response to global warming has increased sediment inputs.

In the present study, we examined the distribution of living benthic foraminiferal assemblages to gain insight into how the climate change affect the strong environmental gradients of Kongsfjorden, leading to elevated physical and geochemical stress on benthic habitats.

The analyses of superficial sediment collected during the August 2021, allow us to identify 3 different assemblages in the innermost fjord: 1. The stations close to the glacier are dominated by monothalamids soft-shell species (>50%) as *Psammophaga zirconia* and the agglutinated species *Capsammina bowmanni*. These are stress-tolerant species, able to overcome the massive and frequent sediment and freshwater input from melting glaciers. 2. In the medial stations (about 5 km far from the glacier terminus), the increased organic fluxes resulted in the dominance of the calcareous species *Nonionellina labradorica*, typically associated with organic-rich sediments. *Micrometula* sp.. The important presence of*A. glomeratum* suggests a strong influence of Atlantic water intrusion in this part of the fjord.

As previously reported by Fossile et al. (2022) we observed distinct assemblage distributions along the Kongsfjorden in response to the environmental stress induced by glacier dynamics and for the first time we report that soft-shelled foraminifera are also sensitive to different environmental stress conditions in this region.

Fossile E. et al. (2022) - Influence of modern environmental gradients on foraminiferal faunas in the inner Kongsfjorden (Svalbard). Mar. Micropaleontol., 173, 102117, https://doi.org/10.1016/j.marmicro.2022.102117.

A lithostratigraphic reappraisal of a Permian-Triassic fluvial succession at Allan Hills (Antarctica) and implications for the terrestrial end-Permian extinction event

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Keywords: stratigraphy, end-Permian extinction, Gondwana.

Between Permian to Triassic, the Earth experienced climatic and biotic crises, included the greatest mass extinction at the Permian-Triassic boundary. These climatic and biological changes are reflected in both marine and terrestrial depositional systems. Over this time span, the Gondwana supercontinent hosted numerous large basins that may preserve the paleoenvironment response to global changes in the sedimentary record. This study provides a lithostratigraphic reappraisal of the latest Paleozoic-Mesozoic alluvial Beacon Supergroup at Allan Hills (Convoy Range), which is one of the most complete sedimentary sequences in Antarctica. Fieldwork stratigraphic-lithological observation, facies analysis, and petrographic characterization of sedimentary rocks allow the identification of six depositional units. The investigations point out for a conformable relationship between depositional and lithostratigraphic units, characterized by changes in the fluvial style. The reconnaissance of a "transitional interval" showing intermediate features between the Permian Weller Coal Measures and the Triassic Feather Conglomerate strengthen the conformable nature of the sequence across the Permian- Triassic boundary in this region. The lithological features of such interval strongly resemble those observed in the coeval deeply studied Eastern Australia successions crossing the Permian-Triassic boundary as well as the end-Permian extinction event. More precisely, the uppermost coal occurrence, just above a glossopterid macroflora-bearing carbonaceous mudstone within the "transitional interval", marks the disappearance of coal-peat forming Permian vegetation which corresponds with the terrestrial end-Permian extinction, thus representing one of the few end-Permian extinction records in Antarctica.

Stratigraphic constraints on the Beacon Succession of the Transantarctic Mountains through palynological data

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Keywords: palynology, end-Permian extinction, transantarctic mountains.

The Permian to Triassic-Lower Jurassic sedimentary sequences exposed along the Transantarctic Mountains play a crucial role in elucidating the evolution of the Gondwanan basins of the Antarctica plate. This study presents one of the most complete palynostratigraphic sequences of Permian to Middle Triassic deposits from Antarctica, in Southern Victoria Land. These deposits were laid down in alluvial settings, exhibiting changes in environment and depositional style over time. Additionally, the revealed continuity in sedimentation between the Permian Weller Coal Measures Formation and the Triassic Feather Sandstone and Lashly formations, allows the reconstruction of the microfloristic trend across one of the most crucial time intervals in Earth's history, the Permian-Triassic Boundary.

The sedimentological and palynological study provides biostratigraphic data for the age attribution of each formation and the correlation with coeval formations across the Transantarctic Mountains (TAM) and other areas of the southern Gondwana.

The sporomorphs assemblage in the Weller Coal Measures Formation, indicates a late Permian age. The upper part of the formation is characterised by a palynofacies mainly composed of long-shaped inertinite, which suggest the occurrence of paleo wildfires, to be linked with the EPE (terrestrial end-Permian Extinction). The uppermost occurrence of a microfloristic assemblage attributable to the *Protohaploxypinus microcorpus* Zone indicates an Early Triassic age. Furthermore, the sporomorphs assemblage, which is also supported by the paleobotany remains, has revealed a profound change in the flora between the Permian and Triassic time. The floristic turnover, which also been observed in many areas of Gondwana, is strictly linked to the deep change of paleoenvironmental conditions between the Permian and Triassic widespread all over the world due to a general greenhouse effect. Following a non-fossiliferous sandstone succession (Feather Sandstone Formation) deposited during Induan and Olenekian time interval, the flora returned to flourish in the Middle Triassic with the deposition of the Lashly Formation. Here different environmental conditions affected the sedimentary sequence, with an alternation of stable and instable landscapes evidenced by an alternation of coal, fine and coarse sandstone deposition, as well as numerous pieces of fossil trunks and other paleobotanical remains.

This study, which is based on the palynological and palaeobotanical composition of the Beacon Supergroup, has been supported by numerous lithological and stratigraphical data for a complete reconstruction of the paleoenvironmental condition that occurred during this fundamental time span. Finally, the palynostratigraphic revision of such crucial sequences, allows a more precise understanding of the evolution of the Gondwanan basins of the Victoria Land, in terms of paleoenvironmental changes and source-to-sink drainage systems.

Geodynamic processes at the Pacific margin of North Victoria Land (Antarctica): new evidence from offshore geophysical data on the crustal structure and seabed morphology (PNRA_BOOST Project)

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Keywords: Antarctica, pacific margin, offshore geophysical data.

The interplay between the West Antarctic Rift System and the Australian-Antarctic plate divergence has played a crucial role in shaping the structure of the Antarctic lithosphere, growth of the cryosphere, formation of sub-ice topography, and uplift of the Transantarctic Mountains. At present, there still remain open questions and lack of data on rift-related structures and their Eocene to Recent geodynamic history. The PNRA2019_BOOST project (Bridging Onshore-Offshore STructures at the Pacific Coast of North Victoria Land, Antarctica: an integrated approach) was addressed to the study of the Pacific margin of the North Victoria Land (NVL), i.e. Oates and Pennell Coasts, a much underexplored area located in a critical position at the boundary region between East and West Antarctica. New offshore geophysical data (multichannel high-resolution seismics, bathymetry and magnetics) acquired on board the Italian R/V L. Bassi (38th - 39th Italian Antarctic Expeditions) as part of the PNRA_BOOST project, allowed the identification of morphological and tectonic features relevant for understanding the geodynamic evolution of the Antarctic continental margin and the influence of lithosphere dynamics on ice-sheet evolution and ice-sheet stability. Main promising new observations and discoveries are represented by morphological features of the seabed, regional scale tectonic structures and volcanic chains. We identified NW-trending fault-bounded basement highs on the shelf and on the continental rise associated with growth strata that point to a tentative dating of tectonic reactivation to Oligocene times. Moreover, a km-scale ridge of basement covered by drift deposits, revealed at a depth of about 2500 m, is bounded by faults pointing to a more recent tectonic activity. In the SW part of the study area, two linear volcanic zones (one belt is ca. 50 km long) occur with a roughly NNW-SSE direction. Various volcanoes and associated fluid-related features cut through the surrounding sedimentary successions showing evidence of recent activity. This volcanism may represent the NNW continuation of the Mid-Miocene to Quaternary Hallett Volcanic Province forming the Adare Peninsula, or may be related to the post-spreading Pliocene-Recent volcanism of the Adare Basin.

Sedimentologic and petrographic characteristics of beach ridges in Terra Nova Bay (Antarctica)

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Keywords: beach ridges, Terra Nova bay, geomorphology.

Beach ridges, found around Terra Nova Bay (Antarctica) are primarily composed of sediments such as sand, gravel, and occasionally shell fragments. The material constituting these ridges can originate from both local and distant sources (Baroni, 1987). While some sediments may come from nearby beaches or eroded cliffs, others might be transported by rivers or ocean currents from more remote locations. The composition and characteristics of these sediments provide valuable insights into the history of deglaciation in the region (Baroni & Orombelli, 1991). Samples of beach sand were gathered from various elevations, encompassing both current and elevated beach areas. This sampling was part of the PNRA-DISGELI national project conducted between October 2022 and February 2023. By analyzing 33 thin sections, conducting granulometric analysis, and identifying both emerged and submerged morphologies, this study can unravel the complex processes of sediment deposition during different stages of deglaciation. Through meticulous sieving of grains and measuring the evolution of weight, it was possible to construct granulometric curves, aiding in understanding the temporal and spatial distribution of sediments and the dynamics of coastal evolution.

The petrographic characterization reveals the presence of abundant lithic fragments showing textural and mineralogical features referable to a large number of different rock types. Isotropic textures are recognizable for plutonic fragments deriving from acidic-intermediate rocks (granites-granodiorites-diorites) and for volcanic porphyritic mafic rocks (olivine basalts). Detritus from metamorphic rocks is also abundant: clasts from Opx-bearing granulitic rocks, Sill-bearing high-T ones and gneisses (Rocchi et al., 2004). In regard to the granulometric analysis, the distributions of grainsize suggest the existence of moraine deposits that are poorly sorted and have been influenced by wave activity.

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Baroni C. & Orombelli G. (1991) - Holocene raised beaches at Terra Nova Bay, Victoria Land, Antarctica. Quaternary Res., 36(2), 157-177, https://doi.org/10.1016/0033-5894(91)90023-X.

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^{14}C age determination of beaches ridges from Terra Nova Bay, Antarctica

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Keywords: beach ridges, Terra Nova Bay, ^{14}C dating.

Terra Nova Bay, a significant inlet on the western margin of the Ross Sea along Victoria Land's coast, harbors both modern and ancient beach ridges within its bays and protected areas. Approximately 8000 to 7500 years ago marked the completion of deglaciation in Terra Nova Bay following the retreat of the grounded ice sheet in the Ross Sea Embayment (Baroni, 1987). The various phases of deglaciation resulted in the formation of elevated beaches ridges at different elevations in Tethys Bay and Adélie Cove, allowing the stepwise retreat of the grounding line (Baroni & Orombelli, 1991). Samples were gathered from various elevations, encompassing both current and elevated beach areas. This sampling was part of the PNRA-DISGELI national project conducted between October 2022 and February 2023. The samples underwent carbon dating analysis, including bioclast fragments, a fish specimen, shells, penguin feathers, bones, teeth, remains, and a vermulid (Hajdas et al., 2021). The primary objective of this study is to determine the uplift rates and scale associated with the undergone deglaciation that shaped these beach ridges.

Baroni C. (1987) - Geomorphological map of the Northern Foothills near the Italian Station, (Terra Nova Bay, Antarctica). Memorie della Società Geologica Italiana, 33, 195-211.

Baroni C. & Orombelli G. (1991) - Holocene raised beaches at Terra Nova Bay, Victoria Land, Antarctica. Quaternary Res., 36(2), 157-177, https://doi.org/10.1016/0033-5894(91)90023-X.

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4D heterogeneity in geological boundary conditions beneath the West and East Antarctic ice sheets: what have we learnt and what do we need to know?

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Keywords: Antarctica, crust and lithosphere, ice sheets.

The Antarctic crust and lithosphere holds critical information to decipher geological influences on past, present and future Antarctic ice sheet behavior. Recent compilations of bed topography, bathymetry, aeromagnetic and aerogravity anomalies, and seismological networks and satellite data are transforming our ability to extrapolate geological information from the coast to the entirely ice-covered interior of Antarctica.

The Paleozoic to Cenozoic subduction system of the Antarctic Peninsula is well known. However, whether the tip of the West Antarctic Rift System (WARS) linked up to the subduction zone remains ill-constrained and this limits our understanding of the geodynamic drivers of rift evolution and changes in crustal and mantle dynamics. Recent progress has been made in imaging the WARS beneath the most rapidly changing part of the West Antarctic Ice Sheet in the Amundsen Sea Embayment, augmenting prior knowledge of the Ross Sea Rift and Siple Coast segments. Overall, we now have a more comprehensive view of the segmentation of the rift system, in terms of the distribution of sedimentary basins, crust and lithosphere thickness, effective elastic thickness, and partially also magmatism and geothermal heat flux. However, there are still open questions, particularly regarding the geological sources of aeromagnetic anomalies within the WARS. Traditional interpretations predict that they reveal huge volumes of Cenozoic rift-related magmatism. Nevertheless, this hypothesis is difficult to reconcile with evidence from glacial erratics and the amount of Cenozoic crust and lithosphere extension. Although the role of different tectono-thermal and ice sheet processes affecting the evolution of Cenozoic magmatism in the WARS has received considerable international attention, it clearly calls for further research.

Understanding the roles of tectonic, thermal, erosional and isostatic processes in the uplift of the Transantarctic Mountains (TAM) also requires further research. For example, whether the was a West Antarctic plateau and a vanished Mesozoic Victoria Basin is debated, and controversy centers on whether the Wilkes Subglacial Basin (WSB) resulted solely from lithospheric flexure linked to TAM uplift and glacial erosion, or if Mesozoic and Cenozoic extension occurred also within East Antarctica.

Aerogeophysical exploration has unveiled major sedimentary basins in East Antarctica, including the WSB, the Aurora Subglacial Basin, the Recovery and Pensacola Pole Basin. However, to develop new models of the crustal and lithospheric cradle of the largest ice sheet left on Earth we need more seismological stations and MT arrays to be deployed atop of these basins, New higher resolution aerogeophysical surveys also need to be flown over major subglacial lake districts, to enhance our knowledge of hydrological influences on East Antarctic Ice Sheet behavior.

Oligocene-Miocene structurally-controlled hydrothermal activity along the Transantarctic Mountains: evidence from apatite thermochronology

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Keywords: Antarctica, fission-track thermochronology, hydrothermal fluid flow.

The Transantarctic Mountains (TAM) constitute the longest extensional mountain range on Earth, forming the Mesozoic-Cenozoic rift shoulder at the boundary between the Antarctic craton and the Ross Sea embayment. Wide rifting accompanied first the Gondwana breakup, characterized by horst and graben structures in the Ross Sea and by topographically high rift shoulder, shaped in time by fluvial and glacial erosion. During the Cenozoic, deep troughs, such the Terror Rift, developed at the front of the TAM following a transtensive reactivation, acting as intraplate termination of transform shear and propagating into inherited Paleozoic shear zones. Eocene to Present tectonics is well-constrained offshore, where thick Cenozoic glacio-fluvial sediments are faulted and invaded by the volcanic products of the McMurdo Volcanic Group during continuous rifting. Few direct time constraints of Cenozoic faulting exist onland, and are mainly available from the Northern Victoria Land. In Southern Victoria Land, fault activity is indirectly constrained by anomalies in age-elevation linear relationship as derived from low-temperature thermochronology data.

In this study, we focused on the Prince Albert Mountains sector of Southern Victoria Land, in the area between Mawson and Mackay glaciers, namely the Convoy Range block. This area has been poorly covered by field surveys; therefore, few thermochronological data are available and brittle structural data are lacking. Here we present results of a multidisciplinary approach aimed at reconstructing the Oligo-Miocene tectonic activity in the region that integrates: (1) multiscale structural analysis (from regional- to micro-scale); (2) geothermometry; and (3) apatite fission-track thermochronology.

Brittle deformation is accompanied by hydrothermal propylitic alteration (secondary chlorite, epidote and sericite) and carbonatisation of the intrusive magmatic host rocks. Chlorite thermometry constrains the temperature environment of rock alteration at ~ 230 ± 20°C. Samples collected along fault zones show fission-track ages as young as ~ 23 Ma, opposed to undeformed samples at similar elevation (from ~ 30 to ~ 50 Ma). Anomalous fission-track ages are correlated with the thermal overprint associated with the structurally controlled hydrothermal event. These results document a case of structurally-controlled hydrothermal fluid flow during the Cenozoic transtensive reactivation in Victoria Land, with important inference on the onset of Cenozoic volcanism in the region.

The use of macrofaunal microfossils to unveil past Holocene changes: a case study from Edisto Inlet (Ross Sea, Antarctica)

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Keywords: Antarctica, Holocene, echinoderms.

Paleoenvironmental reconstructions are essential for the understanding of the evolution of past climatic conditions. These reconstructions rely on various proxies to gain a comprehensive view of environmental characteristics, ranging from geochemical to micropaleontological analyses. Traditionally, micropaleontological studies have focused on foraminifera, diatoms, and other microorganisms, relating changes in species compositions to changes in the physiochemical characteristics of the environment. However, the stratigraphical distribution of macrofaunal-related microfossils (150 µm – 1 mm) has been largely overlooked, particularly for the Holocene and within remote areas like Antarctica. In this study, we examine a Late Holocene (3.6 kyrs BP) high-resolution marine sediment core from a fjord in the northwestern part of the Ross Sea, Antarctica. With a core length of around 14 m, this record provides exceptional subcentennial resolution. Our findings demonstrate that macrofaunal remains, specifically echinoderms, can offer detailed insights into recent past environmental conditions. We identified two distinct echinoderm groups: ophiuroids, or brittle stars (*Ophionotus victoriae*), and irregular echinoids. Despite challenges in estimating population size due to the abundance of ossicles releases upon decay, we employed a statistical approach (Generative Additive Models) on presence/absence data to estimate the probability of occurrence of these organisms. By comparing results with other proxies derived from the same record and nearby cores, we successfully employed echinoderms as a novel proxy for polar environment reconstruction, tracing the evolution of the sea-ice cover. The presence of *O. victoriae* was associated with interannually stable sea-ice cycles with yearly organic matter deposition, owing to its peculiar reproductive physiology. Additionally, its presence indicated periods of a mature benthic community, as it is a widespread component of Antarctic benthos. Irregular echinoids were linked to organic matter presence on the seafloor. Through proxy comparisons, we distinguished a specific climatic phase (The Ophiuroid Optimum), providing additional insights into the environmental evolution of the area beyond standard proxies. In conclusion, this study offers compelling evidence that incorporating macrofaunal-related proxies in paleoenvironmental reconstructions is essential for capturing complex environmental dynamics.

Paleoceanographic changes suggested by planktic and benthic foraminifera in the Western Svalbard Slope (Bellsund Drift) during the last century

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Keywords: sea ice, Svalbard, last century.

The objective of this study is to reconstruct the last century's climatic oscillations in the Western Svalbard Slope (Arctic region) using high-resolution analysis of planktic and benthic foraminiferal assemblages as proxies for surface and deep-water mass properties. In the studied area, warm Atlantic water masses are advected to the Arctic Ocean through the West Spitsbergen Current, representing the northernmost tip of the Global Thermohaline Circulation. The interaction between the cold Arctic and the warm Atlantic water masses significantly influences the entire foraminiferal community. The paleoenvironmental reconstruction obtained with the microfossil assemblages, together with data from satellite monitoring of the sea ice extent and the long-term record of the annual temperature of the West Spitsbergen Current measured over the last 50 years, support the evidence of a progressively rising heat influx into the Arctic Ocean due to an increasing Atlantic water inflow, forcing the consequent decay of the sea ice extent.

Mechanisms driving formation and preservation of the laminated sediments of Edisto Inlet, western Ross Sea (Antarctica): the sub-seasonal variability of particle composition and fluxes

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Keywords: laminated diatomaceous sediments, sea ice dynamics, antarctica.

Laminated diatomaceous deposits have been documented in the Edisto Inlet (western Ross Sea). The sediments show alternating dark, rich in IPSO25 biomarker, indicative of fast ice, and light laminae, dominated by *Corethron pennatum* diatoms. Based on these observations, the dynamics of fast ice was reconstructed over the last 2.6 ka for the western Ross Sea. However, the lack of direct observations introduces uncertainty into the paleoclimatic and paleoceanographic interpretation of these laminated sediments.

The project LASAGNE (Laminated Sediments in the Magnificent Edisto Inlet, Victoria Land: What processes control their deposition and preservation?), funded by the Italian Program of Antarctic Research (PNRA), proposed a multidisciplinary study that integrates the characteristics of fast ice, water column, and surface sediment, aiming to obtain information on the factors influencing formation and preservation of laminated sediment in Edisto Inlet. The project integrates also biological data (phytoplankton, microzooplankton and foraminifera) collected in situ, and time series of satellite images of sea ice. The main goal was to provide new insights into the sub-seasonal formation of laminated sediments, offering a backbone for the interpretation of paleoclimatic sedimentary archives.

An oceanographic mooring was deployed between March 2022 and February 2023, to investigate the mechanisms driving the formation of sediment laminations. The purpose was to test whether the deposition of dark sediments (rich in sympagic diatoms such as *Berkeleya adeliensis*) occurs in late spring-early summer, while light sediment (mainly composed of *Corethron pennatum*) represents sedimentation in late summer-early autumn.

The mooring data reveals that sediment lamination arises from the significant seasonal variability of particle fluxes and composition. Additionally, the thermohaline properties and dynamics of water masses in Edisto Inlet exhibit pronounced seasonal changes. Similarly, diatom assemblages and sea ice cover also undergo significant seasonal variations.

Taken together, these environmental factors contribute to the formation of a pair of laminae (dark in late spring, light in late summer) during years characterized by the retreat of sea ice and the presence of open water conditions in late summer. The preservation of lamination is subsequently guaranteed by a high sedimentation rate, limited oxygen penetration, and reduced biological mixing.

IODP Expedition 403 Eastern Fram Strait Paleo-Archive: preliminary results from the last expedition of the International Ocean Discovery Program

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Keywords: Arctic, paleoclimate, paleoceanography.

The North Atlantic and Arctic Oceans are unquestionably major players in the climatic evolution of the Northern Hemisphere and in the history of the meridional overturning circulation of the Atlantic Ocean. The establishment of the modern North Atlantic Water (NAW) transporting heat, salt, and moisture to the Northern Hemisphere, has been indicated as one of the main forcing mechanisms for the onset of the Northern Hemisphere Glaciation. NAW controls the extent and dynamics of circum-Arctic and circum-North Atlantic ice sheets and sea ice in addition to deep water and brine production. How the ocean system and cryosphere worked during past warmer intervals of high insulation and/or high atmospheric CO_2 content, is still largely unknown and debated and the required information can only be attained by offshore scientific drilling.

IODP Expedition 403 target high-resolution, continuous and undisturbed sedimentary sequences identified on the western continental margin of Svalbard (eastern side of the Fram Strait) along the main pathway and northern penetration of the North Atlantic Waters flowing into the Arctic Ocean. The area around Svalbard is very sensitive to climatic variability and it can be considered as a "sentinel of climate change". Further, the reconstruction of the dynamic history of the marine based paleo Svalbard-Barents Sea Ice Sheet is important as it is considered the best available analogue to the modern, marine-based West Antarctic Ice Sheet, for which the loss of stability is presently the major uncertainty in projecting future global sea level rise in response to the present global climate warming.

We present the preliminary results from the IODP Exp-403 that will take place on the drill ship Joides Resolution during 4th June – 2nd August 2024 (Amsterdam–Amsterdam) as the last expedition of the International Ocean Discovery Program.

The topography of the high latitude mountain chain and the enigma of high-standing plateau

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Keywords: Greenland, north Atlantic margin plateau, detrital fission-track.

Most of the mountain chains located at high latitudes in both hemispheres, such as the Transantarctic Mountains and the North Atlantic continental margins, shows high-standing low-relief surfaces deeply incised by fjords. The origin of such topography in Greenland and Norway is largely debated, and two end-member hypotheses have been proposed. The first hypothesis proposes that the low-relief landscape was formed at low elevations during a Mesozoic peneplanation phase and then uplifted during the Cenozoic; in this context the low-relief surface thus represents a remnant erosional surface where the present erosion is negligible. According to the second hypothesis, the low-relief surface was formed at high elevations in response to a slow, continuous and ongoing process of widespread erosion at high altitudes. These two hypotheses imply different geological and geomorphological processes and different amounts of sediment production over time, especially in the last few million years.

Here we show detrital dating through apatite fission-track (AFT) method from Greenland emipelagic marine record. 10 samples have been collected from two ODP cores, the leg 152 site 918 and the leg 162 site 987, that cover a time interval from late Miocene to Middle Pleistocene. Mixture distribution of AFT ages have been decomposed into age populations, giving population in agreement with the insitu AFT ages.

We interpreted the observed trend as a consequence of relevant contribution of sediment from high-standing plateau that is characterized by older insitu AFT ages.

Contrasting provenance signals during Pleistocene interglacial periods influenced by West Antarctic Ice Sheet climatic response recorded at IODP Site U1524 exp. 37

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Keywords: provenance studies, West Antarctic Ice Sheet, zircon dating.

The study of erosion, dispersal and deposition of sediments represent a useful tool for reconstructing Antarctica's ice sheets during the warmer-than-present interglacial periods of the late Pleistocene, with the aim of informing predictions of Antarctic ice sheet mass loss over the coming decades and centuries. Overcoming uncertainty in how the sedimentary system operates at IODP Expedition 374 Site U1524 could potentially reveal the evolution of the West Antarctic Ice Sheet (WAIS), resulting in improvements in ice sheet model predictions of future sea-level rise. We present new sedimentological provenance data from Site U1524, coupling U-Pb zircon dating (DZ), heavy mineral (HM) analysis, and Nd isotope compositions to reveal patterns of ice sheet erosion and sedimentary dispersal since ~400 ka. Zircon age distributions down the section are dominated by Ross and Nimrod Orogeny zircons, but younger populations of Cretaceous and Carboniferous ages from Marie Byrd Land allow detection of distinct sourcing from West Antarctica (WA) and the Transantarctic Mountains (TAM). HM suites indicate a general provenance from a recycled orogen due to the presence of diagnostic metamorphic and igneous minerals such as amphibole, epidote and garnet, but associated with a low tHMC (2.7 ± 0.6). A clear shift (possibly identified as the late-MIS9) towards a more mafic source is detected by the increase of clino and orthopyroxenes with abundant diopside and hypersthene, pointing to the erosion and contribution from gabbros and andesites. This is further supported by the presence of minor amount of high-pressure Al-silicate (kyanite) and prehnite-pumpellyite diagnostic of detritus from low grade metamorphic source (first cycle or metasediment erosion). The neodymium isotope dataset helps identify glacial periods, with consistent epsilon Nd values of ~-8.5 possibly representing reworked material from the continental shelf. In contrast, different interglacial periods show distinct epsilon Nd excursions; whilst all interglacial periods appear to contain an interval with epsilon Nd values of ~-7, only one has an interval (interpreted as late-MIS9), with epsilon Nd values approaching -10. The HM and DZ datasets concordantly indicate the TAM as the most probable sediment source for this interval. Furthermore, the two topmost samples show contrasting dataset interpretation of possible mixing of WA and TAM detritus. Paleoenvironmental sedimentary records provide new interpretations of the differing response of the WAIS to climatic and oceanic forcing in recent interglacial periods, but only the correct use of multiple datasets could identify source rocks and suggest sediment reworking, unveiling past sediment routing systems and therefore ice sheet extents.

Clast petrography from IODP 374 cores in the central Ross Sea (Antarctica): implications for sediment provenance and source terranes

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Keywords: IODPexp374, provenance, clast petrography.

International Ocean Discovery Program (IODP) Expedition 374 recovered high-quality cores at five sites on the Ross Sea continental shelf, slope, and rise to improve the understanding of the sensitivity of the Antarctic ice sheets to past climatic and oceanic conditions, especially during a warmer-than-present climate. Distribution of gravel-sized clasts along the glacimarine successions recovered in the sites U1521 (Early Miocene to Pleistocene) and U1522 (Late Miocene to Pleistocene) helps to discriminate source terranes and ultimately reconstruct the contribution of West Antarctic Ice Sheet expansion and retreat during past glacial cycles. Granule to cobble sized clasts present in the sedimentary record from both the sites have been counted and grouped into seven lithological groups based on macroscopic and microscopic recognition. Low grade metasedimentary rocks, the most common lithologies in both the drillcores together with granitoid rocks, reflect the main basement composition in the source terranes. In order to discriminate possible source regions of granitoid clasts, chemical analyses were carried out using SEM-EDS on biotite crystals. Biotite composition were then compared with those of the main intrusive formations cropping out along the Transantarctic Mountains and Marie Byrd Land. The less abundant lithologies such as volcanic and subvolcanic rocks, occurring only in specific lithostratigraphic units, are diagnostic in revealing Transantarctic Mountains or West Antarctica provenance. In particular, dolerites from the Ferrar Large Igneous Province, extensively cropping out along the Transantarctic Mountains, are present only in some units from both of the sites, indicating a major influx from East Antarctic Ice Sheet and a minor role of the West Antarctic Ice Sheet in delivering sediments at the drilling site. Instead, felsic subvolcanic rocks such as rhyolitic porphyries are common in late Miocene lithostratigraphic units of U1522 core, where dolerites are rare, pointing out to a terrane currently not exposed in the source region. Four pebbles from these sequences have been dated with zircon UPb geochronology and yielded a prevalently Early Jurassic age. This aspect highlights that the sediment source region, inferred in the West Antarctic Rift System, has been involved in Jurassic magmatism, apparently much more than what the sparce data from outcrops in West Antarctica suggest.

Assessing planktonic foraminiferal species from Antarctic sea-ice as a paleoceanographic proxy: preliminary insights

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Keywords: proxy, foraminifera, Antarctic sea-ice.

Antarctic sea ice greatly impacts the Southern Ocean's biogeochemical cycles and ecosystem dynamics by providing a unique habitat through its intricate brine channels and pockets, known as the sympagic sea ice community. This community, abundant in diverse biota, plays a critical ecological role in the region. However, faunal components like microzooplankton, including foraminifera such as *Neogloboquadrina pachyderma* have been understudied despite their prevalence in contemporary high-latitude planktonic communities and Southern Ocean sediment samples. During the ANT29-7 expedition aboard the RV Polarstern from August 14 to October 13, 2013, ice cores were collected from three dive transects (EB, POL, ROV) on an ice floe at 60°47.76'S and 26°19.73'W in the Weddell Sea. Sampling involved obtaining three replicate ice cores at 2-meter intervals along each transect. The ice cores (each 100 cm long) were analyzed in two sections: the lower 0-10 cm representing the seawater-ice interface and the upper 10-100 cm. Planktonic foraminifera were studied quantitatively and qualitatively, focusing on density (n°/l) and biomass (µgrC/l) across three size fractions (> 150; 150-63; and 63-10 µm). The most common size fraction in both upper and lower sea-ice samples was between 63 and 150 µm. Density ranged from 2.8 n°/l to 97.2 n°/l in upper sea-ice and from 1.9 n°/l to 329.6 n°/l in lower sea-ice across all size fractions. Biomass values followed a similar trend, ranging from 0.4 µgrC/l to 8.9 µgrC/l in upper sea-ice and from 1.0 µgrC/l to 25.9 µgrC/l in lower sea-ice. Planktonic foraminifera were predominantly found at the seawater-ice interface (756 n°/l upper sea-ice vs 1140 n°/l lower sea-ice), consistent with previous Weddell Sea studies where foraminiferal numbers ranged from 87 to 1075 n°/l, mainly in the lower sea-ice core portion with sizes under 100 µm. All planktonic foraminifera identified belonged to the *Neogloboquadrina pachyderma* species. Quantitative and qualitative morphometric analyses differentiate individuals from the water column and sea ice, although with some overlap. Sea ice specimens are typically larger, always have a lip at the aperture, and exhibit more morphological variation compared to those from seawater. Linear Discriminant Analysis (LDA) using Fourier shape analysis effectively distinguishes between these groups with minimal overlap. These findings suggest the presence of a distinct type of *N. pachyderma* in sea-ice, characterized by unique shell features and adaptation to extreme temperature and salinity conditions. Further ultrastructural and genetic analyses are essential to confirm the presence of a sympagic species of planktonic foraminifera in sea-ice, providing valuable insights for paleoenvironmental reconstructions and paleoceanographic studies.

A multidisciplinary investigation into the source and impact of greenhouse gases in the Dry Valleys, Antarctica

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Keywords: permafrost, geochemical and geophysical surveys, Antarctica.

Contemporary studies conducted in northern polar regions reveal that permafrost stability plays an important role in the modern carbon cycle as it potentially stores considerable quantities of greenhouse gases. Rapid and recent warming of the Arctic permafrost is resulting in significant greenhouse gas emission, both from physical and microbiological processes. The potential impact of greenhouse gas release from Antarctica is now also being investigated. In Antarctica, the McMurdo Dry Valleys comprise 10% of the ice-free soil surface areas in Antarctica and like the northern polar regions are also warming albeit from lower mean temperatures.

The work presented herein examines a comprehensive sample suite of soil gases (e.g., CO_2, CH_4, He, 222Rn and 220Rn) concentrations and CO_2 flux measurements conducted in the Taylor Valley and Wright Valley during the Austral summer from 2019/2020 to 2022/2023. Analytical results reveal the presence of significant concentrations of soil gas at the base of the active layer. When compared with the few previously obtained measurements, we observe increasing CO_2 flux rates (estimated carbon dioxide emission in the study area of 21.6 km2 ≈ 15 tons/day; Ruggiero et al., 2023).

Moreover, a 2-D Deep Electrical Resistivity Tomography (DERT) survey in Taylor Valley was performed to visualize the distribution of permafrost, its thicknesses, lower boundaries, and watershed. Results show resistive, discontinuous domains that we interpret as permafrost units. The results indicate resistive and discontinuous domains that we interpret as permafrost units (as already referred by Mikucki et al., 2015). A multi-tiered groundwater circulation model characterizes the extensive brine system in Taylor Valley that was discovered in the obtained dataset.

The geochemical distribution of anomalous areas, compared with geophysical surveys, suggests an origin from deep brines migrating from inland (potentially from beneath the Antarctic Ice Sheet) towards the coast beneath the permafrost layer. These newly obtained data provide a baseline for future investigations aimed at monitoring the changing rate of greenhouse gas emission from Antarctic permafrost, and the potential origin of gases, as the southern polar region warms.

Mikucki J.A. et al. (2015) - Deep groundwater and potential subsurface habitats beneath an Antarctic dry valley. Nat. Commun., 6(1), 6831, https://www.nature.com/articles/ncomms7831.

Ruggiero L. et al. (2023) - Antarctic permafrost degassing in Taylor Valley by extensive soil gas investigation. Sci. Total Environ., 866, 161345, http://dx.doi.org/10.1016/j.scitotenv.2022.161345.

Geological map of the Convoy Range and Franklin Island quadrangles (Victoria Land, Antarctica)

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Keywords: Antarctica, Victoria Land, geological map.

We supply a new geological map (1:250,000 scale) (Capponi et al., 2024) that allows to complete the coverage of Victoria Land, by filling the gap between the GIGAMAP program (Pertusati et al., 2016; a German/Italian agreement of cooperation to produce new geological maps of Victoria Land), to the north, and the maps by the New Zealand Antarctic program, to the south (Pocknall et al., 1994; Cox et al., 2012).

New mapping was performed by a three-person team in the 2017/18 and 2018/19 austral summers (XXXIII and XXXIV ItaliAntartide expeditions). The activity was heli-supported, starting from both the Italian Base Mario Zucchelli (2017/18) and from a tent camp located at Starr Ntk (2018/19).

Field activity included geological and geological-glacial field mapping, photogeological analyses, structural observations and rock sampling. Dolerite sills of the Ferrar Group are prevalent in this area, with limited outcrops of the extrusive correlative Mawson-Exposure Hill Formation. Sandstones of the Beacon Supergroup are limited to small outcrops and to 100 m-long rafts enclosed in the dolerite. Granites and granodiorites of the Granite Harbour Intrusive Complex constitute the crystalline basement underlying the Gondwanian sequence, cropping out only along the lower-lying sector close to the Ross Sea coast. Minor enclaves of Wilson Terrane gneiss are hosted in the Granite Harbour granitoid. Structural data of bedding, fault and fracture were measured. More than 250 rock samples were collected for subsequent laboratory analyses, later stored at the National Antarctic museum in Siena. Subsequent activity has included: digitization of the new cartographic data, elaboration of structural data, microstructural analyses and minero-petrographic analyses of rocks and glacial deposits.

The mapping highlighted some key features of this region, such as the scarce occurrence of rocks of the Wilson Metamorphic Complex, the occurrence of mafic rocks belonging to the Granite Harbour Intrusive Complex and the possible activity of faulting with hundreds of meters of vertical offset, linked to the post Ross Orogeny tectonics.

This new map can be used as the starting point for any future geological investigation in this region.

Capponi G. et al. (2024) - A comprehensive 1:250,000 scale geological map of the Convoy Range and Franklin Island quadrangles (Victoria Land, Antarctica). Geol. Field Trips Map., 16, 21, https://doi.org/10.3301/GFT.2024.05.

Cox S. C. et al. (2012) - Geology of southern Victoria Land, 1:250 000 scale. Geological Map 22, Institute of Geological & Nuclear Sciences.

Pertusati P.C. et al. (2016) - German - Italian Geologic Antarctic Map Programme: Introductory Notes to the Map Case. Terra Ant. Reports, 15, 1-15.

Pocknall D.T. et al. (1994) - Geology of the Convoy Range, southern Victoria Land, Antarctica. GNS Geological Map, 11.

Ice load modulation of plumbing system dynamics: Insights from intracrystalline texture and chemistry at The Pleiades Volcanic Field, Antarctica

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Keywords: crystal cargo, plumbing system, ice load.

The Pleiades Volcanic Field (PVF), located in northern Victoria Land, Antarctica, is made up of a dozen monogenetic scoria cones and two domes, with ages ranging from ca. 800 ka to present. Despite the monogenetic aspect of the edifices, the volcanic products are compositionally diverse and define a complete mildly Na-alkaline evolutionary trend. This makes the PVF a distinctive volcanic field, whose plumbing system has likely evolved under special conditions. To unravel the architecture of the PVF feeding system, we applied high-resolution petrological investigations on the crystal cargo of a set of lavas sampled in the framework of the Italy's National Antarctic Research Program - PNRA. Textural and chemical characterisation of the main mineral phases, as well as reconstruction of P-T conditions of crystallisation, have been conducted on samples representative of the whole intra-association variability. Results of this petro-chemical analysis testify to a combination of magmatic processes, including an efficient and extensive differentiation, crustal assimilation and intra-association mixing among batches of diversely evolved magma. The complexity of pre-eruptive processes suggests endogenous growth due to an incapacity of eruption, which led to a prolonged stall of the magma at crustal depths. We thus interpret a long-lived and vertically extended subvolcanic system, which has periodically fed volcanic activity for hundreds of ka. The existence of such a system, in a volcanic province where the numerous monogenetic cones are mainly mafic in composition, can be reasonably attributed to external factors. Considering the context of glaciated terrain, an efficient forcing to take into account is a variable ice load, linked to climatic fluctuations, capable of influencing the stress field conditions around crustal magmatic reservoirs. This work hence highlights the potential of a climate-controlled modulation of subvolcanic systems in Antarctica, as inferred in other glaciated regions of the world (e.g., Iceland and British Columbia).

S4.

Chemostratigraphy through time and space: Reconstruction of palaeoenvironment and palaeoclimate by using geochemical proxies and isotopes

CONVENERS & CHAIRPERSONS

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Geochemical studies across the Norian/Rhaetian boundary in the Pignola-Abriola section of the Lagonegro Basin, southern Italy

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Keywords: Norian/Rhaetian boundary, major and trace elements, Re-Os isotopes.

The Norian/Rhaetian boundary (NRB) in the Late Triassic is characterized by a faunal turnover of major pelagic groups, such as radiolarians, conodonts, and ammonoids (Rigo et al., 2020). Although catastrophic events such as the emplacement of large igneous provinces (LIPs) and extraterrestrial impacts have been proposed to account for this biotic turnover, firm evidence based on the geochemistry of sedimentary successions is still lacking. To elucidate the trigger for the environmental changes across the NRB, we performed major and trace element geochemistry in carbonate rocks for the Pignola-Abriola section in the Lagonegro Basin, southern Italy. This section is a candidate for the Global Stratigraphic Sections and Points for the Rhaetian Stage and it has been investigated in detail for high-resolution biostratigraphy, carbon isotopes, magnetostratigraphy and rock magnetism (Rigo et al., 2016; Maron et al., 2024). In addition, we analyzed the Re-Os isotopes and highly siderophile element (HSE) concentrations in the Rhaetian shales with the aim of correlating the nearby Sasso di Castalda section where the HSE-enriched layer was detected (Sato et al., 2021).

Our data demonstrate that the lower part of the section (0-36 m) is dominated by SiO_2-poor (<30 wt.%) limestone, sometimes dolomitized, whereas the upper part of the section (36-56 m) contains SiO_2-rich (>30 wt.%) marls and mudstones with variable concentrations of Al_2O_3 (0.2-7 wt.%). This variation is consistent with a progressive increase in the relative abundance of cherty and siliceous components (Rigo et al., 2016; Maron et al., 2024). Although the enrichment factors (EF) of most elements in the upper section do not show remarkable changes, the redox-sensitive elements such as VEF and CrEF show appreciable increases across the NRB (45 m). The stratigraphic profile of ReEF obtained from the corresponding shaley beds provides a consistent variation showing a gradual increase just above the NRB. Thus, VEF in carbonate and ReEF in shale record transient changes to suboxic conditions in the Lagonegro Basin across the NRB. However, it is not clear whether these environmental changes in the Lagonegro Basin were triggered by LIPs or impact events, because our 187Os/188Os and HSE data are limited to the Rhaetian shale. Thus, more comprehensive dataset including the carbonate through the entire section and the Norian shales may provide critical evidence for the causal mechanism of the environmental changes in the NRB.

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Rigo M. et al. (2016) - The Pignola-Abriola section (southern Apennines, Italy): a new GSSP candidate for the base of the Rhaetian Stage. Lethaia, 49(3), 287-306, http://doi.org/10.1111/let.12145.

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Sato H. et al. (2021) - Sedimentary record of Upper Triassic impact in the Lagonegro Basin, southern Italy: Insights from highly siderophile elements and Re-Os isotope stratigraphy across the Norian/Rhaetian boundary. Chem. Geol., 586, 120506, http://doi.org/10.1016/j.chemgeo.2021.120506.

Clay minerals, trace elements and stable isotope geochemistry reveal increased biogeochemical weathering during the Middle Eocene Climatic Optimum: the Ligurian Alps record (northern Italy)

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Keywords: carbon isotopes, clay minerals, MECO.

The Middle Eocene Climatic Optimum (MECO, 40.5-40 Ma) is an abrupt global warming pulse identified in the deep-sea record of the main oceans (Boscolo Galazzo et al., 2014) where it is associated with biocalcification crisis. However, this event is still highly overlooked in shallow-water records, where the dynamics that link warming and carbonate production is still highly debated (Sluijs et al., 2013). In this study, we aim at identifying the impact of such a rapid and intense warming pulse on a shallow water, mixed carbonate-siliciclastic succession. With a multiproxy approach based on facies and microfacies analyses, trace element concentrations, clay mineral assemblages, C and O isotope analyses, we intend to identify the signature of the MECO in the Capo Mortola section (Ligurian Alps, Northern Italy). Age constraints are provided by Larger Benthic Foraminifera and nannofossil biostratigraphy. The Capo Mortola section consists of rudstones to packstones with nummulitids that pass upwards to marly wackestones to floatstones with solitary corals and ostreids. The latter facies is overlain by rudstones with densely packed Discocyclina tests. The peculiar texture of this facies is the result of internal waves impacting the deep portion of the middle ramp, characterized by a significant stratification of the water column. According to biostratigraphy, the onset of the warming pulse occurs within the marly floatstone deposition, while the peak is recorded within the Discocyclina dominated facies. An increase of the terrigenous input during the MECO is attested by a mild increase of continental-derived elements such as Al, Si and Fe, as well as an increase of kaolinite content in the rudstones with Discocyclina, associated to intense weathering of silicate rocks in the land masses. Carbon isotope ratios, measured on LBF tests, show a positive shift in correspondence of the MECO, attesting increased primary productivity triggered by increased nutrient contents, in turn linked to higher weathering rates, in the middle ramp. This integrated approach indicates that shallow water carbonate production itself did not suffer any crisis during the MECO, when instead the oligophotic Discocyclina-dominated factory thrived, favoured by warm temperatures, and by the balance between nutrient availability sustained by runoff and the persistence of light penetration in a wide middle ramp.

Boscolo Galazzo F. et al. (2014) - The middle Eocene climatic optimum (MECO): A multiproxy record of paleoceanographic changes in the southeast Atlantic (ODP Site 1263, Walvis Ridge). Paleoceanography, 29(12), 1143-1161.

Sluijs A. et al. (2013) - A middle Eocene carbon cycle conundrum. Nat. Geosci., 6(6), 429-434.

Geochemical analysis and palaeoenvironmental reconstruction of the laminated limestones from the Villaggio del Pescatore fossil site (Trieste, Italy)

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Keywords: Villaggio del Pescatore, geochemistry, palaeoenvironment.

The Adriatic Carbonate Platform (AdCP) was one of the largest carbonate platforms of the peri-mediterranean region during the Mesozoic, with deposits ranging in age from the Lower Jurassic to the latest Cretaceous. By the end of the Mesozoic, the AdCP probably appeared as several deep troughs separated by shallow marine or partially/completely emerged areas. The Villaggio del Pescatore fossil site (VdP), in Duino-Aurisina, Trieste, Italy, originated in one of these emerged areas during the lower to middle Campanian, between 81.5 and 80.5 Ma. This fossil site is probably the result of the tectonic driven uplifting of a sector of the carbonate platform above the sea level, followed by the formation of a depression inside the emerged limestones. This depression housed a water body in which finely laminated limestones – either light-coloured or black – accumulated. Such deposits host exquisitely preserved fossils remains, including fish, molluscs, crustaceans, ostracods and benthic foraminifera, as well as pterosaurs, crocodilians and dinosaurs. Here we introduce a detailed geochemical analysis of the fossil beds, which represent a unicum in the geological record of the Mesozoic Mediterranean carbonate systems. Thin sections and bulk samples were analysed through XRF, XRD, WD-XRF and LOI. Results suggest that the mineralogy of the laminated limestones is mainly composed of calcite, whilst the LOI value is probably increased by the organic matter conserved in them as a result of bottom water anoxia. In addition, several paleoenvironmental proxies suggest decreasing salinity, progressively drier climate and decreasing quantity and grain size of terrigenous input at the site during the laminated limestones' deposition. Primary productivity at the site seems to have remained relatively constant and the different amount of organic matter preserved in the two kinds of laminated limestones is probably the result of periodic bottom water oxygenation during the light brown strata's deposition. Finally, the laminae have historically been interpreted as varve, but the absence of chemical differences between the darker and lighter micro-laminae forming each lamina suggests that this difference in colour might be the result of bacterial maths being continuously covered by sediment and regrowing on it.

Seawater temperatures, pH and water mass provenance reconstructions over the last century from cold-water coral geochemistry in the North Atlantic Ocean

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Keywords: cold-water corals, Northern Iceland Basin, isotopes.

The geochemical composition of the aragonite skeleton of cold-water corals (CWC) can provide unique information on the physico-chemical changes and dynamics of water masses at intermediate depths at high temporal resolution (e.g. sub-decadal). Previous studies have shown that variations in seawater temperature, water ventilation age, and water mass provenance can be inferred from measurements of skeletal Li/Mg ratios, paired U/Th and ^{14}C, and neodymium isotopes, respectively. In particular, the solitary azooxanthellate scleractinian coral species *Desmophyllum dianthus* is particularly valuable due to its widespread distribution, century long lifespan, and stratified skeletal growth, which facilitates the use of geochemical tracers at sub-decadal intervals.

Here, we investigated several *Desmophyllum dianthus* samples retrieved in 2012 from the Northern Iceland Basin at depths of 570-700 m during the ICE-CTD R/V *Thalassa* expedition, using the Remotely Operated Vehicle Victor 6000 operated by IFREMER. Sub-samples of the coral skeletons collected along the growth axis were analysed for Li/Mg, stable isotopes ($d^{11}B$, $d^{18}O$, $d^{13}C$), U/Th, 14C and Nd isotopes, with the aim to reconstruct the physico-chemical changes of the North Atlantic intermediate water masses (Iceland-Scotland Overflow Water, Sub-Arctic Intermediate Water and Western North Atlantic Central Water), and quantify how their contributions have varied over the past few decades. The Li/Mg ratios revealed sub-decadal temperature records that vary between ~2 to ~6°C, which is closely related to changes in Nd-isotopic compositions. These results can be explained by decadal fluctuations in the North Atlantic Oscillation and East Atlantic atmospheric patterns, with those atmospheric drivers causing strengthening or weakening of the Atlantic Subpolar Gyre, leading to changes in the amount of warmer Subtropical Gyre-sourced water or colder SPG-sourced water. Additionally, the prevalence of ISOW is shown to have roughly halved over the past ~70 years, suggesting an increase in northward transport of warm subtropical waters over recent decades, which may have contributed to recent warming in the Arctic region, as well as substantial multi-decadal weakening of Nordic Sea overflow currents.

The PRIN "REMEPP" project: response of Mediterranean calcareous plankton to CO_2 variability during some intervals of the Plio/Pleistocene

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Keywords: Mediterranean, Pliocene, Pleistocene.

The Mediterranean is an area of particular interest as it is particularly exposed to natural risks, in terms of desertification, acidification of water masses and loss of biodiversity. The REMEPP project aims to reconstruct the effects of CO_2 on the global productivity of calcareous plankton in some key intervals of the Neogene and Quaternary, in which strong climatic variations occurred. The selected successions cover the stratigraphic intervals between 5.2-4.85 Ma (EZWP), 2.95-3.3 Ma (PWP) and 2.7-2.4 Ma (PPT), where outcrop in the land famous successions of Eraclea Minoa/Capo Bianco, Punta di Maiata, Punta Piccola and Monte S. Nicola. These sections, in which the Messinian/Zanclean, Zanclean/Piacentian and Piacenzian/Gelasian GSSPs were defined, are astro-bio-magneto-chronologically well calibrated. Particularly, these intervals are characterized by strong changes in calcareous microfossil assemblages induced by astronomical cycles. In order to understand the mechanisms controlling climate variations, a multidisciplinary approach have been used, carrying out quantitative analysis on calcareous microfossils, stable isotopes ($\delta^{18}O$, $\delta^{13}C$ and $\delta^{11}B$) and alkenones to estimate the paleotemperatures of surface waters, as well as than as a proxy for marine productivity. The great sensitivity of the Mediterranean Sea to climate variations, and the signal stored in these natural sedimentary archives, is fundamental to characterize and quantify for the first time CO_2 levels, and understand how calcareous microfossils respond to these variations.

Middle Miocene paleoclimatic phases: a Central Mediterranean perspective from the SE Sicily sedimentary succession

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Keywords: Middle Miocene, paleoclimatic phases, SE Sicily.

The Middle Miocene climate is marked by a changeover from a warm period (Miocene Climatic Optimum, ~17-14.7 Ma), to a transitional phase (Middle Miocene Climatic Transition), culminating in a cold stage (Icehouse Mode, ~13.8 Ma). This period is associated with a positive excursion of $\delta^{13}C$ ("Monterey Excursion"), showing a series of $\delta^{13}C$ maxima (CM events) highlighted by cooling peaks in the $\delta^{18}O$ values (Mi events).

In south-east Sicily (Hyblean Mountains), the Middle Miocene sedimentation is represented by the marly-calcarenitic deposits of the upper Irminio Fm followed upward by the marly clays of the Tellaro Fm. Due to their excellent exposure and rich calcareous plankton content, the Miocene Hyblean formations have often been selected for detailed integrated stratigraphic studies.

This study illustrated the preliminary results of an integrated stratigraphic study which involves high resolution plankton biostratigraphy and analysis of stable isotopes of C and O carried out on foraminifera tests.

The calcareous plankton biostratigraphy (nannofossils and foraminifers) provides a well constrained age-model for the study succession, which ranges from the basal Langhian (~16 Ma) to the basal Serravallian (~13.6 Ma) stages.

Oxygen and carbon isotope ratios were measured on separated foraminifera tests belonging to Globigerinoides and Globigerina genera. The $\delta^{18}O$ record is consistent with a warm but dynamic climate phase. Furthermore, the preliminary $\delta^{13}C$ curve shows several positive peaks that correspond to different carbon maxima of the Monterey Event. This correlation testifies for a Central Mediterranean Basin extremely sensitive to the global carbon cycle dynamics during Middle Miocene.

Quantitative reconstruction of temperature changes during the last ~13500 years in Georgia through stable isotopes (δ^2H-$\delta^{13}C$-$\delta^{18}O$) from speleothems fluid inclusions and calcite

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Keywords: paleoclimate, stable isotopes, paleotemperatures.

The reconstruction of glacial to interglacial temperature oscillations is extremely important for understanding the full scale of climate variability from global to local scale. Concurrently, rigidly defining temperature variations during the Holocene is key to provide boundary conditions upon which model future evolution driven by the current climate crisis. Unfortunately, there are large areas where multimillennial paleoclimate timeseries are unavailable. Southern Caucasus, is such a region as currently only a few continental climate time series extend beyond the short instrumental records. Importantly, temperature-related proxies are virtually absent here, thus impeding to evaluate how global-scale rapid climate instabilities propagate and impact this area. This work provides the first paleoclimate reconstruction from Georgia (Southern Caucasus) spanning approximately the last 13500 years. Four stalagmites named Zak-1, Zak-3, Zak-4 and Zak-6, measuring 46, 50, 55 and 102 cm respectively, were collected from the Zakariasklde Cave (42°10′ N; 43°20′ E). Dated by the U-Th method, Zak-1 was deposited between 3.1+0.04/-0.03 to 0.32+0.46/-0.44 ka (ka = kiloyears before 1950 AD); Zak-3 between 13.48+0.07/-0.08 to 10.11+0.05/-0.09 ka; Zak-4 between 12.01+0.08/-0.09 to 9.73+0.53/-0.61 ka; and Zak-6 between 8.77+0.07/-0.08 to 0.71+0.16/-0.13 ka, with a possible hiatus between 4.45+0.19/-1.49 and 3.27+1.35/- 0.34 ka. Timeseries of $\delta^{18}O$-$\delta^{13}C$ from calcite show the main patterns of temperature variations during the last glacial-interglacial shift as well as throughout the Holocene, which mostly agree in pace and tempo with global records (ie. Greenland ice and Atlantic/Mediterranean sediment cores). Then, $\delta^{18}O$-δ^2H from speleothem fluid inclusions (FI) are preliminarily applied to quantitatively calculate temperatures. Conveniently, FI resulted well aligned with the modern meteoric water line in Georgia, thus indicating that isotopic fractionation occurred during the karst flow-path and calcite precipitation was negligible. FI-derived temperatures document the effects of climate oscillations in Southern Caucasus related to the last deglaciation, with: a ca. 3ºC decrease of average temperatures from ~13 to ~11.6 ka related to the shift from the Bolling-Allerod to the Younger-Dryas chronozones; a ca. 6ºC of temperature increase from ~11.6 ka to ~10 ka related to the inception of the Holocene interglacial; 3) a peak of temperature, above modern average temperatures, around ~10 ka and consequent multimillennial decreasing trend of about 3ºC shifting toward the late Holocene. This latter identify the presence of a "Holocene Thermal Maximum" in Georgia, which is still a matter of debate and acquire key importance to define a solid Holocene baseline upon which modelling the evolution of global to local temperature in the future. The interpretation of the record is refined by considering changes of rainfall (e.g., amount, provenance and seasonality) as well as soils (e.g., vegetation bioactivity) trough $\delta^{18}O$-$\delta^{13}C$ timeseries and speleothem growth rate patterns. To comprehend the climate mechanisms of South Caucasus climate during rapid global instabilities, the Zak-timeseries is compared to the others from different climate regimes to advance the current characterization of regional climate shifts. Therefore, the results of this study certainly help to further investigate possible climatic teleconnections on a regional to global scale.

Chemostratigraphy study of the Toarcian marine deposits from the Paris Basin southern margin

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Keywords: chemostratigraphy, organic matter, carbonate.

During the Early Toarcian, the ocean–atmosphere system was subject to one of the largest carbon cycle perturbations in the last 250 Myr, known as the Toarcian Oceanic Anoxic Event (T-OAE, about 183 Ma). Several studies reported paleoclimatic variations during this age, primarily drawing from sedimentary facies analysis of marine carbonate rocks, oxygen isotope data (δ18Ocarb), fluctuations in the oxygen and carbon isotope data of carbonates (δ^{18}Ocarb and δ^{13}Ccarb) and organic matter (δ^{13}Corg). If the paleoclimatic crisis and the related paleo-environmental changes of the Early Toarcian are well established in the literature and recorded through chemostratigraphic correlation of different basins worldwide, little is known about the climate recovery occurring during later Toarcian times.

This research aims to study the Toarcian succession (184.2 ± 0.3 - 174.7 ± 0.8 Ma) from a well-core drilled in the southern sector of the Paris Basin (present depth 360-200 m). It consists of exceptionally well-preserved pelagic marls to shales (Hermoso et al., 2009a; 2009b) containing immature organic matter (Ro < 0.5%) that may provide a valuable archive for the investigation of the Torarcian paleoclimatic variations.

To complement the previous studies that primarily focused on T-OAE related basal record (Hermoso et al., 2009a; 2009b), this study will extend the investigation to the whole Toarcian succession, by also introducing paleo-environmental and paleo-thermometric proxies not employed so far.

Detailed facies and biostratigraphic analyses on the core samples led to the reconstruction of depositional environments and a high-resolution sequence-stratigraphy framework. In total, 90 samples were collected and analyzed for XRD to highlight mineralogical changes associated with the evolution of facies/environments. Geochemical analyses on bulk samples estimated total C and N levels. O-C stable isotopes were analyzed on the carbonate fractions, and TOC and C-N isotope compositions will be analyzed in the organic fractions. Due to the overlap between the O-C stable isotope signatures of bulk carbonates and separated biogenic particles (Hermoso et al., 2009b), a selection of bulk samples will be analyzed for clumped isotope (Δ47) thermometry, that could confidently reflect sweater thermal excursions.

Hermoso M. et al. (2009a) - Dynamics of a stepped carbon-isotope excursion: Ultra high-resolution study of Early Toarcian environmental change. Earth Planet. Sc. Lett., 319-320, 45-54, https://doi.org/10.1016/j.epsl.2011.12.021

Hermoso M. et al. (2009b) - Expression of the Early Toarcian negative carbon-isotope excursion in separated carbonate microfractions (Jurassic, Paris Basin). Earth Planet. Sc. Lett., 277, 194-203, https://doi.org/10.1016/j.epsl.2008.10.013.

Deciphering climate changes from stable Isotopes in continental carbonate deposits: the *Lapis Tiburtinus* travertine succession (Acque Albule Basin, Tivoli, Central Italy)

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Keywords: carbon and oxygen isotopes, continental carbonate deposits, MIS5.

Extensive research has been conducted on Quaternary stable isotope records derived from marine and lacustrine carbonate deposits, as well as speleothems, to reconstruct global and regional climatic evolution. This study highlights the relevance of stable isotope records of travertine deposits to provide essential insights into climate dynamics and their impact on fluctuations in groundwater levels. The deposition of the *Lapis Tiburtinus* travertine succession, concurrent with the final phase of activity of the Colli Albani volcanic complex, occurred during the Late Pleistocene period (150–30 ka). Within the Acque Albule Basin, situated 23 km east of Rome, two boreholes (Sn1 and Sn2) were performed, crossing the entire *Lapis Tiburtinus* succession. The Sn1 borehole, located in the central part of the basin, shows a 62.1 m thick travertine succession, while the Sn2 borehole in the southern part of the basin features a 36.3 m thick travertine succession. A total of 118 travertine samples (59 samples each from Sn1 and Sn2 boreholes) were analysed for carbon and oxygen stable isotope ratios. Analysis and correlation of values from both boreholes enabled the determination of the sensitivity of the travertine depositional system to glacial and interglacial cycles, highlighting the intricate dynamics of the oxygen and carbon cycles recorded in this sedimentary succession. Furthermore, the obtained results were correlated with available pollen curves from the Mediterranean area (specifically, from the Castiglione crater, located 25 km east of Rome). The correlation with regional and global oxygen isotope continental and marine curves, calibrated with the stratigraphy of the Acque Albule Basin, alongside available U/Th dating, enabled the identification of at least three phases of the last interglacial period (Marine Isotope Stage 5-MIS5). On the other hand, the carbon isotope record, compared with the reconstructed CO_2 flux associated with the volcanic activity of the Colli Albani volcanic complex, shows the control of groundwater level changes. Particularly, positive shifts observed during arid phases are linked to lower groundwater levels and increased CO_2 degassing, leading to a significant fractionation effect on carbon isotopes. Conversely, negative shifts during more humid periods indicate inhibited CO_2 degassing due to a rise in groundwater level and consequent pressure increase. Thus, travertine deposits, commonly studied for delineating tectonic settings and activity in their respective areas, serve as valuable tools for understanding climate changes and groundwater variations through their stable oxygen and carbon isotope signatures.

ECORD and IODP-Italy Project: the mediterranean deoxygenation dynamics during the Pliocene in the Mediterranean

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Keywords: sapropel, clumped isotope, climate change.

The Mediterranean Sea (MS) stands out as a climate change "hot spot," since it displays a remarkable sensitivity to natural and anthropogenically-driven changes. In the last decades, the climate in the MS has been featured by warming and drying, a trend that is expected to intensify in the future. Unraveling the evolution of the biochemical properties of the MS is crucial for mitigating the impacts of climate alteration. The sedimentary record of the last 15 million years is punctuated by the periodic occurrence of organic-rich sediments (sapropels), which testify moderate to strong deoxygenation events. Sapropels featured water column oxygen starvation that led to the annihilation of aerobic life in deep-sea environments. Some deoxygenation events occurred during warmer intervals than today, reflecting the temperatures predicted for the end of this century in the Mediterranean. The timing and causes of deoxygenation in the MS have varied across different oceanographic and climatic settings. Identifying the primary drivers and ecosystemic effects of deoxygenation from the past is crucial, as it can provide valuable insights into potential future impacts on the MS.

In the frame of the ECORD and IODP-Italy project, we are investigating the IODP cores from the Eastern MS, which comprise the sapropels deposited during the 3.15 - 2.94 Ma time interval; this interval was characterized by "warmer than today" temperature. Specifically, we are studying the deep-sea sapropel corresponding to "i" cycle from 282 to 300, which has also an onshore counterpart in central Italy, allowing to reconstruct deoxygenation dynamics across different depths and settings. Micropaleontological analyses (calcareous nannofossils, planktic and benthic foraminifera) will be performed to evaluate the paleoenvironmental conditions in the upper water column and at the seafloor. We will perform paired stable oxygen ($\delta^{18}O$) and clumped isotope ($\Delta47$) analyses on hand-picked monospecific planktic foraminifera. This approach will allow the reconstruction of the temperature and seawater $\delta^{18}O$, the bottom oxygen content and the paleoproductivity, thus providing key information on the environmental conditions leading to deoxygenation. We will also perform sedimentological and petrographic analyses on sediment chips and thin sections to investigate short-lived events related to seasonal variation or multiannual cyclicity, such as stochastic heatwaves or transient-type events. These analyses will be conducted focusing on the micropaleontological content and petrographic/sedimentological features which highlight variation in the sedimentation regime associated with environmental and oceanographic changes. This approach will allow to complement the long-term reconstruction of deoxygenation with the interannual variability dynamics.

Diagenesis of karsified deposits to reconstruct the sea level drop at the Eocene-Oligocene Transition in the Apulian Platform, Southeastern Italy

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Keywords: Eocene-Oligocene transition, diagenesis, carbonate cements.

The Eocene-Oligocene transition (EOT) marks a critical phase in Earth's geological history, characterized by profound changes in oceanic and climatic conditions (Katz et al., 2008). This period, marked by the Oi-1 positive oxygen isotope excursion, signifies a major shift from greenhouse to icehouse climate modes, impacting shallow marine carbonate systems and leading to extensive exposure of carbonate platforms, primarily due to sea level falls associated with the expansion of the Antarctic ice sheet (Houben et al., 2012).

The aim of this study is to reconstruct the dynamics that affected the Apulian carbonate platform during the EOT, focusing on sea level fluctuations. Adopting sedimentological and geochemical approaches, we examined a 27-meter stratigraphic section at Torre Sant'Emiliano (southeastern Italy), located in the central Mediterranean region. Our study reveals an upper Eocene (Priabonian), 18-meter carbonate succession belonging to the Torre Specchialaguardia Formation (Fm), consisting of coral boundstone and large benthic and planktonic foraminifera wackestones to packstones, transitioning to red algal bindstone. A clear unconformity marks the transition to the overlying 9 m-thick Porto Badisco Fm, Oligocene (Chattian) in age, characterized by larger benthic foraminifera rudstone and red algal floatstone (Pomar et al., 2014).

The unconformity at the Eocene-Oligocene boundary is characterized by pervasive paleokarst features, including breccia deposits and fissure networks, which suggest groundwater dissolution and collapse of carbonate layers followed by refilling. Additionally, calcite-alabaster at the boundary has been found.

Along the entire Torre Specchialaguardia Fm, the carbonate cements reveal a complex diagenetic history: the first 8.5 m feature typically marine first-generation isopachous cements, from fibrous to bladed, and second-generation pore-filling mosaics. The subsequent 9.5 m display crust-like cements forming layers up to 5 mm thick around Eocene bioclasts, consisting of fibrous, microcrystalline, and acicular syntaxial forms. These cements exhibit geometric zonations, alternating between light and dark portions, reflecting the presence or absence of inclusions within the calcite crystals. In the overlying Porto Badisco Fm, typically marine, first-generation bladed and fibrous cements have been recognized. The crust-like cements in the upper part of the Torre Specchialaguardia Fm, as well as the calcite-alabaster, testify to the emersion of the Eocene carbonate platform.

Estimations of sea level fall during the EOT are based on the vertical distribution of carbonate cements, which suggest that meteoric conditions influenced the diagenesis of the Eocene terrain up to at least 9.5 m from the platform top. Moreover, geochemical analyses of calcite-alabaster, as well as the different generations of cements, provide insights into the environmental conditions affecting EOT marine and freshwater.

Houben A. et al. (2012) - The Eocene–Oligocene transition: Changes in sea level, temperature or both?. Palaeogeogr. Palaeocl., 335, 75-83, https://doi.org/10.1016/j.palaeo.2011.04.008.

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Weathering trends in the Norian through geochemical and rock magnetic analyses from the Pignola-Abriola Section (Lagonegro Basin, Italy)

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Keywords: Upper Triassic, paleoclimate, rock magnetism.

The late Norian to early Rhaetian (Late Triassic) interval is characterized by an important biotic crisis that involved marine and terrestrial fauna (mainly conodonts, ammonoids, bivalves and theropods). The climate perturbation that began in the Alaunian (Norian) and persisted up to the Rhaetian seems to be linked to the biotic turnover across the Norian/Rhaetian boundary (NRB). A relevant δ^{13}Corg perturbation occurred in concomitance to the Norian-Rhaetian biotic crisis and led to a negative carbon isotope excursion at the NRB, marked by the disappearance of monotids bivalves and close to the first appearance of conodont *Misikella posthernsteini*. Both the δ^{13}Corg negative excursion and the FAD of *M. posthernsteini* have been suggested as markers of the Rhaetian base (e.g., Rigo et al., 2016). To better understand the climatic perturbations that characterized the late Norian–early Rhaetian interval, we investigated the geochemical and rock magnetic properties of the magnetostratigraphically-calibrated Pignola-Abriola section in Italy (Maron et al., 2015; 2024). We performed experiments on anhysteretic and isothermal remanence (ARM, IRM), and on magnetic susceptibility (χ), to obtain the rock magnetic parameters necessary for our paleoclimatic investigation. An episode of increase in relative quantity of hematite, suggesting enhanced subaerial oxidation of iron minerals, was identified in the Norian from ~217 Ma in the Alaunian up to ~211 Ma in the early Sevatian, followed by a decline up to 207-206 Ma at the end of the Norian (late Sevatian). The results of geochemical and multivariate statistical analyses support a long-term increase and reduction in rock weathering, confirming and extending previous 87Sr/86Sr data from the Pizzo Mondello section in Italy (Onoue et al., 2018). Possible causes of these long-term weathering trends are the multiphase uplifting of the Cimmerian orogen, occurring at mid northern latitudes along the southern margin of Asia in the Late Triassic, and/or the northward motion of Pangea across the equatorial humid belt. Rapid excursions in oxidized iron minerals have also been observed across the Norian/Rhaetian boundary, the origin of which has still to be determined.

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Rigo M. et al. (2016) - The Pignola-Abriola section (southern Apennines, Italy): A new GSSP candidate for the base of the Rhaetian Stage. Lethaia, 49, 287-306, https://doi.org/10.1111/let.12145.

High-resolution radiolarian biostratigraphy across the impact ejecta layer in the upper Norian hemipelagic sediments in the Sasso di Castalda section, southern Italy

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Keywords: Late Triassic, impact ejecta, radiolarian.

The Norian/Rhaetian boundary (NRB; ~205.7 Ma) in the Late Triassic is marked by faunal turnovers of pelagic groups such as ammonoids, conodonts, and radiolarians, and negative organic carbon-isotope (δ^{13}Corg) excursions on a global scale (e.g., Rigo et al., 2020). Catastrophic events such as the large volcanism activity of the Angayucham Terrane in Alaska and the impact event related to the Rochechouart crater in France have been discussed to account for the faunal turnovers across the NRB (e.g., Rigo et al., 2020; Sato et al., 2021). Anomalously high platinum-group element (PGE) concentrations have previously been reported in the Upper Triassic hemipelagic black shales from the Sasso di Castalda section in the Lagonegro Basin, southern Italy, suggesting the impact ejecta layer (Sato et al., 2021). However, the precise depositional age of the PGE-enriched layer is unclear because the detailed biostratigraphy using radiolarians and conodonts in this section is still in progress. Here we show the high-resolution biostratigraphy of radiolarians and the result of major and trace element analysis in the Sasso di Castalda section across the PGE-enriched layer. We found a characteristic radiolarian assemblage including *Betraccium deweveri*, *Citriduma* sp. A, *Livarella valida* and *L. densiporata* across the PGE-enriched layer. This assemblage comparable to the uppermost Norian assemblage (*B. deweveri* Zone) in the Pignola-Abriola section of the Lagonegro Basin (Rigo et al., 2016). Our geochemical study revealed the presence of a siderophile elements-enriched red shale just above the PGE-enriched layer. The abundances of Fe_2O_3, Ni, and Co in the red shale are ~56 wt.%, ~300 ppm, and ~100 ppm, respectively, which is an order of magnitude higher than background levels. Furthermore, this layer contains microspherules with high concentrations of Fe and Co, ranging in size from 20 to 30 μm. Our biostratigraphy reveals that the red shale and PGE-enriched layers were formed in the uppermost Norian. Based on the biostratigraphic age of the studied section and radioisotopic ages for the NRB and the Rochechouart crater in France (206.92 ±0.32 Ma; Cohen et al., 2017), these PGE and siderophile element-enriched layers were possibly formed by the Rochechouart impact event.

Cohen B.E. et al. (2017) - A new high-precision 40Ar/39Ar age for the Rochechouart impact structure: At least 5 Ma older than the Triassic–Jurassic boundary. Meteorit. Planet. Sci., 52(8), 1600-1611, https://doi.org/10.1111/maps.12880.

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Sato H. et al. (2021) - Sedimentary record of Upper Triassic impact in the Lagonegro Basin, southern Italy: Insights from highly siderophile elements and Re-Os isotope stratigraphy across the Norian/Rhaetian boundary. Chem. Geol., 586, 120506, https://doi.org/10.1016/j.chemgeo.2021.120506.

A dilute sodium hydroxide technique for extracting radiolarians and conodonts from chert

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Keywords: chert, radiolarians, sodium hydroxide.

Radiolarians and conodonts are important components of sedimentary rocks and are used for palaeontological, biostratigraphic, palaeoenvironmental, and palaeoclimatic investigations. Research on radiolarians and conodonts has increased markedly since the 1970s, when a method of extracting these fossils from siliceous deposits (chert) using hydrofluoric acid (HF) and the application of scanning electron microscopy techniques were established. However, since HF is a highly reactive chemical, this acid is currently strictly regulated due to environmental and human health concerns. Recently, Rigo et al. (2023) found that the solubility of sodium hydroxide (NaOH) solutions in chert increases significantly with increasing temperature. They reported the use of a 3 mol/L, 80˚C NaOH solution to extract well-preserved conodonts from chert. Here we report the successful extraction of radiolarians and conodonts from Triassic chert using a low concentration of NaOH (1 mol/L) as an alternative chemical to HF. The degree of dissolution of chert in NaOH solution is strongly temperature dependent, being less at 60 or 80°C. However, when heated to 100°C, we show that even a 1 mol/L NaOH solution is sufficient to dissolve the chert. Furthermore, this method has allowed us to obtain well preserved radiolarian and conodont fossils compared to the conventional HF method. In addition, radiolarians that could not be identified to species level due to poor preservation and had been referred to by partial character names (e.g., Skirt F: Sugiyama, 1997) could be observed in their entirety for the first time using the NaOH method. The 1 mol/L NaOH solution is not internationally classified as hazardous, is easy to handle and has very little impact on the environment or human health. This allows radiolarian and conodont fossils to be used extensively for research, education and resource prospecting, even in institutions that cannot use the HF method due to equipment and chemical limitations.

Rigo M. et al. (2023) - A new method for extracting conodonts and radiolarians from chert with NaOH solution. Palaeontology, 66, e12672, https://doi.org/10.1111/pala.12672.

Sugiyama K. (1997) - Triassic and Lower Jurassic radiolarian biostratigraphy in the siliceous claystone and bedded chert units of the southeastern Mino Terrane, Central Japan. Bulletin of the Mizunami Fossil Museum 24, 79-193.

On the potential and pitfalls of REE+Y analyses on fossil microbial carbonates: two case studies from the Triassic of the Dolomites compared

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Keywords: REE, microbialite, Triassic.

The REE+Y (Rare Earth Elements and Yttrium) of marine carbonates yield insights on environmental conditions at the time of their formation. The REE+Y pattern of seawater is depleted in light REE and has a marked, positive Y anomaly. The sign of Ce anomaly yields information on the oxygenation state of the fluids from which carbonates precipitated, while Eu and middle-REE anomalies may be used to track diagenetic alteration. Marine microbialites derive from biologically induced and influenced, rather than controlled, precipitation of carbonate, hence, they should record the chemistry of seawater as inorganic carbonates do, but they are more common in the geologic record and incorporate higher amounts of trace elements (Webb & Kamber, 2000).

REE+Y in microbialites from the Dolomites (Northern Italy) were analysed with multiple techniques. In samples from the upper Anisian Latemar platform, marine cement crusts and aragonitic fossils replaced by calcite occur. In samples from the lower Carnian Cortina d'Ampezzo Basin, marine cements are scarce, aragonitic shells and skeletons were never replaced, and microbialites retained a high-Mg calcite mineralogy with up to 12 mole % $MgCO_3$.

Contrary to expectations, marine cements and microbialites from the upper Anisian Latemar platform show seawater-like REE+Y patterns, while the less diagenetically modified Carnian microbialites of Cortina d'Ampezzo mostly yielded REE+Y patterns that resemble those of burial Fe-rich cements. Petrographic observations show that an initial porosity of late Anisian microbialites was filled by marine cements, while that of early Carnian microbialites was filled by detrital material and burial Fe-rich cements. Thesehave REE+Y contents orders of magnitudes higher than that of microbialites, totally obscuring the original seawater signals. In contrast, in the Anisian Latemar platform, early diagenetic cements preserved and reinforced an original seawater signal. A major issue is that pore fillings and microbialitic carbonates could not be analysed separately. Hence, the main REE+Y signal derived, most likely, from the pore filling. It is suggested that this may be a common issue and that, without careful petrographic characterization of pore fillings, the interpretation of REE+Y (and likely, any trace element) analyses of marine microbial carbonates may be very difficult.

Webb G.E. & Kamber B.S. (2000) - Rare earth elements in Holocene reefal microbialites: a new shallow seawater proxy. Geochim. Cosmochim. Ac., 64, 1557-1565, https://doi.org/10.1016/S0016-7037(99)00400-7.

The Pignola-Abriola section (southern Apennines, Italy): a GSSP candidate for the base of the Rhaetian Stage

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Keywords: GSSP, Rhaetian, carbon isotopes.

The base of the Rhaetian stage (Norian/Rhaetian boundary, NRB) is still awaiting formal designation by the International Commission on Stratigraphy. At present, two sections have been proposed as GSSP candidate for the for the base of the Rhaetian: the 4.30-m-thick Steinbergkogel section (Austria) and the Pignola-Abriola section (Italy). The 63-m-thick Pignola-Abriola section crops out in the Southern Apennines and it is represented by hemipelagic–pelagic carbonate successions belonging to the Lagonegro Basin, which matches all the requirements for a GSSP: 1) it is a continuous basinal succession, well exposed and with minimal structural deformation; 2) easy access along the SS 5 road 'la Sellata' 4 (Potenza); 3) located in the protected area of the Parco Appennino Lucano - Val d'Agri – Lagonegrese; 4) it is fossiliferous and rich in age diagnostic fossils (e.g. conodonts, radiolarians, nannofossils); 5) it has a rich palynofloral association across the Norian/Rhaetian boundary, recording the presence of trilete and cavate spores, pollen of monocolpati, Circumpollens, Crinopolles, Bisaccates, and marine elements such as dinoflagellates and acritarchs; 6) it yields a geochemical record suitable for correlation (e.g. d^{13}Corg/carb); 7) it has a robust magnetostratigraphy and is correlated with the Newark APTS for age approximation of the NRB and additional Rhaetian bioevents.

In particular, the FAD of *M. posthernsteini* s.s., which is the STS-voted biomarker for the definition of the Rhaetian base, occurs at level PIG24 at Pignola-Abriola and this occurrence is along the morphocline from its ancestor *Misikella hernsteini*. Furthermore, the base of the radiolarian *Proparvicingula moniliformis* Zone, which is a second bioevent proposed to mark the base of the Rhaetian, is well documented and calibrated with the FAD of *M. posthernsteini* s.s. Besides, the Pignola-Abriola section depicts a marked δ^{13}Corg negative shift of ca. 6‰, occurring ca. 0.5 meters below the FAD of *M. posthernsteini* s.s. and within the radiolarian *P. moniliformis* Zone. This negative carbon isotope shift has been suggested as the primary physical marker for the NRB (Rigo et al., 2016) because it is a large geochemical signal that has been documented in both the western and eastern sides of the Panthalassa Ocean and in the Northern and Suothern Hemisphere (Rigo et al., 2020). The Pignola-Abriola section is subdivided into 10 magnetozones, calibrated with conodont and radiolarian biostratigraphy and statistically correlated with the Newark APTS, allowing the dating of litho-, bio- and chemo-events. The age model developed for the Pignola-Abriola section, placed the NRB (FAD of *M. posthernsteini* s.s.) at ca. 205.7 Ma, in agreement with recent high-precision U-Pb data.

Rigo M. et al. (2016) - The Pignola-Abriola section (southern Apennines, Italy): a new GSSP candidate for the base of the Rhaetian Stage. Lethaia, 49, 287-306.

Rigo M. et al. (2020) - The Late Triassic Extinction at the Norian/Rhaetian boundary: Biotic evidence and geochemical signature. Earth Sci. Rev., 204, 103180.

Organic carbon isotope (δ^{13}Corg) curve and extinction trends across the Triassic/Jurassic boundary at Mt Sparagio (Italy): a tool for global correlations between peritidal and pelagic successions

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Keywords: Triassic, Jurassic, mass extinction.

The Triassic/Jurassic boundary (TJB, 201.3 Ma) is characterized by profound turnovers in both marine and terrestrial biota, known as End-Triassic mass Extinction event (ETE). During this severe event, significant and distinct negative carbon isotope excursions (CIE) have been globally observed, and they were linked to volcanogenic emissions or methane release by dissociation of clathrates. The triggering factor of the negative CIEs was attributed to the emplacement of the Central Atlantic Magmatic Province (CAMP) and the break-up of the Pangea. Specifically, three significant carbon-cycle disruptions named Precursor, Initial and Main CIE have been recorded in several stratigraphic successions deposited in terrestrial and pelagic environments. We investigated the organic carbon isotope curve from the subtidal facies of the Mount Sparagio section, which is a continuous peritidal succession representing an Upper Triassic to Lower Jurassic carbonate platform edging the south-western side of the Tethys Ocean. For the first time, we achieved a complete C organic profile (δ^{13}Corg) during the End-Triassic mass Extinction event (ETE) in a carbonate shallow water environment. The δ^{13}Corg profile highlights the 3 negative excursions that characterized the Triassic/Jurassic boundary time interval in pelagic and deep-water successions. The documented CIEs correspond to significant biotic turnovers recognized along the Mt Sparagio section, suggesting that also the Upper Triassic-Lower Jurassic carbonate platforms were affected by the onset of the Central Atlantic Magmatic Province. Furthermore, although the Mt Sparagio section has been studied in detail for microfacies associations and it is well biostratigraphically constrained with shallow marine macro- and microfossils, only the documented δ^{13}Corg negative shifts allowed to correlate peritidal environments with pelagic successions, making the organic carbon curve (δ^{13}Corg) a powerful tool for global correlations.

Post-impact marine environment within the Chicxulub impact basin inferred from Re-Os isotopes

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Keywords: K-Pg boundary, Re-Os isotopes, hydrothermal activity.

The delivery of platinum group elements by the Cretaceous-Paleogene (K-Pg) asteroid impact to the ocean is recorded globally as a negative osmium isotope ($^{187}Os/^{188}Os$) excursion in distal marine sediments from the Chicxulub structure on the Yucatán Peninsula in the Gulf of Mexico (Ravizza & Peucker-Ehrenbrink, 2003; Ravizza & VonderHaar, 2012). The reconstructed marine Os isotope curves can be used for global age correlations of K-Pg sediments and as an Os isotope-based geochemical clock to trace the early Paleocene on the ~10 thousand years (kyr) scale (Ravizza & VonderHaar, 2012). However, no Os isotope records from proximal sites exist to date and it remains unclear whether the K-Pg Os isotope clock can be used within the Gulf of Mexico. Here, we present new records of $^{187}Os/^{188}Os$ in the early Paleocene limestones deposited from within the Chicxulub impact basin, obtained from the IODP-ICDP Expedition 364 at Site M0077 together with other Gulf of Mexico early Paleocene sites (Bochil, Guayal, El Mulato and La Lajilla) calibrated with recent biochronological scales for planktic foraminifera (Arenillas et al., 2021). The Os isotope data show that in the Gulf of Mexico, it took at least 700 kyr, for the $^{187}Os/^{188}Os$ of seawater to return to pre-impact level after a rapid decline following the K-Pg boundary. This is much longer than the ~200 kyr negative $^{187}Os/^{188}Os$ global excursion caused by the oceanic supply of Os from the Chicxulub impact (Ravizza & VonderHaar, 2012). During the negative Os isotope ratio excursion, excess concentrations of Os were detected in all studied sites, and those for mainly Mn, Fe, P, Pb and Os were also found in the limestones of Site M0077. Higher concentrations of these elements and the decrease in Os isotope ratios suggest that the $^{187}Os/^{188}Os$ ratios in the Gulf of Mexico may recorded a long-term supply from the hydrothermal system within the Chicxulub structure after the impact event. Our results support the estimate of the longevity of the hydrothermal system based on mineralogical evidence at Site M0077 within the Chicxulub impact basin (Kring et al., 2020).

Arenillas I. et al. (2021) - New Biochronological Scales of Planktic Foraminifera for the Early Danian Based on High-Resolution Biostratigraphy. Geosci., 11(11), 479, https://doi.org/10.3390/geosciences11110479.

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Ravizza G. & VonderHaar D. (2012) - A geochemical clock in earliest Paleogene pelagic carbonates based on the impact-induced Os isotope excursion at the Cretaceous-Paleogene boundary. Paleoceanography, 27, PA3219, https://doi.org/10.1029/2012PA002301.

Oceanic anoxia during the Carnian Pluvial Episode (Late Triassic) in the Panthalassa Ocean

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Keywords: carnian pluvial episode, anoxia, Panthalassa.

The Carnian Pluvial Episode (CPE) was a short interval of extreme rainfall in the Late Triassic that caused significant changes in marine ecosystems. This enigmatic global event is thought to have been triggered by the eruption of the Wrangellia flood basalts in the Panthalassa Ocean, as well as the Carnian Panthalassic oceanic island basalt (OIB) volcanism recorded in the Jurassic accretionary complexes of East Asia (Tomimatsu et al., 2021; 2023). Global warming induced by Wrangellia volcanism is thought to have resulted in increased continental weathering and caused oceanic anoxia during the CPE, but the detailed redox changes in the pelagic environment remain unclear. To better understand the global extent, duration, and severity of oceanic anoxia, and its effects on major pelagic taxa during the CPE, we investigated stratigraphic variations in geochemical proxies (major and trace element compositions) of paleo-ocean redox conditions, and the conodont and radiolarian biostratigraphy in Panthalassic pelagic sequences in Japan. The synchronous increase in VEF and UEF values suggests that anoxic conditions were temporarily widespread in the pelagic deep-sea Panthalassa during the late Julian. However, the enrichment factor of Mo is consistently low during the periods of V and U enrichment, suggesting that the deep-sea environment was not euxinic. Late Julian marine anoxia has been identified based on the widespread deposition of black shales and organic-rich marls in Tethyan marginal basins. This suggests that marine anoxia may have developed from the shallow continental margin into the equatorial deep-sea Panthalassic basin.Conodont extinction occurred during the period of oceanic anoxia, whereas radiolarians were less affected and their diversity increased after the recovery from anoxia. The increased radiolarian diversity during the early Tuvalian (late Carnian) can be attributed to chemical weathering and enhanced nutrient fluxes associated with global warming and the more humid climate of Pangea.

Tomimatsu Y. et al. (2021) - Marine osmium isotope record during the Carnian “pluvial episode” (Late Triassic) in the pelagic Panthalassa Ocean. Global Planet. Change, 197, 103387, https://doi.org/10.1016/j.gloplacha.2020.103387.

Tomimatsu Y. et al. (2023) - Pelagic responses to oceanic anoxia during the Carnian Pluvial Episode (Late Triassic) in the Panthalassa Ocean. Sci. Rep., 13, 16316, https://doi.org/10.1038/s41598-023-43525-9.

S5.

Geosciences for Cultural Heritages

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Itria Valley limestone: a multidisciplinary study on the use of the Apulian georesources in the Cultural Heritage

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Keywords: Itria valley geology, architecture, archaeology.

The Apulian limestones, wholly constitute the historic building constructions of that region named Trulli and other stone buildings of the well-know Itria Valley. These stones have been utilized not only in recent times but also trace back to prehistoric periods. Their petrographic characteristics, extraction sites, and architectural applications are intricately intertwined. This research, carried out by the contribution of architects, archaeologists , geologists and engineers, aimed to elucidate the significant historical and technological aspects of limestone widely employed in the Apulian region. Furthermore, it aimed to explain the high value of this landscape recognized by UNESCO as World Heritage site . The results of this research have been widely explained in the book "Natural Stone and World Heritage - Itria Valley and Alberobello, Apulia Region, Italy" edited by Taylor and Francis.

The transdisciplinary approach can be distinguished in the following steps:

- Description of Itria Valley with its towns and landscape and the Alberobello town from geological and architectural point of view;
- Study of the different example of building constructions in local stone of the Itria Valley and their origin (ancient and contemporary quarries);
- Analysis of the petrographic and physical-mechanical characteristics of the main kind of limestones quarried;
- Presentation of the significant example of stone architecture of Itria Valley, distinguishing the historical rural building from the other historical civil ones;
- Discussion of the best practice of evaluation action, protection rules and restauration methods for Stone Heritage in Itria Valley and Alberobello.

The physical mechanical characterization has been carried out both on site and in laboratory , after the selection of the most interesting case studies of Itria Valley. On site the ultrasonic pulse velocity is the main not destructive test used to recognize the mechanical features of the limestone, taking into consideration of the decay state. In laboratory together the conventional destructive test , analysis by means Scanning Electron Microscope (SEM) were carried out to detect the conservation state of ornamental stone.

The techniques used to detect the stone durability should be strictly linked to the knowledge of land and the buildings organism in order to better finalize the effort toward the monitoring and preservation of geo-resources: in this sense the case of Itria Valley is a recent application of this approach.

Archaeometric investigations on iron slags from the metallurgical workshop of Caselle in Pittari settlement (Campania region, southern Italy): a first look

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Keywords: iron slags, archaeometallurgy, Caselle in Pittari.

During 2019, the excavation in the Lucanian settlement of Caselle in Pittari (SA) unearthed a metallurgical workshop, located in the center of the site, near the main plateia that crosses it from north to south (Serritella & Rizzo, 2021). The building is perfectly integrated into the topographical system of the site; up to now, it is not yet clear whether this workshop is part of a house or is an exclusively artisanal structure. This finding is particularly important since metallurgical workshops are generally indicated by extremely light traces, which do not allow the identification of all the spaces relating to the different phases of the processing cycle. In the Caselle in Pittari settlement, it was possible to identify the bottom of a furnace and a casting basin with two terracotta crucibles as well as many remains of iron slags (Serritella & Rizzo, 2021).

Iron slags were the byproduct of smelting iron ore to extract metallic iron (consisting in some processing steps) in the past. Its study can provide valuable insights into ancient metalworking technologies, socio-economic organization of past societies, trade networks, and help to identify the raw materials used in iron production (Giardino, 2017). Preliminary archaeometric investigations have been carried out to identify the mineralogical composition of the iron slags, also aimed at giving clues on metallurgical processes as well as on provenance of metallic raw materials. To characterize the Caselle in Pittari iron slags, optical microscopy, X-ray diffraction (XRD), scanning electron microscopy coupled with electron-dispersive spectroscopy (SEM–EDS) were used for selected samples. The first mineralogical data show that the slags have heterogeneous colors ranging from blackish to red-brown, sometimes with vesicles having in size several microns in diameter. Some parts of the samples are more compact and denser, with patinas of various colors. The slags are composed of mixtures of silicates, mainly quartz and K-feldspar, together with iron oxides (likely wüstite, magnetite, + hematite) and hydroxides (goethite). The presence of wüstite, if confirmed, points to hearth temperature between 560 °C and 1200 °C, whereas magnetite can indicate poor control of the ventilation system, with a large oxygen supply to the furnace leading to FeO oxidation (Portillo et al., 2018). Glassy matrix is quite widespread, locally containing droplets of pure iron which suggest poor production efficiency during iron processing (Portillo et al., 2018). Trace amounts of galena, as well as apatite and zircon are also found. Further analyses are ongoing to fully characterize the ferrous materials from the Caselle in Pittari site.

Giardino C. (2017) - I metalli nel mondo antico. Introduzione all'archeometallurgia. Laterza, 350 pp., ISBN 9788842092018.

Portillo H. et al. (2018) - XRD, SEM/EDX and micro-Raman spectroscopy for mineralogical and chemical characterization of iron slags from the Roman archaeological site of Forua (Biscay, North Spain). Microchem. J., 138, 246-254, https://doi.org/10.1016/j.microc.2018.01.020.

Serritella A. & Rizzo M.L. (2021) - Un'officina metallurgica a Caselle in Pittari (SA). The Journal of Fasti Online, 13 pp., www.fastionline.org/docs/FOLDER-it-2021-507.pdf.

Reconstructing Pompeii's past: insights from fossilized archaeological remains in reused amphorae from Civic Building 3, Via dell'Abbondanza

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Keywords: amphorae, phosphates, carbonates.

In this study, the contents of 8 amphorae reused to seal pit latrines in the Pompeian archaeological context of the workshop named civic 3 (Regio VII, insula 14, Via dell'Abbondanza, Pompeii) were examined using a multidisciplinary approach combining OM, XRPD and SEM-EDS data.

Insula 14 of Regio VII, discovered before 1820, has been studied by the University of Genoa since 2016 (Pallecchi, 2018) through a detailed stratigraphic analysis, which allowed us exploring stratifications between the end of the 3rd century BC and the 79 AD eruption of. The study of the stratifications made it possible to learn about the transformations of the area over time.

Initially, the area was used for vegetable gardens and courtyards, with the construction of a first atrium house at the end of the 3rd-2nd century BC. This house was flanked by two structures: i) a small building, ii) pit latrines, then sealed with three amphorae bound with mortar. During the 1st century BC, a small garbage dump was built, replaced at the end of the 1st century BC by a cesspit. Subsequently, three buildings were erected: civic buildings 1, 2 and 3. Civic 3, probably a commercial building, like many other constructions along Via dell'Abbondanza, was a structure of at least two floors. Inside a gully was set up, with two quadrangular holes, in which two amphorae were placed. A destructive event, probably an earthquake followed by a small fire, in the third quarter of the 1st century AD, damaged the buildings. Then renovations followed, including the latrines reconstruction at civic 3 (Pallecchi, 2018; Pallecchi & Santoro, 2019).

The amphorae contents consisted of heterogeneous fragments including: pyroclastic sediments, encrustations, wood and bone. In addition, the presence of fungal hyphae and mineralised pollen was observed in some samples. The XRD analysis conducted on the sampled contents, previously ground, revealed in many cases the presence of apatite, as well as calcite, quartz and phyllosilicates.

Preliminary results of SEM-EDS analysis possibly confirm previous studies (Pallecchi, 2018), highlighting the presence of two different kinds of findings preservation: i) burnt and ii) mineralised archaeological relics. This suggests a different origin of the deposits: while the burnt remains could derive from hearth waste, which could provide evidence of the ancient 'sanitisation' procedures; the mineralised ones would seem to suggest the circulation of phosphate- and carbonate- saturated solution.

The study of this typology of finds has fundamental importance to reconstruct the archaeological context and obtaining information on the lifestyle of the inhabitants of Pompeii at the turn of the 3rd century B.C. and 1st century A.D.. Indeed, it provides information on the use of amphorae and the structures in which this type of ceramic artefacts were reused, identified as pit latrines.

Pallecchi S. (2018) - Pompei: indagini archeologiche della regio VII Campagna 2016: (VII, 14, 1-3). The Journal of Fasti Online, 1-23, http://www.fastionline.org/docs/FOLDER-it-2018-417.pdf.

Pallecchi S. & Santoro E. (2019) - Pompei: indagini archeologiche nelle botteghe della Regio VII Campagne 2017-2018 (VII, 14, 1-7). The Journal of Fasti Online, 1-22, http://www.fastionline.org/docs/FOLDER-it-2019-456.pdf.

Evaluating erythrite as a potential source for arsenic-free cobalt blue pigment production: replication of historical recipes and thermal treatments

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Keywords: cobalt pigments, glaze, calcium arsenates.

This study investigated the thermal behaviour of erythrite, a hydrated cobalt arsenate mineral possibly used in the production of cobalt blue pigment in historical times (Gratuze et al., 1996; Soulier et al., 1996). Indeed, several ancient recipe treaties, describe the production of cobalt blue, mentioning the use of a red mineral also called cobalt bloom, still used to identify erythrite. The mineral is also found in the Erzgebirge mines that became the largest exporters of cobalt in Europe from the 15th century onwards.

The aim is to understand whether this mineral could actually have been used to produce the pigment. For this purpose, the phases obtained from the experimental temperature runs were studied and compared with historical pigments, which have evolved compositionally over time. Specifically, the possibility of removing the arsenic in the mineral was investigated in order to obtain an As-free pigment, similar to that used in ceramic and glass production until 1520.

Erythrite, hand-picked from a Bou Azzer (Morocco) mineralogical sample, was roasted individually, to replicate the *saffron* production recipes, and with different fluxes, which were used to obtain the enamel: two cobalt by-products that began to be produced in the Erzgebirge region respectively from 1520 and 1540-60 (Meltzer, 1716).

The compositional and structural changes that occurred in the ore during heating (conducted in an oxidising atmosphere, up to a maximum temperature of 1020°C) were investigated using XRF, XRD, SR-XRD and SEM-EDS.

The experiments showed that it is possible to remove part of the arsenic from the ore: XRF analyses revealed that the arsenic quantity reduced progressively, at last corresponding to 22.4% total loss in the bulk. However, according to results conducted on skutterudite (Molera et al., 2021), some arsenic remains in the ore even after thermal treatment. Furthermore, the replication of a historical mixture with erythrite, borax and CaO, heated up to 900°C, demonstrated the possibility of obtaining separate cobalt and arsenic phases: Co-Fe-Ni oxides and Ca-Co-Na-Ni arsenates.

Gratuze B. et al. (1996) - De l'origine du cobalt: du verre à la céramique. Revue d'archèometrìe, 20, 77-94.

Meltzer C. (1716) - Historia Schneebergensis Renovata. Das ist: Erneuerte Stadt- u. Berg-Chronica Der im Ober-Ertz-Gebürge des belobten Meißens gelegenen Wohl-löbl. Freyen Berg-Stadt Schneeberg. Fulde. 635-683, https://digital.slub-dresden.de/werkansicht/dlf/82512/1.

Molera J. et al. (2021) - Experimental study of historical processing of cobalt arsenide ore for colouring glazes (15th-16th century Europe). J. Archeol. Sci. Rep., 36, 102797.

Soulier I. et al. (1996) - The origin of cobalt bue pigments in french glass from the bronze age to the eighteen century. Revue d'Archéométrie, 20, 77-94.

Surface degradation and conservation strategies in the marine environment: the case of the church of S. Salvatore, in Monopoli (Bari)

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Keywords: porous calcarenite, marine exposure, decay.

The church of San Salvatore, one of the oldest in the city of Monopoli, is located within the ancient city walls and in a position overlooking the sea. The first foundation of the church dates backs to the early Christian age and is mentioned in the 12th century in a Papal Bull. The church was rebuilt in the 16th century, and successively underwent structural changes. The façade, which preserves the evidence of this phase, was rebuilt together with the bell tower in the first decades of the 18th century.

Before recent restoration works, a study of the constituent materials and their state of conservation was conducted, and possible conservation strategies were evaluated.

The façade was made with blocks of calcareous tuffs, covered with cement-based mortars, especially in the basement part, and by lime washes on the remaining surface. The stone was affected by surface erosion and disintegration phenomena with a strong material loss, leading to different states of conservation on adjacent ashlars.

The mineralogical-petrographic study of the façade materials highlighted the sequence of mortar layers and lime washes applied over time, as well as the presence of grouting mortars containing gypsum. It also identified two different calcarenitic materials, in terms of textural and porosimetric characteristics, which could account for the different responses of adjacent ashlars to the salt damage and consequent states of conservation observed on the façade (Calia et al., 2016).

The analyses of soluble salts by ion chromatography revealed a very high presence of chlorides, directly originating from marine aerosols and identified by XRD in the form of halite. Sulphates and nitrates were also found at lower extents. The former, as well as from the sea, could also have a source from the plasters and groutings found on the surface of the façade. Indeed, gypsum crystals within the stone were microscopically observed.

In the conditions of exposure of the church to the sea, where the salt supply is continuous and cannot be removed, the use of films based on organic products for the protection of the façade against external factors, was excluded, as they could hinder the circulation of saline solutions towards the surfaces, thus introducing a further risk of damage for stone. Instead, it was more appropriate to re-propose traditional interventions, based on the application of a lime wash with a protective and sacrificial function with respect to the action of degradation agents (Calia et al., 2011).

Calia et al. (2011) - Cultural heritage study microdestructive techniques for detection of clay minerals on the surface of historic building. Appl. Clay Sci., 53, 525-531, http://dx.doi.org/10.1016/j.clay.2010.10.021

Calia et al. (2016) - The role of the petrophysical characteristics on the durability and conservation of some porous calcarenites from Southern Italy. Geological Society, London, S. P., 416, 183-201, https://doi.org/10.1144/SP416.10.

Ancient Roman mortars under synchrotron light: unravelling the nature of disordered phases

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Keywords: pdf analysis, ancient roman mortars, disordered phases.

The characterization of mortars of interest in the cultural heritage field generally comprises a series of well-established techniques, such as optical microscopy (OM), scanning electron microscopy with microanalysis (SEM-EDS) and X-ray powder diffraction (XRPD), which give an overall comprehension of the material under study (Cuevas et al., 2023). However, some aspects remain not well understood, such as the formation and composition of amorphous phases in the binder of hydraulic mortars.

In this study, we applied Pair Distribution Function analysis (PDF), a synchrotron-based technique, to attest the presence of amorphous phases (Cuesta et al., 2017) in some *cocciopesto* samples coming from the inner duct of Aqua Traiana, an ancient Roman aqueduct built in 109 AD and still working nowadays. The combination of well-established techniques with synchrotron-based ones allows to obtain a more complete vision on the material employed for the formulation of mortars that are resisting through millennia.

Cuesta A. et al. (2017) - Synchrotron radiation pair distribution function analysis of gels in cements. Crystals, 7(10), 317, https://doi.org/10.3390/cryst7100317.

Cuevas K. et al. (2023) - Chemical, Mineralogical and Mechanical Characterization of Ancient Roman Concrete and Mortar: A Review. Int. J. Archit. Herit., 1-25, https://doi.org/10.1080/15583058.2023.2256259.

APENNINESCAPE: a transdisciplinary approach to investigate the relationship between settlement dynamics and material exploitation in the northern Apennines during the 1st millennium BC. Preliminary archaeometric results

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Keywords: ceramics, metals, Apennine.

The project "APENNINESCAPE: Marginal landscapes and production processes along the Reno and Bisenzio-Sieve valleys during the 1st millennium BC" (funded by MUR, PRIN 2022, 2022LE33T8) focuses on the mountainous area between the Po valley and northern Etruria and its historically anthropized landscape, characterized by the development of Etruscan settlements with their specific socio-political structure.

One of the main objectives of the project is to improve the understanding of the relationship between settlements, production processes and resource exploitation through a transdisciplinary approach. Among the various research lines of the project, particular attention is given to the archaeometric analysis of ceramics and metals to establish reference groups, locate the area of origin of raw materials, possibly highlighting the exploitation of local resources and/or links with productions from the Northern Etruria and Po valley area, and to define production technologies. In addition, to identify and collect the range of raw materials that may be exploited in the area, geological surveys of the study area are planned.

For ceramics and metals, a wide range of analyses, including petrographic and geochemical (OM, XRF, XRD) characterisation of vessels and technical ceramics associated with metal production, microchemical (XRF, SEM-EDS) and isotopic analyses of metals (mainly copper alloys) and their slags, are currently being carried out on materials from Marzabotto (Chiarantini et al., 2010; Komosek et al., 2022), Gonfienti (Poggesi, 2011) and from other areas of northern Etruria (particularly the Pisa area).

In this paper preliminary results will be presented, with particular emphasis on the characterisation of metals and copper alloys from the different study areas, highlighting the contribution of analytical studies in support of the interpretation of the dynamics of material circulation between the two mountainsides and the wider area of Northern and Po Valley Etruria.

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Chiarantini L. et al. (2010) - Indagine archeometrica di alcuni resti di lavorazione metallurgica. In: Govi E., Marzabotto. La Casa 1 della Regio IV, 2, 439-454, ISBN 978-88-7849-057-4.

Komosek M. et al. (2022) – Marzabotto on its own? Archaeometallurgical investigation of copper based finds from Etruscan city of Kainua-Marzabotto (IT). In: Abstract Book of 28th European Association of Archaeologists Budapest meeting, Praque, 600-601, ISBN: 978-80-88441-02-1.

Poggesi G. (2011) - Il popolamento del territorio in età etrusca e romana. Carta archeologica della Provincia di Prato. Dalla preistoria all'età romana. All'insegna del Giglio, Firenze, 31-53, https://doi.org/10.1400/210655.

Deep Learning as new approach for the classification of Holy Sepulchre ceramics

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Keywords: ceramics, archaeometry, deep learning.

Ancient ceramic artifacts represent social and human markers within archaeological contexts, playing a fundamental role for the study of trade relationships and technological development of past societies. In the recent years, the adoption of automated methodologies, such as classification algorithms applied to group ceramics, has significantly contributed to the recognition of specific compositional, technological, or stylistic patterns (Bickler, 2021; Ruschioni et al., 2023). Therefore, the objective of the present project is to develop a Deep Learning (DL) image classification model based on Convolutional Neural Networks (CNNs) to categorize ceramics from the complex of the Basilica of the Holy Sepulchre, Jerusalem. During archaeological excavations at the site (License by Israel Archaeological Antiquity no. G 20/2022), numerous ceramic sherds have been found in the filling layers of the Basilica's foundations, revealing intense and particularly complex stratigraphy. In this scenario, the application of the CNN model on these samples plays a crucial role in clarifying the archaeological context and ceramic production in Jerusalem.

The starting point for the development of the model consisted of a phase of selection and acquisition of a significant number of ceramic thin-sections images from representative archaeological contexts across the Near and Middle East, forming the training dataset.

The second phase of the project focuses on the minero-petrographic and chemical characterization of the ceramic samples to determine their composition and provenance. This analysis is carried out through a multi-analytical approach that includes Optical Microscopy (OM), X-ray Powder Diffraction (XRPD), Scanning Electron Microscopy with Energy-dispersive Spectroscopy (SEM-EDS), Fourier Transform Infrared Spectroscopy (FTIR), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Finally, the third step aims at comparing the results of the archaeometric analysis with those obtained from the DL model, serving as an additional tool to evaluate its effectiveness.

Bickler S. H. (2021) - Machine learning arrives in archaeology. Adv. Archaeol. Pract., 9(2), 186-191.

Ruschioni G. et al. (2023) - Supervised learning algorithms as a tool for archaeology: Classification of ceramic samples described by chemical element concentrations. J. Archaeol. Sci. Rep., 49, 103995.

Geomineralogical and geoarchaeological findings in Roccia San Sebastiano cave at Mondragone, central Italy

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Keywords: geoarchaeology, mineralogy, ochre.

The Roccia San Sebastiano cave represents one of the most significant underground paleoenvironments discovered in central Italy for its findings of Neanderthal, H. sapiens, and Uluzzian transitional culture of Paleolithic, as well as bony remains of meals, traces of a fireplace with charred wood, flint tools and fossil teeth of children in the silty-sandy layers of the floor (Aiello et al., 2018; Collina et al., 2020). Since 2001, systematic archaeological excavations of the prehistoric deposit referable to the Upper Paleolithic and radiometric dating were carried out. In 2021, ten sediment samples were collected from some selected levels ranging from 40 to 20 ka BCE to identify their mineralogic composition, granulometry, and quartz and silicate morphoscopic features. The analysis highlighted the presence of many bioclasts of bones of different animals also of large dimensions, over 500 blunt-edged translucid grains, about 260 not abraded transparent granules, and 175 rounded opaque grains of genetic-depositional environments in the sandy fraction of 250 mm. Moreover, mineralogical features of some selected samples suggest the occurrence of sediments due to the reworking of trachytic pyroclastic materials (likely Campanian Ignimbrite, 40 ka BCE). Surprisingly, fragments from millimetric to centimetric size of yellowish-reddish ochre dispersed both in the emplaced and reworked deposits were identified for the first time. These pigments, extracted from rubefacient soil and mainly formed from varieties of limonite (yellow ochre) and hematite (red ochre), were likely used for artistic and ceremonial purposes, as suggested by the coloration of the whitish carbonate surface of a short and hollowed-out stalagmite, shaped like a female pubis, in the middle part of the cave and along its roof. This speleothem and the whole cave underwent to a high-resolution three-dimensional digital survey.

Aiello G. et al. (2018) - Geomorphological and paleoenvironmental evolution in the prehistoric framework of the coastland of Mondragone, southern Italy. Quatern. Int., 493, 70-85, https://doi.org/10.1016/j.quaint.2018.06.041.

Collina C. et al. (2020) - Refining the Uluzzian through a new lithic assemblage from Roccia San Sebastiano (Mondragone, southern Italy). Quatern. Int., https://doi.org/10.1016/j.quaint.2020.03.056.

Exploring the role of heavy metals in sulphation processes and black crust formation on outdoor exposed monuments

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Keywords: black crusts, heavy metals, accelerated ageing chambers.

This study examined the development of black crusts, a significant form of degradation commonly found on exposed outdoor artworks. It is believed that heavy metals and carbon particles found in polluted environments play a role as catalysts in the sulphation process, which occurs prior to the formation of sulphuric acid through the oxidation of atmospheric sulphur dioxide (SO_2). These catalysts consist of various heavy metals adsorbed onto carbonaceous particles, but their specific functions in the process are not fully understood.

To investigate further, we conducted experiments using Carrara marble mock-ups, treated Therefore, the present experimental study involved exposing Carrara marble mock-ups, suitably treated (either through deposition on the surface of mother solutions or mixtures of metal cations with graphitic carbon, and deposition of atmospheric particulate PM 2.5 extracted from filters collected in ambient air), placed in climate simulation chambers to evaluate the catalytic action. to mimic real-world conditions, and placed them in specialized climate simulation chambers. These chambers, divided into 'corrosion' and 'xenon arc UV radiation' sections, allowed us to replicate environmental factors conducive to sulphation and outdoor solar radiation, respectively. Our research comprised two separate exposure campaigns (Comite et al., 2022; 2023), each serving as a distinct experiment. During these campaigns, we carefully controlled sulphur dioxide concentrations to observe its effect on sulphation and the catalytic activity of the metals involved.

We conducted thorough chemical and physical analyses on the mock-ups before and after exposure using a range of analytical techniques. These methods included stereomicroscope observation, SEM-EDX (Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy) analysis, colorimetric analysis, IC (Ion Chromatography) analysis, XRPD (X-ray Powder Diffraction) analysis, and OM (Optical Microscope) analysis. Our findings shed light on how certain metal cations accelerate the catalytic process, while others exhibit slower activation. We also observed synergistic effects among different metal mixtures, leading to increased gypsum formation. Additionally, the data were instrumental in calculating the growth rate of the gypsum patina on the surface over time, confirming certain hypotheses regarding predictive mathematical models.

Comite V. et al. (2022) - Climatic chamber tests to evaluate the catalytic action of heavy metals in the sulphation process. 2022 Imeko TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Metroarchaeo 2022, 294-299, https://doi.org/10.21014/tc4-ARC-2022.056.

Comite V. et al. (2023) - Study of the catalytic action of heavy metals to understand the phenomenon of sulphation and the formation of black crusts. conference paper. 2023 Imeko TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Metroarchaeo 2023, 1095-1100, https://doi.org/10.21014/tc4-ARC-2023.203.

Chert supplies in Early Neolithic of Matera area: new data from Giavarra, Murgia Timone and Trasanello

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Keywords: Early Neolithic, chert, provenance.

In the Matera area several evidences testified the prehistoric human presence. Numerous settlements, located on the eastern side of Matera, show a strong frequentation of this area since the Early Neolithic. In this contribution we focus on the knapped lithic industries from the sites of Giavarra, Murgia Timone and Trasanello as indicators of the chert supply during the Early Neolithic. The Giavarra site is located near the SP51 Matera-Gioia del Colle. The excavation context is represented by five sub-circular pits. Based on the typological characteristics of the pottery and the radiometric dating, the site can be framed in an archaic phase of the Early Neolithic Impressed Ware, between the end of the seventh millennium and the beginning of the sixth millennium BCE. All the 86 Early Neolithic knapped chert artefacts were analyzed. The settlements of Trasanello and Murgia Timone (Matera, Basilicata) is two ditched villages typical of the Early and Middle Neolithic of the Southern Italy. The Early Neolithic phase of Trasanello (first half of VI millennium cal BC) provided 100 chert artefacts consisting mainly of unretouched and common tools with a low number of cores. As for Murgia Timone only 12 chert artefacts found during the new excavation of the site (2020) were attributed to the Early Neolithic phase of settlement occupation. All the samples were investigated underwent nondestructive petrographic and chemical (pXRF) analyses to understand the provenance of raw materials according to NM-PCI protocol. The chert lithotypes identified show different chert supply patterns in three investigated sites. If at Giavarra we have the prevalent use of cherts from Gargano promontory formations, at Murgia Timone and Trasanello the main component is produced using local secondary chert sources (radiolarite, silicified calcarenites and nodular chert) originated from the outer geological units of the Southern Apennine. These evidences fits well the archaeologic hypothesis of occupation strategies for the neolithization of Matera area.

De-faience. Unveiling ancient craftsmanship: egyptian faience technique in Early Ethiopian beads

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Keywords: beads, Ethiopia, faience.

The archaeological site of Seglamen has unearthed a set of beads originating from around 950 BCE thatbear profound implications for comprehending the use and diffusion of ancient glass-based materials within the region.

The primary aim of this study is to investigate whether the production technique of these artifacts can be attributed to Egyptian faience and, if so, to determine the specific type of faience involved (Nicholson & Peltenburg, 2000). Such insights could illuminate the spread of this technology into Ethiopia.

To achieve this goal, a preliminary archaeometric investigation, utilizing surface spectroscopic analysis techniques (pXRF, Raman spectroscopy) and laboratory-based methods (stereomicroscopy, ATR-FTIR, SEM-EDS), was conducted.

Stereomicroscopic observation of the bead sections reveals a distinct stratification, comprising a glazed core and a coating of varying colours and compositions.

Examination via SEM-EDS further elucidates this layered structure, highlighting a clear boundary between the core, that shows an amorphous structure with a Si-based composition, and the coating, showing chemical differences, also evidenced by pXRF. Chemical analysis performed on the external surfaces reveals a composition characterised by a ubiquitous presence of Si and Ca, alongside transition metals primarily represented by Fe, Mn, Cu, and Ti. Notably, Fe is prevalent in most samples, with lower concentrations observed in the external sides. The external (iridescent) side is characterised by high amounts of Mn, whereas higher amounts of Si, Cu and Ti are present in variable quantities.

Interesting results were also provided by vibrational spectroscopy, in particular ATR-FTIR. Infrared spectra, in fact, closely resemble those of amorphous silica, exhibiting opal-like characteristics. Moreover, on the coatings, infrared bands at ca. 2930, 2858, 1630, 1520 and 1390 cm^{-1} suggested the presence of protein-based organic compounds.

These first outcomes provided interesting insights to unveil ancient craftsmanship of the Egyptian faience technique in early Ethiopian beads. They might also help to reconstruct their origin, whether local or imported.

Nicholson P. T. & Peltenburg E. (2000) - "Egyptian Faience" in Ancient Egyptian Materials and Technology. P. T. Nicholson and I. Shaw eds., Cambridge University Press, Cambridge, 177-194.

The Etruscan necropolis of Sasso Pinzuto (Tuscania, VT): preliminary mineralogical characterization of geomaterials

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Keywords: etruscan necropolis, geomaterials characterization, non-destructive analysis.

The Etruscan necropolis of Sasso Pinzuto (Tuscania, Central Italy) was investigated by means of a geological multidisciplinary approach. Minero-petrographic analyses were carried out on selected samples, to deepen the knowledge about geomaterials used in the site. The aim of this preliminary study was to highlight the main types of geomaterials: building materials (natural and/or artificial) and pigments.

In the necropolis, known since the 19th century, more than 120 chamber tombs dating back to the first half of the 7th century BCE to the Hellenistic (3rd - 2nd century BCE) have been explored (Naso et al., 2024).

Experimental approach to geomaterial characterization, included analytical techniques such as: 1) in-situ (non-destructive) investigation on coloured portions by means of X-ray fluorescence spectrometry (XRF) and laboratory analyses such as X-ray powder diffraction (XRPD) and microscopic study on thin sections (PLM-Polarised Light Microscopy).

The investigation focused on eleven samples for in-situ analyses and micro-sampling of geomaterials collected from three chamber tombs named 58, 125 and 129. The points of interest chosen both for in situ analyses and micro-sampling were identified following the indications of the archaeologists working on the site.

Preliminary results allowed us to obtain information about geomaterials used in the necropolis:

a) XRF analyses did not give positive responses regarding the presence of mineral pigments but, indirectly, suggested the organic nature of the colours present on the walls.

b) XRPD results evidenced that the samples' mineralogical composition is in line with the typical mineralogy of the products from the Latium volcanic district (Cappelletti et al., 1999).

Samples collected from 125 and 129 are basically identified by an external layer and the wall reddish in color. The external layer presents ceramic fragments together with pyroclastite powder and therefore seems to be only a coating layer. The wall, however, unlike the tuff samples from 58, present a slightly different mineralogical composition (the absence of analcime) suggesting their origin from another, but similar, geological formation. The presence of hematite (iron oxide) is probably the reason for the reddish color of the sample.

Cappelletti P. et al. (1999) - Mineralogical and technical features of zeolite deposits from northern Latium volcanic district. Period. Mineral., 68(2),127-144.

Naso A. et al. (2024) - La necropoli di Sasso Pinzuto a Tuscania: campagna 2022. In: Come Federico opera sul campo 2022. Atti del Convegno, 43-56.

A multidisciplinary approach to understand exploitation of ancient georesources for the matt painted pottery production from Basilicata: technology and provenance in the north-Lucanian district

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Keywords: pottery technology and provenance, matt painted, north-Lucanian district.

A multidisciplinary approach to the study of the matt painted pottery involves the interaction of data and results obtained from the analysis of archaeological, anthropological, ethnographical, semiotic aspects with archaeometric and geoarchaeological data. The matt painted pottery productions from the north-Lucanian district present differences in their ceramic styles but are connected by substantial cultural similarities. The analyzed potteries come from the lucanian archeological site of Atena Lucana, Baragiano, Buccino, Oppido Lucano, Potenza, Ripacandida, Ruvo del Monte, and Serra di Vaglio sites and several potsherds were selected to understand the pottery productions and to depict the workshops.

Technological aspects have been drawn from the analysis of red and brown pigments carried out using micro-Raman spectroscopy and powder/micro X-ray diffraction. The brown pigment of the pottery contains the simultaneous presence of hematite and jacobsite ($MnFe_2O_4$) (Lubraco et al., 2024). Hematite and jacobsite reveal their presence from both Raman spectroscopy and XRD. The jacobsite formation is consequence of firing in an oxidant environment of manganese oxides (mainly MnO_2) and iron oxides (Fe_2O_3). A mixture of these two oxides were applied and the artefact was fired at temperatures ranging from 900–1000°C, where the manganese oxides react with hematite to form jacobsite [$MnFe_2O_4$] (Schweizer & Rinuy, 1982). A "before firing" application of the decoration can be hypothesized as well as the use of the well-known "manganese black technique". The manganese source for the jacobsite formation may be identified in the black sand from Mt. Vulture (PZ).

The desirable red color could be obtained by firing an iron–rich clay in an oxidizing atmosphere, which could cause the oxidation of iron (Striova et al., 2006). The higher intensity of the 297–299 cm^{-1} Raman band of hematite and its intense XRD peak on sample from Baragiano could be due to the use of a more crystalline phase of hematite when comparing to hematite from all other potsherds from other sites.

On the other hand, analysis of the ceramic body and comparison of its composition to the compositional characteristics of clay rich sediments outcropping in the Basilicata region (Schiattarella et al., 2024) - and contextualized in the geomorphological scenario - and to their firing tests has evidenced that differences raw materials were used to produce pottery from Ruvo del Monte and Oppido Lucano sites with respect to those from Baragiano. The raw material can be identified in the Pliocene-Pleistocene gray-blue clay and the clay of intrachain basin, respectively. The existence of different workshops for the matt painted pottery productions from the north-Lucanian district can thus be hypothesized, and a possible reconstruction of raw material circulation achieved. This mainly occurred through rivers as primary routes: the hydrographic right of Bradano river and the Melandro basin.

Lubraco G. et al. (2024) - A multidisciplinary approach to unravel technology and provenance of the matt painted pottery from the north-Lucanian district., Actes du Colloque international La céramique matt-painted de l'Italie méridionale entre productions, contextes et iconographies. Nouvelles données et perspectives, Institut français de Naples, 11-12 Avril 2024.

Schiattarella M. et al. (2024) - Landscape planning-addressed regional-scale mapping of geolithological units: an example from Southern Italy. J. Maps, 20(1), 2303335, https://doi.org/10.1080/17445647.2024.2303335.

Schweizer F. & Rinuy A. (1982) - Manganese Black as an Etruscan Pigment. Stud. Conserv., 27, 118-123.

Striova J. et al. (2006) - Prehistoric Anasazi ceramics studied by micro–Raman spectroscopy. J. Raman Spectrosc., 37, 1139-1145.

Provenance analysis of stone tesserae and mortars used in the mosaic pavements of São Simão Roman Villa (Penela, central Portugal): preliminary data

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Keywords: Roman mosaics, petrography, mineralogy.

Roman mosaics are an essential part of our cultural heritage. They not only provide us with a glimpse of history but also offer invaluable insights into the past. To preserve these artefacts properly, it is essential to have a thorough understanding of the raw materials used and their properties. Successful restoration and protection require a basic knowledge of the source before applying various effective treatments in conservation science. The Roman Villa of São Simão is an archaeological site in the Penela municipality (central Portugal). The Villa, which belonged to the ancient Municipium of Conimbriga in the Lusitania Province, was built between the late second and early third centuries AD and inhabited until the mid-fifth century. It serves as a remarkable reminder of the wealthy Roman history of the area. The Villa boasts colourful and suggestive mosaic pavements, revealing an impressive occupation and providing new insights into the Roman rural rule of this territory. Archaeologists have been studying these mosaics since 2015, analysing their decorative motifs, state of conservation and in situ interventions. The main aim of this work is to examine and geologically classify the various types of stone tesserae and mortars used in the mosaic pavements of São Simão Roman Villa. The research investigates the production technologies and establishes a framework for understanding the origin of raw materials. Several stone tesserae were collected, representing the mosaics' different colour nuances. Additionally, two undisturbed and large-format mortar-tesserae pieces were also gathered. All samples were analysed using standard mineral-petrographic and geochemical techniques, including optical microscopy on thin sections, SEM-EDS spectroscopy, and colourimetry measurements. Initial findings have uncovered various carbonate lithologies and microfacies within the sampled stone tesserae. Our current understanding of the local and regional geology suggests that whitish, greyish, dark-greyish, pinkish, and yellowish fossiliferous carbonate tesserae were likely sourced from the outcrops of Lower to Middle Jurassic dolomitic-limestone, limestone, and marly limestone units. Some brownish and orange tesserae made of waste ceramic fragments were also identified. Further samples of presumed raw materials are being processed for comparison purposes. The mosaic mortars have a layering structure with siliciclastic sand as the aggregate, large ceramic particles added in the lower strata, and locally sourced limestone lime as a binder. Using natural and artificial materials can explain the mortars' excellent conservation status, high mechanical resistance, and long-term durability. By examining this information alongside similar evidence discovered at other coeval and nearby archaeological sites, such as Rabaçal and Conimbriga, it will be possible to understand better the sourcing strategies used over time and the networks involved in exchange and kinship.

The Openlit Project: a first step for an open access lithotheque of italian knappable rocks

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Keywords: virtual lithoteque, prehistory, Italy.

A few regional projects in various European countries have recently been launched for the characterization of lithic resources including the creation of geo-referenced lithoteques that have been designed according to shared scientific protocols. Italy is still lacking such tools for systematizing research in the field and enhancing our knowledge of knappable materials.

OPENLIT project aims to build up the core of the first Italian open access lithoteque, a reference collection of knappable rocks based on a multi-parametric GIS-based database. The goal of this project is to develop a standard analytical descriptive system for defining knappable rocks, based on laboratory testing, and to make it available to the scientific community through an open access repository aimed at data sharing and dissemination.

The first step in achieving this goal consists in organizing a large set of information on knappable rocks available to prehistoric communities in Italy. Various lithoteques of knappable rocks from different Italian regions are currently stored in Italian University labs. These lithoteques have been assembled over time by several researchers with different methodological approaches and are not always accessible to scholars and students.

Starting from cherts, OPENLIT will provide the scientific community with a powerful, open and implementable research tool aimed at depicting the availability of knappable rocks in some key-territories in Italy. The open access repository will host the shared lithoteque and the geo-samples mapping as part of a WebGIS platform. For the first time data will be analysed at a national level with a shared approach combining different methodologies. Macroscopic, petrographic and compositional characterization of selected geological chert will provide target values to establish reference groups for further comparisons with prehistoric collections from both the Italian peninsula and neighbouring territories.

Archaometric study of two Hellenistic pottery kilns in Ascoli Satriano (FG): a combined minero-petrographic and archaeomagnetic approach

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Keywords: Apulia, firing temperatures, thermoremanent magnetization.

Multidisciplinary investigation of ancient kilns can offer very useful information about the ceramic production technology and the ancient fire control skills during the different chronological periods in the past. In this study, we present the results of combined mineralogical, petrographic and archaeomagnetic investigation of two Hellenistic pottery kilns excavated in in 2022 at Ascoli Satriano (FG), Giarnera locality, in order to analyse the raw materials used for their construction, assess the temperature reached during their use and estimate the time of their abandonment.

The two kilns (USM1 and USM2) were discovered during rescue archaeological excavation for railway infrastructures. The productive context is confirmed by the discovery of discharged level of medium and large-sized stones, tiles and ceramic fragments. Both kilns could be dated from the end of the 4th to the middle of the 3rd century BC.

Coordinated sampling for both mineralogical and archaeomagnetic study was carried out, collecting a total of 30 samples for petrographic (POM, SEM-EDS), mineralogical (XRPD), and chemical analyses (XRF), and 45 in situ oriented samples for archaeomagnetic analysis.

The analysis performed showed that in USM1 rectangular kiln, a marly clay was used to prepare unfired bricks bound with the same clay and laid to set the inner structure. Some straw was added to the bricks and to the lining clay. At least two reparations phases were identified in the wall stratigraphy. A temperature distribution throughout the kiln was reconstructed indicating temperatures as high as 1300°C for the vault. The USM2 circular kiln shows an inner lining consisting of limestone blocks and recycled bricks and tiles bound together with clay. In this case, the estimated temperatures attained during use are below 1000°C.

In both cases, the firing temperatures reached during the use of the kilns are high enough to enable the baked clay to acquire a thermoremanent magnetization, making them good recorders of the ancient geomagnetic field during their last use. Archaeomagnetic directions determined through stepwise alternating field and thermal demagnetization procedures are well defined, with Dm=348.9°, Im= 61.0° and α95= 4.4° for USM1 kiln and Dm=358.1°, Im= 60.9°, α95= 1.7° for USM2 kiln. These directions were then compared with the reference Secular Variation curves for the Italian Peninsula in order to estimate the time of the abandonment of these structures. The results obtained confirm the Hellenistic age of both kilns.

Provenance of the raw materials used in the mortars and bricks take from Hagia Sophia (Istanbul, Turkey): preliminary results

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Keywords: mortars, archaeometry, provenance.

The purpose of this study is to formulate preliminary hypotheses on the provenance of the raw materials used to prepare ancient mortars and bricks take from Hagia Sophia (Istanbul, Turkey) by archaeometric analysis. Different studies were previously carried out to determine the compositional features of the mortars and bricks of Hagia Sophia (Moropoulou et al., 2002; Miriello et al., 2017; Taranto et al., 2019); however, the raw material sources of the building materials used in Hagia Sophia have not been studied before.

In previous studies (Miriello et al., 2017; Taranto et al., 2019), the compositional features of mortars and bricks have been determined by SEM-EDS, XRPD, XRF and optical microscopy (OM) analyses. As a result of this study, mortar samples were petrographically divided into seven different groups, which most likely belong to different construction phases and ancient restorations. According to Miriello et al. (2017), the aggregates in mortars generally contain “cocciopesto”, quartzite, granite and carbonate rock fragments in different ratios. Four groups of bricks are determined petrographically according to chemical and microscopic data (OM). The study of the bricks highlighted the presence of quartzite, granite and volcanic rock (basalts, andesites, dacites, rhyolites) fragments (Taranto et al., 2019).

In the present study, to determine the provenance of the raw materials used in mortars and bricks from Hagia Sophia, 45 geological samples (sands, limestones, clay and magmatic rocks) were taken from different geological formations in Istanbul and its surroundings, according to the places mentioned in Byzantine and Ottoman written sources regarding bricks and lime production. These geological samples were studied by polarized light optical microscopy (OM) on thin sections, XRF and XRPD analysis methods and the data obtained were compared with those of the ancient mortars and bricks. Although the production location of the bricks used in Hagia Sophia is unknown, it has been a matter of debate. According to some scientists, the bricks were brought from regions outside Istanbul. According to one of these views, the bricks are brought from the island of Rhodes (Moropoulou, 2002). At the end of this study, the debate on the raw material sources of bricks will be answered.

The data presented here are preliminary results. Further investigations and checks on these samples are underway. The results of this study will constitute an important database for subsequent restoration works, because it is important to identify the provenance of the original raw materials to use as compatible building materials.

Miriello et al. (2017) - New compositional data on ancient mortars from Hagia Sophia (Istanbul, Turkey). Archaeol. Anthropol. Sci., 9, 499-514, doi:10.1007/s12520-016-0375-3.

Moropoulou et al. (2002) - Provenance and technology investigation of Agia Sophia Bricks, Istanbul, Turkey. J. Am. Ceram. Soc., 85(2), 366-372.

Taranto et al. (2019) - The bricks of Hagia Sophia (Istanbul, Turkey): a new hypothesis to explain their compositional difference. J. Cult. Herit., 1-10, https://doi.org/10.1016/j.culher.2019.02.009.

Further insight into the provenancing of terracottas from the Athenaion in Castro (Apulia, Italy)

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Keywords: terracottas, Castro, provenance.

Systematic archaeological research carried out since 2000 brought to light the ancient sanctuary of Athena in the indigenous settlement of Castro (Lecce), on the Adriatic coast of the ancient Messapia region (southern Apulia). Here native groups, the Greek inhabitants of Tarentum, and the Greeks from Macedonia, Epirus and the Corinthian colonies in the Adriatic Sea used to meet between the 7th and the 2nd century BC. Since the late 6th century BC, temples and other sacred buildings were constructed and adorned with colorful terracotta roofs. Many roof types were identified and assigned to Tarentine workshops, because of their morphological and stylistic features, while other groups cannot be clearly determined based on morphological and stylistic features alone (Ismaelli, 2023). Various sampling campaigns were performed to get analytical data on their provenance. This selection of 20 samples is representative of the different roof types from the Archaic and Classical periods identified during the archaeological study. Optical microscopy (OM), X-ray powder diffraction (XRPD), X-ray fluorescence (XRF), and SEM-EDS analyses were applied for minero-petrographic and geochemical characterization. Both crystalline and amorphous fractions were calculated using internal standard method by applying the Rietveld method. Four groups based on different content of volcanic and carbonate inclusions were identified through cluster analysis on both petrographic and mineralogical data. EDS microanalysis on clinopyroxenes, feldspars, and volcanic glass was also performed. Diopside, sanidine, and glass fragments ranging from phonolite and trachyte were recognised. Volcanic inclusions, especially clinopyroxenes, were effectively used for determining the provenance. The analytical results allowed us to have a clearer picture of the origin and transport of rough materials, as well as the technical know-how of Tarentine craftsmen.

Ismaelli T. (2023) - Riflessi dell'architettura tarantina a Castro. In: D'Andria F., Degl'Innocenti E., Caggia M.P., Ismaelli T., Mancini L. (Eds), Athenaion - Tarantini, Messapi e altri nel Santuario di Atena a Castro, Catalogo della mostra, MArTA - Museo Archeologico Nazionale di Taranto, MAR di Castro - Museo Archeologico "Antonio Lazzari" di Castro, Bari, 125-131.

Mortars in the archaeological site of Hierapolis of Phrygia (Denizli, Turkey) from Imperial to Byzantine age

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Keywords: Hierapolis, mortars, building technologies.

Hierapolis of Phrygia is a well-known archaeological site in southwestern Turkey, protected by UNESCO since 1988. Located in one of the most geologically active areas in the world, the city has suffered from the effects of earthquakes that have repeatedly destroyed or severely damaged it. During numerous archaeological campaigns, in the framework of the "Marmora Phrygiae" project (Ismaelli & Scardozzi, 2016), mortar samples belonging to the buildings from the Julio-Claudian to the middle Byzantine period were collected. The analysed materials include 71 samples of plasters, bedding and grouting mortars coming from 9 of the most important public buildings of city (i.e Plutonium, Theatre, St. Philip Church). We examined each sample with a well-established multi-analytical approach, combining optical microscope analysis (PML) on thin sections with digital image analysis, X-ray powder diffraction analysis (XRPD) and SEM-EDS analysis. The sampling was aimed at tracing the sources of raw materials and understanding the evolution of the composition and technologies of mortar-based materials with different functions over time. During the Roman period, travertine and marble were used as raw materials in binder production, while marble was more common in the Byzantine period. The aggregates consisted mainly of sands, coming from the geological formations of Lycian Nappe and the Menderes Massif, consisting of carbonate rock fragments as travertine, marble, micritic, and fossiliferous limestones, together with silicate metamorphic rocks as meta-sandstone, schist, gneiss, and quartzite. In the Roman samples we found ophiolitic rock fragments which were not present in Byzantine samples. This difference allowed us to hypothesise different sources of raw material: Çürüksu stream or local streams as Suini Dere or Gök Dere during the Roman age, and closer waterways in the Byzantine age. Cocciopesto was mainly used in waterproof masonries from Flavian to Severian age. During the early Byzantine age, we commonly observed the use of cocciopesto in areas of the building where a hydraulic function was not required, as in the bedding and grouting mortars of St. Philip Church. Straw was a common organic additive in the Byzantine age plasters. This was a remarkable technological change compared to the Roman age mortars exclusively containing inorganic aggregates.

Ismaelli T. & Scardozzi G. (2016) - Ancient Quarries and Building Sites in Asia Minor. Research on Hierapolis in Phrygia and Other Cities in South-Western Anatolia: Archaeology, Archaeometry, Conservation. Edipuglia, Bari, Italy, pp. 908.

Natural and artificial glass in the floor mosaic of Otranto Cathedral (Apulia, Southern Italy)

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Keywords: obsidian, glass, medieval mosaics.

The floor mosaic of Otranto Cathedral (12th century AD) is one of the most extensive medieval lithostrotes in Europe. Commissioned by the Idruntine archbishop Ionathas, it was created by the presbyter Pantaleon between 1163 and 1165 AD. The mosaic occupies the entire floor surface of the nave, the presbytery, the transept and the apse of the Cathedral and show a complex and articulated iconographic programme, on which the previous studies have focused (Settis Frugoni, 1970; Ungruh, 2000). No attention has so far been paid to techniques and materials. This paper discusses the preliminary results obtained on natural and artificial glass tesserae. The mosaic's tesserae measure one centimetre on each side, and they were cut largely from polychrome limestones or marbles. However, in some areas of higher liturgical relevance and in several scenes with high symbolic value, tesserae of natural black and coloured artificial glass are present; the natural glass, mainly black obsidian, is particularly used in zoomorphic and anthropomorphic figures to represent the eyes. We conducted a chemical analytical study on few samples of natural and artificial glass tesserae through portable X-ray fluorescence (pXRF) and through scanning electron microscopy coupled with energy dispersive microanalysis (SEM-EDS). The aim is differentiate natural and artificial glass, define their provenance and calibrate the pXRF to extend the in-situ analysis to numerous other tesserae, in order to correctly discriminate the provenance of the obsidian (Frahm et al., 2014). The pXRF allow to detect only heavy elements (Z>16) but enough to measure different amounts of K, Ca, Mn, Fe and Pb. These data allow to distinguish natural from artificial glass. The latter are opaque sodic calcic glasses, excepting someone opacified with stannate or antimoniate. Medieval glass was primarily composed of silica, alkali like potash or soda and lime, so the composition results very different from natural glasses (Raynaud et al., 2023); the obsidian composition, instead, can vary depending on the source magma and the conditions under which it formed. Differences in chemical composition or presence of microphenocrystals can lead to variations in colour, texture, and overall characteristics of the obsidian glass and different geological sources of obsidian can be detected using both techniques. In this way the analysis can extended on a large number of sample, using in situ not-destructive methods.

Frahm E. et al. (2014) - Handheld portable X-ray fluorescence of Aegean obsidians. Archaeometry, 56(2), 2228-2600.

Raynaud M.P. et al. (2023) - Corpus des mosaïques d'Albanie. Volume 2. Les églises de la via Egnatia. Ausonius, Bordeaux.

Settis Frugoni C. (1970) - Per una lettura del mosaico pavimentale della Cattedrale di Otranto. Bollettino dell'Istituto Italiano per il Medioevo e Archivio Muratoriano LXXXII, 243-270.

Ungruh C.V. (2000) - Zur Ikonographie von Apokalypsekommentaren: das Apsisbodenmosaik der Kathedrale von Otranto. Concilium medii aevi 3, 59-82.

Multi-analytical characterization of main lithotypes employed in the Val di Noto UNESCO sites (south-eastern Sicily)

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Keywords: limestone, lavas, south-eastern Sicily.

In the historical buildings of the Val di Noto UNESCO World Heritage Site (including Syracuse, Catania, Ragusa, Noto, Modica, Scicli, Palazzolo Acreide and Avola) there is a close relationship between the building materials and the geological context, testifying the intense reconstruction activity that followed the 1693 CE earthquake. Indeed, the cities chromatic features reflect those of the locally available stone materials, often quarried in the surroundings of the urban centre (Occhipinti et al., 2021). A very common feature in late 17th century Baroque architecture is therefore the bichromy due to the combined use of black magmatic rocks or bituminous limestone (Pitchstone) with whitish sedimentary rocks (Punturo et al., 2023 and references therein).

Unfortunately, stone materials employed in buildings are exposed to time and atmospheric agents (e.g. rain, wind, solar radiation, aggressive atmospheric pollutants, freeze-thaw cycles, crystallisation of saline solutions, growth of organisms) and can therefore show signs of deterioration (Occhipinti et al., 2021; Punturo et al., 2023). Therefore, as fabric-related petrophysical properties (e.g. petrography, porosity and seismic behaviour) play a key role on the durability and ageing of such rocks, a comprehensive multi-analytical investigation is essential for both new construction and for the conservation and restoration of cultural heritage monuments.

In this contribution, we focused on three main lithotypes employed in historical buildings in the Val di Noto: Noto Stone, bituminous limestone (Pitchstone) and Etnean lavas. The results highlighted the close relationship between microstructural features and damage and allowed us to relate them to the environmental context.

In conclusion, our multi-analytical study has succeeded in providing a useful basic tool for both the conservation of cultural heritage monuments and their restoration. Furthermore, in the context of the European policy of circular economy and resource efficiency, the stone materials of south-eastern Sicily can play a strategic role not only in the local economy as available raw materials, but also in the progress of society in terms of sustainable building and geomaterials for construction.

Occhipinti R. et al. (2021) - Chemical and colorimetric analysis for the characterization of degradation forms and surface colour modification of building stone materials. Constr. Build. Mater., 302, 124356, https://doi.org/10.1016/j.conbuildmat.2021.124356.

Punturo R. et al. (2023) - Petrographic, microstructural and petrophysical study of asphaltic limestone employed in the Late Baroque towns of the Val di Noto UNESCO site (south-eastern Sicily). Constr. Build. Mater., 371, 130730, https://doi.org/10.1016/j.conbuildmat.2023.130730.

Kras-Carso II Interreg European project. Multidisciplinary research towards promoting the geological heritage of the Classical Karst

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Keywords: classical Karst region, geopark.

The Classical Karst cross-border area represents a "Gateway to the East," connecting the Mediterranean region to Europe. Spanning over ~800 km^2, it is the cradle of karst studies. The first systematic studies of the karst phenomena worldwide started in the mid-18th century, in this area, and were driven by researchers looking for drinking water to supply the growing town of Trieste.

Thanks to the EU Interreg Italy-Slovenia Program, researchers from both countries have the opportunity to join their efforts and contribute to the sustainable valorization of the unique geoheritage of the Classical Karst region. In this context, the Kras-Carso II Project of strategic importance was established. It involves many partner institutions from Slovenia and Italy, including the University of Trieste (MIGe – UNITS) and the Geological Survey of the Regione Autonoma Friuli Venezia Giulia.

The main goal of the project is to promote sustainable development in the Classical Karst region, including establishing the cross-border geopark. Researchers of the MIGe and the Geological Survey of the Regione Autonoma Friuli Venezia Giulia target the geosites of significant geological and geomorphological value to raise public interest and knowledge of this exceptional region. These efforts involve creating 3D models and virtual outcrop representations to make geosites more accessible, conducting dye-tracing experiments to better understand the hydrogeological processes of the karst, and drilling a core across the Cretaceous-Paleogene boundary (K-Pg) to assess the local sedimentary evidence of the Chicxulub meteorite impact; an event marking the end of the dinosaur era. The scientific findings of these studies are translated into popular language for the professional training of geopark guides, who will subsequently lead guided tours along routes that both highlight the geological heritage and encourage eco-friendly tourism in the region. Dedicated paths and cycling routes are being designed to guide visitors through fascinating geological storytelling, raising environmental awareness among the public. Furthermore, workshops, traveling exhibitions, interactive games, and similar initiatives are being arranged to engage school children and families, fostering awareness of the geological richness present in their local environment. Collectively, the joint effort of the partners of this project converges toward the establishment of the Kras-Carso Geopark that will help valorize the unique geological features of the Classical Karst, an area that deserves preservation along with responsible and sustainable development.

Bridging gaps in blue expertise through a triple transition training model for the UCH field: new challenges in uBlueTec project

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Keywords: underwater technologies, blue economy, blue/green/digital skills.

The evolving landscape of the Blue Economy highlights critical gaps in blue skills and expertise (directorate-General for Maritime Affairs and Fisheries. Skills and career development. Available: https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/skills-and-career-development_en), particularly in the context of achieving sustainability and embracing zero-carbon, technology-driven solutions. Key to addressing these gaps are advancements in underwater (UW) technologies, pivotal across several sectors such as marine biodiversity and cultural heritage conservation. However, a pervasive challenge persists: the lack of qualified professionals skilled in implementing UW technologies in the context of the green and digital transition, also related to the Underwater Cultural Heritage (UCH) field.

Motivated by these challenges, the project uBlueTec - Training framework on Underwater Tecs as key enabler for blue careers development - (uBlueTec project website. Available: http://www.ubluetec.eu) proposes a comprehensive triple transition training and skills development model (green, blue, digital skills) that promotes long-lasting partnerships between universities, vocational education and training (VET) providers, industrial clusters and small and medium-sized enterprises (SMEs) within blue economy value networks.

In particular, the uBlueTec model aims to: a) develop educational materials and curricula to facilitate skills enhancement in state-of-the-art UW technologies with a green and digital focus; b) pilot the developed assets within higher education (HE) and VET institutions to validate effectiveness and relevance; c) establish a Hub on UW technologies, serving as a permanent capacity-building structure to sustain collaboration among stakeholders; d) deploy a recruitment platform for blue jobs, offering online courses and facilitating seamless matching of labor force skills with industry demands. Additionally, the platform will serve to identify and address skills gaps at regional, national, and EU levels, and also to attract and nurture young talents through initiatives like Career Days and Entrepreneurial Bootcamps, in order to fostering a vibrant ecosystem of skilled professionals in the blue economy. By addressing the skills shortage and aligning training with the evolving needs of the blue economy, uBlueTec endeavors to propel sustainable growth and innovation in underwater technology sectors worldwide, such as in UCH field.

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Multianalytical study of lithic materials from the prehistorical site of Pirro Nord: preliminary results

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Keywords: chert, lithic tools, non-destructive analyses.

Pirro Nord is a prehistoric site dated 1.6 - 1.3 Mya in Southern Italy (Apricena, Puglia) testifying the oldest presence of hominins on the Italian peninsula. Inside a quarry for the exploitation of limestone (Apricena Stone), paleontological remains (Pirro Nord Faunal Unit) associated with the lithic industries were found inside Pleistocene paleokarst formation at the top of the Mesozoic limestone formation (Arzarello & Peretto, 2010). The archaeological evidence suggested that raw materials, selected based on their morphology, were probably collected in secondary deposits (river beds or slope deposits). However, the distances are unknown and the opportunistic behaviour in lithotypes selection has not been supported by scientific data so far.

The aim of this research deals with the identification of the raw material's supply areas by investigating both archaeological and geological samples using an interdisciplinary and combined analytical approach encompassing non-invasive spectroscopic, minero-petrographic and geochemical techniques, which will be supported by territorial mapping analyses, to create an integrated geological, geo-archaeological and environmental web-GIS system to infer the sourcing, the technology and the mobility patterns in a referenced space.

In this study, we present preliminary results obtained on 70 lithic samples by using Digital Microscopy (DM), Fourier Transform Infrared Spectroscopy using an External Reflectance module (ER-FTIR), and Fiber Optical Reflectance Spectroscopy (FORS) in a visible range, providing the preliminary identification of the specific lithic types used for the lithic industry, to select representative samples to analyse by in-lab techniques.

The main lithic types consist of cherts and rare limestones. Microscopic observation in DM and colorimetric measurement via FORS permitted the identification of main groups, featured by different textures and colours. Cherts with brown-yellow colour (av. L*=53.3; a*=6.3; b*=24.9) have hyaline or granular with inclusions like oolites, the grey cherts (av. L*=53.7; a*=11.3; b*=11.9) are featured by small inclusions and microfossils whereas the reddish samples (av. L*= 39.8; a*=13.1; b*= 18.1) are homogeneous, occasionally containing microfossils.

Interesting features were also revealed by ER-FTIR; spectra, in fact, show the characteristic Reststrahlen band of chert between 1300 and 1000 cm^{-1} (Si-O stretching) along with the doublet at ca. 800 and 780 cm^{-1} (Si-O bending and Si-O-Si stretching). However, the shape of Reststrahlen band, which can change in function of the surface treatment and grain size of the chert, appears different on samples with knapped or polished surface, and shows more intense in lithic types with coarser grain size. Moreover, statistical analysis carried out on the FTIR spectra highlighted similarities between the geological and archaeological samples, further confirming the similarities in microscopic description.

Arzarello M. & Peretto C. (2010) - Out of Africa: The first evidence of Italian peninsula occupation. Quatern. Int., 223-224, 65-70, https://doi.org/10.1016/j.quaint.2010.01.006.

Lime mortar production: the case of Panchina calcarenite from Tyrrhenian coast

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Keywords: limestone, lime, geomaterials.

Since ancient times, lime has been utilized in the production of mortars and plasters. Generally, the process of lime production commences with the quarrying and crushing of limestone, a material comprised primarily of carbonates and occasionally containing minor impurities. Limestone is transformed into lime through heating in a kiln, a process known as calcination. When pure limestone is subjected to high temperatures, it undergoes chemical decomposition, yielding lime (CaO) and emitting carbon dioxide gas (CO_2). To achieve complete thermal decomposition of limestone into lime, the stone must be heated to the dissociation temperature of the carbonates and maintained at that temperature for a certain duration. The dissociation temperature varies depending on the type of limestone being burned. Less commonly known is that in the past, lime mortars were also obtained by burning suitable calcarenites without the addition of anything other than water.

The objective of this study is to investigate the physical and mechanical characteristics of lime mortars obtained using the Panchina calcarenite from the Tyrrhenian coast, burned at 900°C. The mortar's carbonation rate was evaluated using TG/DSC, while its primary physical properties were assessed through measurements of apparent density and water absorptions. Mortar shrinkage and uniaxial compressive strength were also measured directly, as well as indirectly through ultrasonic techniques. The results obtained indicate that lime mortars produced from burned Panchina calcarenite exhibit a high carbonation rate and relatively high values of compressive strength, capillary rise coefficient, and porosity accessible to water compared to conventional lime putty mortars. Additionally, the conducted tests demonstrate that the Panchina calcarenite is a beneficial material for producing lime mortar from a natural source, requiring minimal to no additional sand to mitigate shrinkage.

Preliminary results of the petrographic and mineralogical study of the Oenotria ceramic artifact (Southern Italy)

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Keywords: ceramic artifacts, archeometry, Southern Italy.

The archeometric study of ceramic archaeological finds has, since the second half of the 20th century, an increasing importance. The objective of the present work is the compositional characterization, based on mineralogical and petrographic study, of Oenotrian ceramic finds from the Archaic Age (6th - 5th centuries B.C.) from archaeological excavation campaigns conducted in the necropolis of the Oenotrian communities of Anzi, Garaguso and Brindisi di Montagna (PZ). The Anzi-Calvello basin (hereafter ACB) is a small Plio-Pleistocene basin extending in the ENE-WSW direction for about 10 km. The deposits of this basin unconformably overlie a substrate composed of the Sicilide Units, the Lagonegro Units, and flysch deposits of the Gorgoglione Miocene Basin. Marine-derived deposits of Plio-Pleistocene age of ACB are widely distributed in this area and have a predominantly marine feature. The outcropping successions are dominated by pelitic facies, consisting mainly of clays, silty clays, and sands, which are followed by fluvial conglomerates that close the marine successions of the basin. Petrographic and mineralogical characterization of manufact fragments from Anzi and Garaguso were assessed by using polarized light microscopy, scanning electron microscopy (SEM-EDS), and X-ray Powder Diffraction (XRPD), allowed to define the compositional difference between the matrices of the Anzi and Garaguso artifacts. To define the natural materials used for the studied artifacts, several samples of natural clayey-marly sediments were collected in the nearby the center of Anzi and Calvello villages, which is part of the ACB. The mineralogical composition of the collected clay sediments is dominated by quartz and calcite with discrete amounts of feldspar and varying amounts of clay minerals. The comparison between the studied artifacts and the natural sediments revealed a difference regarding the mineralogical abundances of clay minerals which are more enriched in the analyzed artifacts. This finding suggests that the raw materials used in the Oenotrian ceramics come from an area which not fall in the ACB. In addition, the results of the compositional analysis allowed the characterization of the manufacturing process, and particularly to provide a preliminary characterization of the black pigments, with a maximum temperature of 850-900°C for firing the artifacts, and a more controlled firing atmosphere in the case of the manufacture of the Brindisi di Montagna and Garaguso artifacts. These results show that knowledge of the composition of materials used in artifacts can give information not only about their origin but also about production methods.

Artificial weathering and surficial consolidation techniques applied to the 'Peperino' from the Alban Hills volcano (Latium, Italy)

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Keywords: Peperino, consolidation, restoration.

Degradation affects all stone monuments and artifacts, although the effects vary with the lithotype involved, as well as with the exposure to atmospheric agents, the climatic conditions, the urban/industrial pollution and the natural hazards. In the future, also climatic change will contribute negatively to increasing degradation problems in the cultural heritage, calling for actions to restore or prevent damages.

Peperino, from the Latin piper (i.e. pepper) derives from phreatomagmatic eruptions of Alban Hills related to the potassic and ultrapotassic magmatism of the Roman province (Middle to Upper Pleistocene), with mafic (K-foidites) to differentiated (trachites and phonolites) compositions. Peperino has been employed since the antiquity in the construction of buildings and ornamental elements (Marra et al., 2022), although it is subjected with time to degradation phenomena.

Peperino samples have been preliminarily evaluated by optical microscopy, Scanning Electron Microscopy (SEM), X-ray Diffraction, X-ray micro-tomography aimed at determining mineral composition and texture, but also by physical tests to determine porosity, absorption by total immersion and by capillarity. All samples have been artificially weathered by heating them at 400°C for an hour (Franzoni et al., 2013), then the tests have been repeated to evaluate the effects of the artificial weathering on the samples. The results have demonstrated how the artificial weathering allows to simulate in the laboratory an accelerated alteration, useful to investigate how strongly alteration affects mineralogy, porosity and permeability.

Two inorganic consolidants (i.e. ethyl silicate and nanosilica) have been chosen and tested by treating the sample surface with the aim to verify the effects of the consolidation treatments. The effects of the consolidation, evaluated by observations under the optical microscope and SEM, have been compared. The capillarity absorption tests have been carried out to enlighten the possible permeability variations after the consolidation, to be compared to the heated and to the natural samples. Micro-tomography has been used to assess the variations in volume porosity, pores distribution and micro-fractures after the artificial weathering and the consolidation treatment. Surficial colour changes occurred and alterations were measured by a spectrophotometer.

The results showed that consolidation treatments have contributed to:

– an increase of the surficial grains cohesion;
– a decrease of the surface permeability, especially using ethyl silicate;
– porosity and micro-fractures variations;
– slight colour alterations.

This preliminary data will be useful to determine the problems related to the degradation of Peperino, as well as evaluate the most efficient consolidants for the protection from alteration.

Franzoni E. et al. (2013) - Artificial weathering of stone by heating. J. Cult. Herit., 14(3), e85-e93, https://doi.org/10.1016/j.culher.2012.11.026.

Marra F. et al. (2022) - The peperino rocks: historical and volcanological overview. B. Volcanol., 84(7), 69, https://doi.org/10.1007/s00445-022-01573-5.

Evaluating biosurfactants as eco-friendly biocides (TEch4YOU Project)

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Keywords: biosurfactant, stone materials, biocides.

The colonization of stone substrates by biological organisms is instigated by photoautotrophic pioneers like cyanobacteria, algae, and lichens, along with chemolithotrophic and chemioorganotrophic bacteria. These organisms harness the limited energy resources available on the stone surface and adapt to challenging environmental conditions, including variations in solar radiation and exposure to precipitation, as well as fluctuating nutrient availability. This process often leads to the establishment of a distinct ecological niche characterized by specific micro and macroflora. Operators typically remove this colonization through a combination of mechanical and chemical methods, primarily utilizing Quaternary Ammonium Compounds (QACs). However, QACs have been detected in wastewater, surface waters, and sediments, with documented effects on antibiotic resistance, necessitating the development of new biocides with enhanced biodegradability.

The TECH4You project under the PNRR is founded on the integration of established technologies with emerging ones such as biosurfactants (Walter et al., 2010). This study presents the selection of potential biosurfactants for use as inhibitors of microbial growth. Biosurfactants derived from strains including *Pseudomonas aeruginosa*, *Rhodococcus qingshengi*, *Pseudomonas glycinis*, *Microbacterium hydrocarbonoxydans*, and *Acinetobacter sp*. were extracted to develop marketable products. Extraction trials were conducted to achieve consistent percentages of cationic, anionic, and non-ionic surfactants, with preservation tests assessing the durability of the products over time. The biocidal efficacy of the products was evaluated both in laboratory settings and in situ.

In laboratory tests, the antimicrobial activity was evaluated against pathogenic strains P. aeruginosa ATCC 15692 and S. aureus ATCC 9144 (Ceresa et al., 2019). The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of both filtered and unfiltered samples, were determined 30 days post-biosurfactant production.

In situ, biosurfactants were applied to artificial stone materials, and their biocidal efficacy was evaluated through macroscopic and microscopic observations under visible light, as well as ATP analysis using a bioluminometer. The strains *Rhodococcus qingshengi* (OSS 19) and *Pseudomonas glycinis* (A2-5) exhibited the highest biocidal efficacy.

Ceresa C. et al. (2019) - Medical-Grade Silicone Coated with Rhamnolipid R89 Is Effective against *Staphylococcus spp*. Biofilms. Molecules, 25-24(21), 3843, https://doi.org/10.3390/molecules24213843.

Walter V. et al. (2010) - Screening concepts for the isolation of biosurfactant producing microorganisms. Adv. Enzymol. Relat. Areas Mol. Biol., 672, 1-13, https://doi.org/10.1007/978-1-4419-5979-9_1.

The Mg/Ca ratio in mortars used in ancient rural buildings in the north-Eastern Piedmont plain: a methodology to support archaeological studies

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Keywords: ancient mortars, cultural heritage, archaeometry.

Rural architecture deserves to be considered a cultural heritage because it bears witness to the development of territories over the centuries. Rural settlements in the Piedmont Po Valley present a wide range of structures dating back to Roman and early medieval times. These structures are characterised by considerable irregularity in texture and height, and consist of wooden walls with cobblestone bases or brick fragments, parts of older and more recent walls, and reused older elements. Therefore, these types of structures do not allow for an architectural dating and chronological classification. The only material coeval with the construction and with specific characteristics are mortars.

Mortars are made up of a mixture made up of an inert material (usually sand), a binder (lime) and water. Lime, obtained by cooking carbonate rocks (limestone, dolomitic limestone, dolomite), is one of the most popular building materials in the world and has been used since ancient times.

This study presents a low-cost and efficient diagnostic method based on the geochemical characterization of two oxides present in the lime of mortars and in carbonate rocks of the area: MgO and CaO.

The Mg/Ca ratio of the carbonate fractions of the limestones quarries remains almost constant within the same depositional environment, and is therefore characteristic at the outcrop scale.

The Mg/Ca ratios of the mortar samples taken from three rural settlements, Brusasco, Trino and Ticineto, of Roman and medieval origin, located in the plain area along the alluvial belt of the Po river, were analysed and compared with those of the mortar samples carbonate rocks taken from ancient limestone quarries in the nearby hilly area of Monferrato, in the Piedmont region (Italy).

Through the analysis of the MgO/CaO ratio in the limestone rocks of the ancient quarries and in the lime present in the mortars of the sampled rural buildings, it was possible to carry out spatial and temporal correlations with the historical phases identified in the various archaeological sites.

Furthermore, it was possible to identify the original quarries used for the production of limestone and, in some cases, establish the period of exploitation.

In this context, mortar has proved to be an important diagnostic tool to identify the original limestone quarries and the period of exploitation, and to provide interesting information on the network of trade routes and their changes over time.

Finally, the study showed that quarries exploited in an earlier period (e.g. Roman times) were often no longer exploited in more recent periods (e.g. medieval or late medieval times). The reasons may not only be related to the impossibility of quarrying or need of different characteristics of limestones, but also to political and road changes.

Influence of clay processing on bulk chemistry signature in ancient pottery productions

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Keywords: clay depuration, chemistry, mineralogy.

The production of many ceramic materials in ancient times required the base clay (the clayey material collected from primary or secondary deposits) to be processed according to various methods. Among others, the depuration by sedimentation (in clam water or in water flow) was probably one of the most used one. It allowed to obtain a clayey material finer in terms of grain-size than the base clay due to the removal of the coarser fraction, and therefore more plastic and suitable to produce fine pottery. But, the removal of the coarser fraction, even with different degree of depuration, determined important changes on both the mineralogy and chemistry of the depurated clay with respect to the originally exploited one. It is important to remark that the provenance especially of fine ceramic is normally based on their chemical composition and the comparison with reference groups (ceramic materials of known provenance, often linked to attested production centres/workshop) and/or clayey materials available in the possible production regions. Therefore, clay processing affected the composition of the clay paste and the relative fired products (ceramics). Despite many archaeometric studies remark that possible differences between the ancient productions and the possible used base clays are ascribable to depuration processes, not systematic works as been done coupling the grain-size analysis and workability (plasticity, Atterberg limits) of the original and depurated clays with their mineralogical and chemical composition, as well as microscopic features. This research therefore report the results of the depuration of different types of clays in terms of their grain size, mineralogy and geochemistry with respect to the sampled clays . In particular 4 different types of raw material, representing “clays systems” widely exploited in the past to produce ancient pottery, were selected: i) illitic-chloritic clays rich in calcite; ii) illitic-chloritic clays poor in calcite; iii) illitic-kaolinitic clays rich in acidic-rocks sand; iv) chloritic-smectitic clays rich in iron. These clays were collected from well-known exploited deposits used in antiquity (Cyprus, Crete, Nile Valley, Arezzo, Veneto region) and then depurated, separating the coarser fraction for sieving and sedimentation in water, in order to obtain a depurated clay from each raw material. Each of these products, as well as the original base clays and of the separated coarse fractions, were characterized under a granulometric, mineralogical, microscopic (optical and electronic microscopy) and chemical point of view.

Investigating post-depositional alterations in underwater ceramics. The case of the archaeological site of Torre Santa Sabina (south-eastern italy)

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Keywords: archaeometry, underwater ceramics, post-depositional alterations.

An archaeometric investigation is currently in progress on a series of amphora fragments from the underwater archaeological site of Torre Santa Sabina (Apulia, south-eastern Italy), dating back to the Republican period (late 2nd century BC) (Auriemma et al., 2022). The main aim is to analyse the post-depositional alterations occurring in ceramics in the underwater environment by studying the systematic physical, chemical and mineralogical transformations. All the results obtained contribute to discriminate which chemical element changed in terms of concentration due to interactions with the underwater environment from those that are indicators of provenance, allowing the archaeometric data to be properly tuned. This will also help provide important evidence of cultural and technological identity and deepen knowledge of the site's ancient maritime history. Geochemical, mineralogical and micro-stratigraphic characteristics of 40 amphora samples from the underwater site of Torre Santa Sabina and 13 from the terrestrial production areas of Apani and Giancola, have being analysed combining optical and spectroscopic techniques. A comparison between marine and terrestrial samples was considered to verify the nature of the main transformations in objects exposed to different burial environments and to detect compositional similarities that may be indicative of the provenance of underwater ceramics. In order to identify the factors determining the precipitation of specific secondary phases in the pores and the enrichment or depletion of certain chemical elements (Maritan, 2020), and to verify their systematic nature, sherds of similar production but recovered from other submerged and terrestrial sites were also considered. The preliminary results show that the underwater ceramic bodies are characterised by a chromatic stratigraphy linked to post-depositional processes that is not detected in terrestrial samples. Some chemical elements, such as sulphur, show great variability as they are related to the precipitation of secondary phases during burial (e.g. pyrite) the presence of which is confirmed by XRPD data. The preliminary SEM-EDS analysis verified the frequent presence of pyrite microcrystals and highlighted the occurrence of lamellar structure of hydrotalcite-like layered double hydroxides (LDH) in underwater fragments. These phases are absent in terrestrial samples. Statistical treatment of chemical data is carried out by selecting the elements least susceptible to alteration in order to use them for the comparison of samples from different burial environments and to properly assess the provenance of ceramics found on the seabed. All the outcomes will provide useful information for the Underwatermuse project, of which Torre Santa Sabina is the reference site, aiming to create an underwater archaeological park through experimental methodologies, encouraging the conservation of the submerged heritage and promoting cultural activities.

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Maritan L. (2020) - Ceramic abandonment. How to recognise post-depositional transformations. Archaeol. Anthropol. Sci., 12, 199, https://doi.org/10.1007/s12520-020-01141-y.

The POW camp 65 (Altamura, Southern Italy) as a case study for archeometry and contemporary archaeology

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Keywords: archeometry, contemporary archaeology, petrography.

Located in close proximity to Altamura (Puglia, Italy), the site, commonly referred to as PG65, spans an area of 31 hectares. It held the distinction of being the largest concentration camp for prisoners within fascist Italy during World War II. Following the armistice in 1943, it underwent a transformation into a training facility for Yugoslav partisans and, subsequently, in the 1950s, evolved into a center for gathering refugees. Later on, it served as a military training ground before being almost completely burned to the ground in the late 1980s (De Felice, 2021).

The site's history is intricate and so its materials. Archaeological investigations, conducted by the Universities of Bari and Foggia since 2021, have been aimed to research material traces in order to reconstruct the history of the site and understand the material transformations associated with those phases. A total of 65 samples, primarily extracted from the remaining elements such as floors within two kitchens, a lavatory, and a dormitory, were collected and analyzed. The particular military building context raises questions about the binder and aggregate provisioning during and after World War II and provides evidence of lime and cementitious binders technology in the mid-20th century. Mineralogical and petrographic analyses (SEM-EDS, POM, XRD, etc.) have been fundamental to answer these questions and understand the chronological succession and the materials employed, particularly focusing on mortars.

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Reproduction of ancient lime mortars from the Baroque built heritage of Catania (Sicily): an experimental study

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Keywords: lime, cultural heritage, Catania.

The Baroque built heritage of the historic center of Catania (Eastern Sicily) is the result of the city reconstruction after two devasting natural events occurred during the second half of 17th century, i.e. the eruption of 1669 and the earthquake of 1693. Volcanic stones from Mount Etna have been used in combination with limestones from the Hyblean area giving the buildings a peculiar bichromatic appearance. Basalt blocks were mainly used for the base of building facades and for church columns due to their strong physical-mechanical properties (Barone et al., 2021). In addition, volcanic materials have been also used in the formulation of both bedding and rendering lime mortars. Specifically, two different volcanic aggregates were used, locally known as azolo and ghiara. Azolo, now obtained from the fine grinding of basalts, in its ancient meaning was an incoherent pyroclastic rock, while ghiara is a peculiar reddish material deriving from the transformation of palaeo-soils due to lava flows (Belfiore et al., 2022; 2023). These two aggregates peculiar of the Etna territory were used as the main source of aluminosilicates to be mixed in variable proportions with lime to produce the ancient mortars.

In this contribution, an experimental approach is used, based on the reproduction in laboratory of historic mortars for conservation and restoration purposes. Specifically, different formulations were prepared by using a binder/aggregate ratio of 3:1 and 4:1 for the ghiara-based mortars, while 3:1 and 2:1 for the azolo-based ones, according to the ancient recipes known from literature (Battiato, 1988). In addition, further specimens have been prepared by adding specific quantities of pozzolana to the above mixtures to enhance the hydraulic behavior of mortars. The specimens were left curing for 28 days at room temperature in laboratory and then underwent the following investigations to assess their physical-mechanical features as well as their behavior to decay processes: i) mineralogical analysis through X-ray diffraction (XRD) of both binder and aggregate fractions to identify the constituent phases; ii) thin section analysis by polarized optical microscopy; iii) SEM-EDS investigations along with a semi-automated image processing procedure based on the multivariate statistical analysis of X-ray maps to highlight and quantify the hydraulicity index of the mortars as a function the binder/aggregate ratio; iv) water absorption by capillarity; v) water absorption at atmospheric pressure; vi) accelerated aging test by salt crystallization and salt mist; vii) uniaxial compressive test; and viii) perforation resistance test.

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Investigating the past: a multi-analytical approach for the analysis of Phoenician pottery from the archaeological site of Pani Loriga

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Keywords: archaeological ceramics, multi-analytical characterization.

The information provided by the study of ancient archaeological materials often allow the reconstruction of cultural and technological contexts of the artifact's production. The archaeological excavations recently carried out in the Sulci's region are bringing to light data of remarkable implications, as they provide evidence of Phoenician populations settlement in this area of the Sardinian region, at the site of Pani Loriga (Santadi), an area of strategic relevance and, thus, inhabited since the ancient times.

In the present work, we provide a multi-analytical characterization of a set of 46 samples of different use and shape from the Pani Loriga site, dated back to the end of the 6th and 5th BCE. In order to fully characterize the sherds, we performed chemical, mineralogical, and petrographic characterizations (on thin sections) using analytical techniques such as X-ray powder diffraction (applying the Rietveld full-profile fit to the diffraction patterns for phase quantification), portable X-ray fluorescence and scanning electron microscopy (SEM-EDS).

Coupling different techniques lead to have an in-depth knowledge of this class of materials and a complete picture of their trademark, for the reconstruction of the raw materials assemblages and their firing conditions, making it possible to trace-back the history of products and trades of an important civilization for the Mediterranean history.

Sand slaking in the lime mortars of Tertiveri (Foggia, 12th-15th century)

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Keywords: Apulia, medieval mortar, aggregate.

Tertiveri, the ancient Tortiboli, was a small medieval Episcopal see that probably dates back to as early as the 10th century in the Byzantine period and reach a maximum extension of some 7 hectares. The medieval settlement was in a strategic position for the defence and control of the territory in intervisibility with the coeval settlements of Castel Fiorentino and Montecorvino, along the border between Capitanata and the Beneventan territories.

The site was given in fief to the Muslim nobleman Abd al-Aziz and his family – the clan consisted of 60 women and 40 men- by Hong Charles II in 1296, after having been temporally abandoned. In 1300, the rights over Tertiveri were again conferred on a Christian, the knight Johannes Pipinus de Barolo. The only upright leftovers of its medieval constructions are the distinctive remains of a residential tower built only quite late, i.e. around 1340. The bishopric of Tertiveri was present until 1450, but in the 15th century, was formally united with that of Lucera. In 1456 Tertiveri was destroyed by an earthquake.

Archaeological excavation from 2011 to 2023 revealed the outlines of some major building, including two churches, and its fortifications. The bigger church was the former cathedral in which a family tombs of the local elites, including the tomb of a bishop dated around 1250-1260 BC, were excavated.

In this work, the lime mortars of the excavated area are considered. Thirty samples were analyzed by POM, XRPD, SEM-EDS and XRF, in order to identify the type of lime and the technological aspects.

Petrographical and chemical evidence of the use of siliceous limestone for calcination. The presence of charcoal in the mortars suggests mobile calcination structure, where the bottom ash is more easily mixed up with the quicklime blocks. Although all the mortars were obtained by mixing feebly hydraulic lime and fluvial sand as aggregate, some compositional and microstructural differences were detected between the bedding mortars of the tower and those from the cathedral area. In the residential tower, the siliciclatic component is prevalent on the carbonate one. In particular, clasts of chert and marls show a reaction rim with the lime, formed during the pozzolanic reaction, which imparted greater mechanical strength to the mortar. The mortars from the cathedral area are less uniform with each other, show nodular structure and a more calcareous aggregate. The results obtained point to sand slaking for all the analyzed mortars, with differences related to the aggregate composition and texture and water/lime/aggregate ratios.

The mortars as a marker of the evolution over time of materials and construction techniques in the Benedictine Monastery of Catania

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Keywords: cultural heritage, mortars, multylayer context.

The present contribution falls within the research activities of the PNRR project CHANGES – Spoke 6 – History, Conservation and Restoration of Cultural Heritage. The main focus of the spoke is to develop and apply integrated methodologies, strategies and approaches to support the processes of historical understanding, conservation, restoration, monitoring, sustainable and participatory planning in multi-layered contexts of cultural heritage. In this framework, the Benedictine Monastery of Catania has been selected as first case-study. The Benedictine Monastery of Catania is a late Sicilian Baroque masterpiece founded by a Cassinese congregation in 1558. Afterwards, it underwent significant transformations due to natural disastrous events, namely the 1669 lava eruption and the 1693 earthquake, which led to its partial destruction (Branciforti & La Rosa, 2007; Pafumi, 2015). The following reconstruction interventions resulted in a unique combination of different historical periods. In 2002, UNESCO included the monastery, along with other late Baroque sites in South-Eastern Sicily, to the World Heritage List. A thirty-year restoration project uncovered the town's history from the Roman period to the present day, revealing an entire Roman neighborhood (including the Cardo and Decumanus Maximus), as well as Hellenistic and imperial-era houses beneath the monastery. Some remains can be seen in the main courtyard and under the former stables, where a Roman domus with its peristyle seamlessly integrates with the 16th-century monastery structure and the contemporary "hanging" structures in the university library.

The present contribution focuses on the analysis of historical mortars covering a broad time span, from the Roman era to the late Baroque period. This research is of great importance because it allows for an examination of how the materials and manufacturing methods of mortars have changed and developed over the centuries. Furthermore, mortars play an essential role in the stability and structural integrity of historical buildings, and comprehending their behavior over time can provide valuable insights for conservation and restoration efforts. A multianalytical diagnostic approach has been used for the complete characterization of the selected materials. The chemical and mineralogical-petrographic composition of mortars has been assessed through both non-destructive in-situ investigations and conventional laboratory techniques. The manufacturing processes and construction techniques used in different periods together with the impact of technological and cultural evolution on the quality and durability of mortars have been also evaluated.

This research can be considered pioneering since no study to date had ever concerned the construction materials of a such valuable site of the Catania built heritage.

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Preliminary diagnostic analyses of the wall painting materials of the Vignale's villa (Tuscany region, central Italy)

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Keywords: plaster, pigment, archaeometry.

Located on the Tuscan coast near the ancient Via Aurelia, the archaeological site of Vignale was an important crossroads linking the inland areas with the maritime routes. Its strategic position gave it great economic importance and justifies the long history from the 2nd century BC to the 11th century CE. Archaeological research unearthed a prominent villa maritima overlooking the Falesia lagoon, which underwent various developments and transformations in its southern part at the beginning of the 1st century CE; moreover, in the 4th century CE, the atrium and the adjoining rooms constituted a great hall, decorated with an impressive polychrome mosaic, located in the immediate vicinity of the lagoon (Giorgi, 2016).

A total of twenty-three samples of painted plaster were collected from the different spaces using a sampling strategy based on their colours and stratigraphy, in order to study the differences in plaster materials and painting techniques during the phases of occupation.

A preliminary study was carried out on the pictorial surfaces by means of digital microscopy (DM), fiber optic reflectance spectroscopy in the visible range (FORS-VIS), portable X-ray fluorescence spectroscopy (pXRF), Fourier Transform Infrared Spectroscopy in attenuated total reflectance mode (ATR-FTIR) and μ-Raman spectroscopy (RS). Multi-layered mortar-based supports, instead, were investigated by minero-petrographic analyses performed via polarized light microscopy (PLM).

The archaeometric analysis of the pictorial surfaces reveals the extensive use of natural and synthetic pigments, i.e. yellow and red ochres, green earths, and Egyptian blue, used both in their pure form and in mixtures; different shades, in fact, were achieved by mixing pigments of different hues, as, for example, observed for vivid greens obtained by mixing Egyptian blue with green earths.

While the typology of pigments appears to be consistent, there are significant differences in the composition of the plasters among the different areas. These differences indicate different preparation techniques, possibly associated with different phases of construction. A first group of samples shows two layers: the stratigraphy is given by an internal layer composed by lime-based binder mixed to carbonate and silicate aggregate covered by a marmorino layer. Conversely, the second group shows only one thick layer composed of lime-based binder with frequent lumps, mixed to the aggregate composed of limestone fragments, quartz and chamotte; the same mix-design was also found in a group of samples preserving incannucciata imprints. Only in one sample, the support is constituted by cocciopesto, covered by a thin layer containing angular calcite grains.

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New application prospectives of reaction path modelling for the conservation of cultural heritage: preliminary presentation of a novel research project

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Keywords: climate change, cultural heritage, reaction path modelling.

Nowadays climate change is an additional potential threat for the Cultural Heritage, as it exacerbates the expected rates of decay phenomena by affecting the structure and composition of the stone materials and leading to a greater need for preventive interventions (Sesana et al., 2021). Therefore, the application of innovative methods, able to monitoring and predicting the effects of climate change on Cultural Heritage, becomes essential. For this purpose, Reaction Path Modelling represents a high-potential geochemical tool, based on the use of software packages to study different geochemical processes, including materials weathering. A geochemical process can be represented by a series of chemical reactions describing mass transfer from reacting minerals to other phases in the system, that include the aqueous solution as well as minerals precipitated as reactions products (Helgeson et al.,1970).

This work aims to apply Reaction Path Modelling in order to study the weathering processes occurring on cultural heritage sites in two environmental conditions, coastal environments versus urban ones, both particularly exposed, albeit in different ways, to pollutants and meteorological agents. In this research, the rock-water interaction process, which is the basis of geochemical modelling will be applied to the study of the interaction of water with stone materials used in Cultural Heritage. Water, in fact, is among the most aggressive mediums of deterioration of building materials. The preliminary phase of the research involves the collection of data necessary for the geochemical modelling setup. In particular, the research will involve the following steps: a) selection of case studies of cultural interest made of stone material (pilot sites), in urban and coastal contexts; b) recovery of samples of stone material (altered and unaltered) at the pilot sites, to investigate the minero-petrographic and geochemical properties and compare the data according to the recognized alterations; c) collection and comparative study of environmental data (i.e., temperature, rainfall and rainwater composition) in the vicinity of the selected pilot sites in order to model current weathering processes and hypothesize future degradation scenarios on heritage materials; d) simulation of the weathering processes through software. Specifically, such simulation will be performed using EQ3/6 software package (Wolery et al., 2003) and the code PhreeqC Interactive (Charlton et al., 2002), adopting the kinetic mode approach; e) data comparison and future predictions on the alteration processes of stone materials. The expected results of this research should provide an understanding of the processes involved in the weathering of stones belonging to Cultural Heritage, predicting their evolution and dependence on current and future environmental factors exacerbated by the effects of climate change.

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Assessing construction techniques through minero-petrographic analysis of Roman mortars: insights into Imperial economic investments in building projects

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Keywords: minero-petrographic analysis, roman mortars, imperial economic investments.

This paper is part of the ongoing Economy of Roman Imperial Architecture project, which aims to assess the nature and extent of imperial investment in Rome's construction industry during the 2nd to 4th centuries CE through qualitative and quantitative evaluations of masonry and mortars from imperially sponsored, functionally and chronologically compatible buildings. The research was funded by the Rome Transformed project (ERC grant agreement No. 835271) and by Newcastle University PGRAs research funds (Haynes et al., 2023; 2024).

The masonry data capture process involved visual inspection, structural analysis, and 3D laser scanning of the structures to assess their structural function, chronology, and state of conservation. Additionally, we conducted a comprehensive evaluation of the technical, qualitative, and dimensional qualities of the masonry, including assessing the size, type and quality of bricks, the presence of pointing or surface reworking, and determining the height of modules.

Mortars were then sampled from structurally compatible and chronologically coeval walls and analysed. Information regarding the textural and mineralogical characteristics of the samples, including the identification of the main minerals constituting the aggregate, its grain size and shape, and the evaluation of the binder/aggregate ratio, was obtained through Optical Microscopy (OM) observations followed by SEM/EDS analysis, enabling data acquisition concerning the chemical composition of the samples.

Preliminary results from the analysis indicate that all types of mortars are characterized by a lime-based binder with a cryptocrystalline and micritic texture in varying proportions. The binder fraction also contains lime lumps, ranging from common to rare. The aggregate fraction mainly consists of volcanic fragments (red and black scoriae) ranging in size from mm to cm, exhibition reaction rim and secondary carbonation evidence. This volcanic component of the aggregate is consistent with ultrapotassic products of the Roman Magmatic Province, likely originating from the volcanic district of the Alban Hills (Peccerillo, 2005), providing insight into the main area of procurement of aggregate situated in the immediate proximity of the buildings.

The results we have obtained thus far have provided us with interesting preliminary insights into the composition of the mortars, as well as their likely production techniques. This information is crucial for our final assessment of the economic investment required for the procurement of raw materials, including binding materials and aggregates, necessary for the construction of the imperial buildings.

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Haynes I. et al. (2024) - The changing face of the eastern Caelian in the 1st–4th centuries AD: work by the Rome Transformed Project. Launaro A. (ed.) Roman Urbanism in Italy, Cambridge: Oxbow Books: 22-43, https://doi.org/10.2307/jj.9941113.6.

Peccerillo A. (2005) - Plio-Quaternary Volcanism in Italy. Petrology, Geochemistry, Geodynamics. Springer-Verlag, Berlin-Heidelberg, Germany, XIV, 365, https://doi.org/10.1007/3-540-29092-3.

Archaeometric investigation of lithic materials from the archaeological site of the Holy Sepulchre (Jerusalem)

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Keywords: provenance, holy sepulchre, white marbles.

Archaeological excavations have been conducted inside the Church of the Holy Sepulchre in Jerusalem by Sapienza University of Rome as part of a project to restore the floor of the religious complex (IAA license G-20-2022). In the north-western part of the Rotunda the rock level emerged after removing the current flooring and close to the base of Aedicula cleaning operations revealed the presence of lithic and marble slabs. They are placed in direct contact with the rocky bank to create thickness, as well as remains of marble cladding from an earlier phase of the same Aedicula (Stasolla, 2022). For the present study, an archaeometric investigation has been carried out on the building materials used as basement of the Aedicula by applying a multi-analytical approach using Optical Microscopy (OM), Infrared Spectroscopy (FTIR), X-ray powder diffraction (XRPD) and isotope-ratio mass spectrometry (IRMS) to reach information about the minero-petrographic composition and the provenance of the samples. The results allowed to divide the lithotypes used into four groups based on their micro and macro characteristics: white marbles, limestones, bitumen rocks and red rocks. Regarding the provenance, the lithic materials are compatible with local geology, except for the white marbles for which hypothesis have been proposed basing on the microscopic features and the isotopic results.

Stasolla F. R. (2022) - Archaeological excavations in Jerusalem, Holy Sepulchre: a preliminary report. Liber Annuus, 72, 449-486, https://doi.org/10.1484/J.LA.5.134546.

Statistical analysis of IR spectra of mortar for studying the relationship between building phases

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Keywords: IR spectroscopy, mortars, geomaterials.

Typical applications of diagnostic methodologies focus on the characterization of constituent materials, their origin, degradation products, and the causes that led to degradation. Among the widely applied methodologies in cultural heritage analysis, FTIR spectroscopy is one of the most applied for the characterization of artworks. However, the heterogeneous nature of geomaterials in cultural heritage usually negatively affects the interpretation of spectroscopic data. Indeed, this heterogeneity results in numerous peaks (often overlapping) and shoulders, which are challenging to resolve.

Statistical treatments of experimental results are, therefore, a useful complementary analysis to improve the interpretation and highlight analytical data relationships among different samples. In particular, multivariate statistical techniques are the most commonly applied methodologies to correlate a large number of variables, allowing the identification of groups based on spectral profile similarities and differences. The most common statistical analysis applied to define "pattern recognition" in spectra is principal component analysis (PCA).

This project (funded by PNRR PE05 – CHANGES_SPOKE-5-DST - CUP B53C22003780006 - Medeghini) aims at exploring the potential of the PCA treatments of attenuated total reflectance Fourier transform infrared spectra (FTIR-ATR) as a tool to compare and correlate different building phases in archaeological sites. In particular, FTIR-ATR spectra of mortars have been considered, being the material which are mainly related to the timing availability and building construction knowledge of skilled workers.

The proposed procedure has been applied to mortars from the archaeological site of the Holy Sepulchre in Jerusalem (IAA license G-20-2022) to correlate different building phases identified below the floor of the Holy Sepulchre. The results have been compared with data obtained by an usual multi-analytical approach using Optical Microscopy (OM), X-ray powder diffraction (XRPD) and Scanning Electron Microscopy with micro-analysis (SEM-EDS) to validate the procedure.

Advancing in underwater cultural heritage monitoring: the case of NERITES Project

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Keywords: underwater technologies, cultural heritage, decay.

The EU HORIZON EUROPE NERITES project (Systematic Autonomous Remote Surveying of Underwater Cultural Heritage Monuments and Artefacts, using non-destructive, cost-effective, and transportable digital solutions) employs innovative monitoring solutions tailored for underwater cultural heritage (UCH) sites that will allow autonomous site's condition inspection. These advancements offer enhanced cost-effectiveness and precision compared to traditional methods, with a particular emphasis on addressing stone and ceramic degradation caused by biological agents and environmental pollutants prevalent in marine ecosystems, in a cost-effective manner of the overall system at design and operational (mission execution) phase.

Leveraging interdisciplinary scientific approaches, NERITES stands out for its integration of state-of-the-art technologies, offering a unique and innovative solution for in-situ monitoring of UCH assets. Its novel framework facilitates systematic autonomous (self-managed) remote assessment of the preservation status of various UCH elements, including materials, artifacts, and monuments.

The project core lies in the development of a digital infrastructure centered around an Autonomous Underwater Vehicle (AUV) piloted by elaborate deep AI for mission planning and motion control; while equipped with cutting-edge, non-destructive sensing devices and techniques. These include 1DoF LIBS for metal mapping, innovative QCL-based IR sensor system for detecting hydrocarbons and minerals, and advanced Artificial Intelligence models for detailed visual analysis. An integral component of this system is the subsea docking station, accompanied by a surface buoy. The buoy serves as a communication bridge between the autonomous underwater vehicle (AUV) and external monitoring systems. It is equipped with renewable solar collectors to meet the energy requirements of the mission. Together, these technologies promise comprehensive autonomous monitoring and assessment of UCH site conditions.

The NERITES monitoring scheme will be tested in two UCH sites, one Italian, Pozzuoli Bay, the offshore counterpart of the Campi Flegrei caldera and one Greek, Fournoi Archipelago, where 58 shipwrecks have been surveyed so far.

NERITES seeks to transform UCH preservation and degradation assessment protocols by minimizing operational costs, improving assessment accuracy, and reducing human risks. Through rigorous comparison with validated results from laboratory and in-situ tests, alongside new experiments and samplings, NERITES aims to establish a new standard for efficient and reliable UCH monitoring methodologies using high-end autonomous underwater multi-torpedo-shaped vehicles.

The technologies developed in NERITES will provide a new approach in monitoring UCH sites from an environmental and conservative point of view in order to preserve the submerged heritage and make it accessible and usable for present and future generations.

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SOUTH - Safeguard Of sUbmerged culTural Heritage: project presentation

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Keywords: underwater cultural heritage, antifouling, machine learning.

In the present SOUTH project, a comparative study of the degradation forms that occur on different types of stone materials typically present in submerged historical/archaeological sites will be proposed. The study focuses on the experimentation of innovative formulations to protect materials from biofouling by monitoring the growth of colonization and decay processes over time. The monitoring process will be automatic and it will take advantage of the application of new methods of image acquisition, image processing and machine learning algorithms for the reduction of noise of the images captured under-water and the study of the growth of microorganism by means in situ data collection. This automated process will allow to avoid to extract the manufacts from the under-water position at interval defined of time. The main objective is understanding the main characteristics of the phenomena in a long period of time with a continuous monitoring of the stones and manufacts. Furthermore, the new protective formulations and the monitoring of biofouling on stones will be carried out both in the laboratory and in situ. The pilot activities will be implemented in southern Italy by selecting an ideal submerged site in the Mediterranean area to carry out all the experimentation. Solutions adopted, tested and validated by the SOUTH system, could be then applied to other Mediterranean historical/archaeological sites suffering the same conservative problems. For this reason, the partnership will disseminate the project results and outcomes to all relevant stakeholders and sector operators who deal with the maintenance and protection of underwater sites, at the local, regional and national level.

Inside the stone: new elements for targeted conservation of Sicilian Baroque Monuments

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Keywords: calcarenites, conservation, stone degradation.

The Sicilian Baroque Architectonic style represents an "unicum" significantly modifying the aspect of cities and towns in South-Eastern Sicily such as Catania, Noto, Ragusa, and Siracusa since XVII cent. such that UNESCO included this area in the World Heritage List since 2002. Baroque monuments owe mainly the refinement of the architectural forms and decorations and the variability of the colours to the different local calcarenites used as building materials. Despite their wide diffusion in the construction field, they are subject to different degradation processes (Belfiore et al., 2010) evolving with heterogeneous rates and forms. In this regard, Comiso, Modica and Ragusa stones have been selected and analysed because, on one hand, they are very similar macroscopically (e.g. colour), on the other hand, their responses to degradation phenomena differ visibly. These differences depend on mainly the petrographic and physical features of the materials (Anania et al., 2012; La Russa et al., 2015). Factors such as mineralogical composition, pore size, and differential mechanical properties are determining the type of degradation observed (Belfiore et al., 2021). Thus, minero-petrographic and physico-mechanical analyses will be carried out on representative samples of each stone (Belfiore et al., 2021). Specifically, the analyses consist of optical microscopy, x-ray diffraction (XRD), mercury intrusion porosimetry (MIP), salt crystallization test, determination of ultrasound speed, uniaxial compressive strength, flexural strength, and elastic modulus. Samples of Comiso Stone were directly extracted from quarries, while those of Modica and Ragusa stone come from natural outcrops. Finally, the definition of the intrinsic properties and the related criticalities of these stones will provide crucial information useful for the planning of conservation strategies adapted to the different materials and able to preserve the Baroque monuments over time.

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Belfiore C.M. et al. (2010) - The Baroque monuments of Modica (Eastern Sicily): assessment of causes of chromatic alteration of stone building materials. Appl. Phys. A, 100, 835-844, https://doi.org/10.1007/s00339-010-5659-3.

Belfiore C.M. et al. (2021) - The susceptibility to degradation of stone materials used in the built heritage of the Ortygia Island (Syracuse, Italy): A laboratory study. Int. J. Rock Mech. Min., 146, 104877, https://doi.org/10.1016/j.ijrmms.2021.104877.

La Russa M.F. et al. (2015) - The behaviour to weathering of the Hyblean limestone in the Baroque architecture of the Val di Noto (SE Sicily): An experimental study on the ‘‘calcare a lumachella’’ stone. Constr. Build. Mater., 77, 7-19, https://doi.org/10.1016/j.conbuildmat.2014.11.073.

The "Cantine di Sant'Angelo Le Fratte" geosite and the historical-cultural heritage used as a growth driver for an inland area of Basilicata

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Keywords: cultural heritage, geosite, geodiversity.

The work addresses on the geological and geomorphological geodiversity of a portion of Sant'Angelo Le Fratte municipality area, approximately 30 km SW of Potenza.

The investigated zone falls in the axial part of the Apennine Chain, whose evolution has given rise to a differentiation of geological environments, clearly visible in the area, each of them characterized by their own geodiversity.

The greatest peculiarity is represented by cavities, utilized as cellars, which are the result of the accumulation of collapsed tens of metre-sized limestone blocks.

To characterize the geosite of the "Cantine di Sant'Angelo Le Fratte" a detailed geological and geomorphological survey and an extrapolation of the landslide map has been carried out. This allowed us to highlight the peculiarities of the site and to learn about the origins of the cellars themselves.

These are natural caves originating from the collapse of large blocks from the carbonate wall of the mesozoic formations of the Apennine Platform Unit (Upper Triassic-Jurassic). This outcrop appears as an intensely fractured sub-vertical wall, in tectonic contact with the arenaceous-clayey-marly succession of the Monte Siero Formation (Miocene), on which much of the town develops. The Monte Siero Formation area extends from the town towards the valley until it connects with the terraced alluvial deposits of the Melandro River (Holocene).

The study highlighted the numerous landslides affecting the town, in particular the landslides involving the limestone wall to the NW of the town. Landslides due to rotational sliding, flows and complex mechanism, that develop in the medium-lower part of the slopes, also occur.

The large blocks, collapsing, were arranged in such a way as to create caves which over time were used by man, first as homes and then for food conservation. The spaces between the blocks were closed in the front part by building a wall with the entrance to the cellar.

The combination of geological-geomorphological evolution and man's capacity for exploitation and adaptation allows the site of the "Cantine di Sant'Angelo Le Fratte" to be defined as a "geosite" and therefore a place to be geopreserved and enhanced, as required by the R.L. 32/2015 "Conservation and enhancement of the geological heritage" of the Basilicata Region.

The geosite must be associated with aspects of historical and cultural interest of the place to ensure that it becomes a sustainable tourism destination.

The geosite welcomes many visitors during the "Open cellars" event which is held every year in August. Attractive place, with more than 100 cellars set in the rock, over 50 full-sized and life-size statues representing the history of this ancient village, museums, multimedia itineraries and the open-air museum of around 170 murals.

In this work we want to give suggestions on how to preserve this geosite and attract more and more tourists throughout the year to make its geological and cultural heritage known.

African amphorae from Cumae: archaeometric study for provenance and technological features

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Keywords: mineralogical, petrographic roman, amphorae cumae.

The aim of this research is to define the technological characteristics and the provenance of African amphorae found in Cumae (Southern Italy), an ancient settlement known for the presence of some of the most powerful families of the rising Roman aristocracy.

Representative fragments of African amphorae, covering a chronological arc from the 1st century CE to the 6th century CE, were selected among all of the archaeological types found in Cumae in order to better represent the variety of amphoric products.

This research fits into the body of the much wider context of the ancient trade definition between the Campania's coasts and North African areas involved in the production of amphoras, which include Zeugitania and Byzacena in the south-central Tunisia, Tripolitania between southern Tunisia and western Libya, and Mauretania Caesarensis located between Marocco and Algeria.

After a first morpho-typological study of the materials, archaeometric analyses were performed via mineralogical-petrographic analytical techniques.

Polarised light microscopy (PLM) allowed the samples to be divided into two petrographic groups, which show affinities with the geological features of the lithologies of the supposed production areas and with archaeological materials used for comparison.

X-ray powder diffraction (XRPD) reported quartz as the predominant mineralogical phase followed by calcite, feldspar, and sporadic mica, along with calcium silicates formed during firing.

Highly relevant information for estimating the temperatures to which the amphorae were exposed during firing is provided by the mineral phases detected via XRPD and by microstructural features observed on fresh fractured samples at the scanning electron microscope (SEM) to investigate the vitrification degree.

Chemical analysis via X-ray fluorescence spectrometry (XRF) revealed a high concentration of CaO (> 6%) in the majority of the samples. Again, through comparison with other chemical elements, the samples turned out to be divided into two groups, which show affinities with the petrographic ones.

The initial paleontologic study of the microfossils observed in thin section promises an interesting output. The identification of the microfossils that were still recognisable in the ceramic paste upon the firing process provided a more accurate recognition of the raw materials exploited for making the amphorae.

Combining literature data on local geology with compositional data of archaeological materials (kiln rejects, locally found ceramic finds belonging to the same ceramic class, mainly from the Tunisian coast) used as a comparison, it was possible to associate each group of samples to a specific atelier of production.

Mineralogical and technological characterization of pozzolan mortars from the Brick Amphitheater in Nola (NA)

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Keywords: roman mortars, hydraulic mortars, cocciopesto.

The 'Brick' Amphitheater is an archaeological site located in Nola (NA), at Masseria d'Angerio, dating back to the 1st century BC. Part of this structure was excavated during essays conducted in 1992 by the Superintendency, revealing an elliptical plan, dimensions of 138 m on the major axis and 108 m on the minor axis, with a total capacity of about 20,000 spectators. Since the extended use and the several architectural interventions over time, the archaeological area is of particular interest. The present preliminary study is aimed at: i) characterize the different types of the used mortars (Miriello et al., 2015); ii) investigate the origin of the raw materials used for mortars production (Columbu et al., 2022); iii) identify similarities and/or differences between the various samples analyzed, in order to make hypotheses about the different construction stages (Lezzerini et al., 2018). Furthermore, this study will try to evaluate, with the help of historical sources, whether and how much the analyzed samples might be related to different socio-economic situations. Eighteen mortar samples, 12 taken from different areas of the amphitheater and 6 from ancient walls, were investigated (Rispoli et al., 2021). An initial macroscopic observation was conducted, followed by a more detailed thin-section examination through Polarized Optical Microscopy (POM), which enlightened the type and distribution of elements constituting the mortar and the background matrix. X-Ray Powder Diffraction (XRPD) technique was used for qualitative mineralogical characterization. The obtained results allowed to assess that the raw materials used for mortars production were locally sourced, as they were compatible with the geological features of the Vesuvian Area. In particular, preliminary results confirmed the occurrence of lime-based mortar, in which the binder shows a prevailing cryptocrystalline texture and subordinately micritic, with a volcanic aggregate fraction around 40-50% mainly composed by pumice, leucite slag, amphibole, biotite and garnet. The analyzed mortars, especially those related to the amphitheater structure, are hydraulic, as they show reaction rims at the volcanic aggregate-binder interface. Comparison between different mortar samples shows three different groups, which differ in the production technology and are presumably attributable to three different construction phases of the archaeological site. The first group (samples A1-A9) stands out for the accuracy of preparation and choice of aggregates, the second group (samples A11-A13) and the third group (M2-M6) have a higher binder fraction and more lime lumps at with respect to the aggregate fraction. Moreover, the aggregate fraction of groups 2 and 3 appear to be coarser in the samples taken from the walls. These preliminary data represent a good starting point for further investigation in order to develop a suitable pozzolan mortar for future conservative interventions of the monument, and for the re-using of waste geomaterials in a view of a more sustainable restoration.

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Rispoli C. et al. (2021) - Ancient Roman Mortars from Villa del Capo di Sorrento: A Multi-Analytical Approach to Define Microstructural and Compositional Features. Minerals, 11(5), 469, https://doi.org/10.3390/min11050469.

Air pollution related deterioration of limestone heritage: an overview

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Keywords: air pollution, limestone, deterioration.

Air pollution-related stone deterioration has been investigated since the beginning of the 20th century (Grün, 1931), and it has been noticed that the most sensitive lithologies are carbonates. Limestone, mainly porous limestone, shows various forms of deterioration. The main stone decay processes are gypsum formation and carbonate dissolution. The process differs from the region and is influenced by local climatic factors, exposure, pollution level and the substrate's lithology, micro-fabric and mineralogical composition. The presentation gives an overview of the deterioration process of carbonates using examples of heritage structures located in different parts of Europe. The studied buildings are exposed to industrial, urban, and rural pollution fluxes representing limestone monuments of seven countries (Belgium, Czech Republic, France, Germany, Hungary, Italy, and Poland). Weathering crusts and host rocks were sampled, and environmental conditions and pollution fluxes were documented. Mineralogical analyses (XRD, polarizing microscopy, SEM) and elemental composition (XRF, LA-ICP-MS), as well as organic compounds (GC-MS), were detected. The concentration of compounds was compared, and correlations were found between water-soluble calcium and gypsum content and between sulphate and gypsum content of weathering crusts and the limestone substrate. PAH and Pb content of selected samples was also measured. A trend was identified regarding the Pb and PAH content of samples collected from different environmental settings. The study suggests that despite decreasing trends in SOx levels and the use of unleaded petrol, large amounts of air pollution-related elements (Pb), minerals, and organic pollutants are still found on the facade of buildings and in the black weathering crusts of European limestone heritage structures.

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Finishes in architectural elements: "Domus Pasolini" of Faenza

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Keywords: cultural heritage, architectural finishes, analytical characterization techniques.

This work presents a case study of analytical micro-characterization applied to architectural finishes. In the historic centre of Faenza (Italy), at Palazzo Pasolini, between 1994 and '95 the Superintendence for Archaeological Heritage of Emilia Romagna brought to light a rich Domus of the Augustan age. The Domus was inhabited for a very long period, at least until the end of the 4th century CE (Grillini, 1998; Guarnieri et al., 1998). The finds of the architectural decoration of the Domus Pasolini ("stucco" plasters and "marmorino" plasters) have today been taken up again for in-depth analytical micro-characterization studies, with a new analytical approach, within the Department of Biological, Geological and Environmental Sciences (BiGeA) of the University of Bologna (Valdrè & Grillini, 2021). Polarized optical microscopy, X-ray Diffraction, Scanning Electron Microscopy, specific ultrasound sample treatment to separate binder from aggregate, and granulometric analysis, have been employed for the characterization of the materials.

The analytical results of the multi-layered plasters have highlighted a particular construction technology, especially as regards the surface finishing layer, used to imitate noble materials such as "marble". They are aerial lime plasters, as a binder, while the aggregate used for the finishing layer is not the classic "marble dust", but heterogranular spathic calcite with a tabular and rhombohedral appearance. The spathic calcite comes from the crushing of macrocrystalline calcite veins present in the carbonate geological formations of the Alberese area in the Bolognese Apennines (Monte Canda, Piancaldoli, etc.) and in the Forlì and Rimini Apennines (San Marino, San Leo, etc.). The choice of this particular technology, in architectural elements in ancient times, by Hellenistic, Phoenician-Punic to Roman workers to cover poor, porous and not pleasing-to-the-eye materials, leads back to two properties: high toughness of the plasters and reflective power of the surface ("mirror effect"), due to the crushing and orientation of the spathic calcite following surface smoothing and polishing, obtained with particular tools or, perhaps, even with hot iron (Grillini et al., 2004).

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Arianna's Palette: a diagnostic study of the painting walls of the house of Arianna in Pompeii

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Keywords: pigments, non-invasive methods, multi-analytical approach.

The House of Arianna represents, with its 1700 square meters of floor space, one of the most majestic examples of a residence within the Pompeii archaeological site.

The domus also known as the House of Colored Capitals due to the decorations that have been found, included about 70 different units on the ground floor alone, organized around three distribution areas: the atrium, the central peristyle, and the North peristyle.

The research developed within Cultural Heritage Active Innovation for Sustainable Society CHANGES - Spoke 6 - History, Conservation and Restoration of Cultural Heritage, reports the first outcomes of the archaeometric study of polychrome wall paintings which decorate the room number 6 of the House of Arianna. This room was chosen for the richness and variety of the palette used.

To achieve this goal, non-invasive on-site techniques were employed, including digital microscopy (DM), colorimetry, Raman spectroscopy, X-ray fluorescence (pXRF), Fourier Transform Infrared Spectroscopy (FT-IR). In addition, laboratory-based IR method (Attenuated Total Reflection mode) was performed on micro-samples to reach our characterization scope. This approach was applied to wall paintings, allowing the composition of the pigments used to decorate the rooms to be defined, revealing the use of a characteristic Roman palette (Germinario et al., 2018).

The results show that different colors were obtained by using pure, natural, and synthetic pigments including calcite, red and yellow ochre, red lead, cinnabar, green earth, Egyptian blue, and carbon black. These pigments were also combined to obtain specific shades, such as a mixture of green earth and Egyptian blue for green shades, addition of Egyptian blue to red pigments brightened with calcite for pink, a mixture of red ochre and red lead for red and brownish tones. Lastly, signals of incipient alteration have been highlighted by spectroscopic analyses Raman and FT-IR.

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S6.

Geosciences on display: the role of Natural History Museums in the future of our planet

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What is the role of Natural History Museums in the future of our planet?

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Keywords: natural history museums, collections, society.

In recent decades, the role of museums has been extensively examined, prompted by debates on the concepts and societal value of cultural heritage. The strengthening of the social and educational use of heritage has also fueled discussions on its income-generating potential and the development of related economic strategies.

Traditionally considered as places for the preservation of material evidence, museums have increasingly developed into venues for cultural initiatives and educational activities, becoming hubs for diverse audiences that engage with them in continuous historical, political, and moral relations. Alongside their educational and cultural enrichment functions, museums have also embraced roles in entertainment and amusement, activities found in other institutions but distinguished in our case by the presence of collections.

On the front of collections, museums are tending to evolve the sense of ownership towards the value of accessibility, through sharing policies on digital platforms that facilitate the circulation of images and data related to artifacts. This facilitates connections and linkages between objects, disciplines, stories, places, and people, emphasizing the material evidence that holds extraordinary value in terms of shared knowledge.

Nevertheless, it is advisable not to overlook that Natural history museums, within the aforementioned changes, preserve collections of extraordinary importance and vast dimensions that have been the basis of scientific research for centuries. In recent decades, they have acquired a fundamental role, thanks to their increasingly close ties with contemporary society, which they can influence the future through education about nature and its conservation.

This intervention aims to reflect on how natural history museums can contribute to the understanding and conservation of the planet and the sustainable management of its resources.

The SIMP Commission on Museums: a network for sharing and promoting museum activities

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Keywords: mineralogical and lithological museums, collection preservation and conservation, dissemination.

The Italian Society of Mineralogy and Petrology (SIMP) established the "Commissione Musei" (SIMP-MuseiCom) in 2019 with the aim of networking the mineralogical component of the Italian Natural History Museums and Universities and other public mineralogical collections. SIMP-MuseiCom aims to be a place for discussions and promotion of joint initiatives for the valorisation of the public mineralogical and lithological collections. Up to now, the SIMP-MuseiCom network has about 40 members. SIMP-MuseiCom's activities started with on-line meetings to present the situation of the public mineralogical collections from the network members and discuss problems and opportunities.

SIMP-MuseiCom is also acting to improve the accessibility, fruition and promotion of the mineralogical and lithological collections preserved in Italian museums through traditional and innovative means. Some examples are multi-sensory experimental geological laboratory @Museo dei Saperi e delle Mirabilia Siciliane, (UniCatania), production of a comics volume ("The Colors Issue" - Comics&Science) for the Exhibition "Il mondo a colori: uno sguardo su Arte, Pigmenti e Minerali" @MANU (Pg), photo exhibitions with guided tours for educational workshop @Andora(Ge), preparation of multimedial and 3D photogrammetric models of minerals @Milano. As part of the celebration for the International Year of Mineralogy, 2022, a national event "Gli zolfi italiani" was organised by SIMP-MuseiCom. The events took place in June 2022 with exhibitions, guided visits and videos by 15 Museums around Italy.

Among its many activities, SIMP-MuseiCom also promotes the accreditation of individual university museums to the National System of University Museums, with the aim of creating a structured network to manage collections according to common criteria. A focus on the catalogue activity following the ICCD (Istituto Centrale per il Catalogo e la Documentazione, Ministero della Cultura) catalographic standards is ongoing, and an online short course on the ICCD national standard for the cataloging of the geo-mineralogical heritage has been done.

In the future, new activities regarding curatorial aspects (e.g., collection preservation and conservation, digitalization and cataloguing, as well as dissemination activities) will be organised. Moreover, a second event involving Italian museum will be planned. Upcoming activities will be publicised by the SIMP mailing list and if someone working in the mineralogical collections is interesting to be part of the network, please send an email to simpmusei@gmail.com.

Development and valorization of the historical and modern mineral collections of the Department of Earth, Environment and Life Sciences (DISTAV), University of Genova

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Keywords: ligurian minerals, type locality, museum.

Liguria displays an outstanding mineral diversity despite its limited area (less than 5500 km^2), since currently 35 mineral species have their type locality (TL) in this region. Two thirds of them have been found in the renowned manganese deposits of Val Graveglia and Cerchiara mine, often representing unique findings. Such a valuable heritage has been preserved in the historical and modern mineral collections of the Department of Earth, Environment and Life Sciences (DISTAV) of the University of Genoa, whose first nucleus dates back to the beginning of the XIX century thanks to the effort of the naturalist Domenico Viviani (1772-1840). The historical collections then increased significantly during the XX century mostly due to the monumental work of Arturo Issel (1842-1922), who became the Director of the Museum of Mineralogy and Geology of the University of Genoa and fostered a dense network of scientific and didactical interactions. After that, a number of eminent mineralogists, such as Gabriele Lincio (1874-1938) and Alberto Pelloux (1868-1948), continued the development of the mineral collections by enhancing its quality and diversity. The modern part of the DISTAV mineral collections was built during the 1960s and 1970s by virtue of the fruitful collaboration between the academic community and keen-eyed amateur mineralogists, like Paolo Onofrio Tiragallo (1905-1987), to whom was dedicated a new mineral species found in the Mn ores of Val Graveglia (tiragalloite, IMA1979-061). The recent acquisition of important local mineral collections generously donated by both private citizens and eminent scholars, like Angelo Stagnaro (1940-2018) and prof. Andrea Palenzona (b. 1935), further increased the scientific value of the collections due to the rarity and quality of some specimens. The historical and modern collections of the University of Genova academic museums will get a renovation and full digitalization in the framework of the project "Università degli Studi di Genova per la Cultura Scientifica (Unige-CS) – ricognizione sistematica, digitalizzazione e diffusione dei Beni Culturali dell'Ateneo genovese", Bando Diffusione della Cultura Scientifica (Cod. ACPR20_00227), funded by the Ministero dell'Università e della Ricerca (MUR).

An "enlightened" museum of Nature, Art and Science. Rediscovering Specola 250 years after its foundation

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Keywords: La Specola museum, 250 years, new museological project.

On February 21, 1775, Grand Duke Peter Leopold of Lorraine inaugurated, in the ancient Bini-Torrigiani palace in Via Romana in Florence, the Imperial and Royal Museum of Physics and Natural History, probably the first scientific-naturalistic museum open to the public.

The Grand Duke of Lorraine did not limit himself to welcoming the heritage of art, science and culture collected by the Medici over three centuries. As a convinced Enlightenment thinker, he immediately understood the importance that these collections, especially those of a scientific nature, could have for the education of his people, It was an unprecedented operation: his museum was literally the "Museum of Nature" because, as its first director Felice Fontana wrote, nature was represented in it as a whole, "from earth to sky", with the establishment of the first Florentine astronomical observatory, (i.e., the Specola), on the top of the Palace. The purpose was "to enlighten his people and make them happy by making them more cultured", and in fact the museum was open to everyone "as long as they were cleanly dressed". Thus, at the end of the eighteenth century, a museum was born for the cultural growth of the people, thus anticipating by almost 250 years the Faro Convention of the Council of Europe on the value of cultural heritage for society and the contemporary concept of "museum" as an institution at the service of society, open to the public, accessible and inclusive.

After more than four years of structural work and refurbishment, the Specola Museum reopened its doors to the public on February 22, 2024. After almost a century and a half away, the mineralogical collections return to the Specola with a new exhibition itinerary that develops in four large monumental rooms. The museological project and the museographic arrangement of the collections intended to ideally reconnect with the conceptual framework of Peter Leopold's museum. A special section of the exhibition is dedicated to illustrating some of the infinite applications of minerals for the satisfaction of the needs of our society, with particular emphasis on the indispensable need for ethically and socially sustainable exploitation.

The specimens exhibited here are only a very modest fraction (about 1200) of the more than 50,000 specimens that the Museum preserves, a priceless heritage that the Florentine mineralogical tradition has been able to put together and preserve for over five centuries.

On the preservation and the availability of holotype minerals

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Keywords: holotypes, IMA-CM, IMA-CNMNC.

Since its foundation in 1958, the International Mineralogical Association (IMA) takes care about the preservation of holotype minerals, namely the sample on which the first description of a given species has been carried out. Among the guidelines for the approval of new mineral species set up by the IMA Commission on New Minerals, Nomenclature and Classification (CNMNC), it is explicitly stated that the holotype must be deposited in a public institution, typically a museum, with a catalogue number assigned, and made forever available upon request for possible later re-examination.

This is a relevant piece of information concerning new mineral species: for this reason the name and address of the public institution, as well as the catalogue number, are mentioned in the CNMNC Newsletters, which are the first public testimony of all new minerals approved each month.

The good practice of conservation in public collections of mineralogical samples which were the subject of analytical studies by far precedes the birth of IMA. Nowadays mineralogical museums are plenty of historical samples, dating back to the 19th Century and even older.

The IMA Commission on Museums (CM) maintains the Catalogue of Type Mineral Specimens (CTMS). More precisely, this is a joint effort by the CNMNC, which manages the official IMA List of Minerals, and the CM, through a dedicated Subcommittee. For recent minerals the designation of type material is straight, as it occurs at the time of the approval. For those mineral species which have been known since before the IMA era, the so-called grandfathered minerals, the recognition of the holotype material is made by searching literature data and based upon time priority. In some rare cases, holotype material may be no longer available, therefore a neotype may be defined. Neotypes should be sampled whenever possible at the same locality of the original material.

Statistics on the designed type material for all valid species and on the museums in which they are preserved will be provided.

For the years 2023 and 2024, updating the CTMS, which is largely carried out on a voluntary basis, will receive partial funding from the Swiss Academy of Sciences as part of the SwissCollNet project SCN201-VD, a national initiative for digitisation of natural history collections. The CTMS is available online: www.ctms-jack.ch

Interactive exhibits, gamification and digital storytelling in Scientific Museums: the case of MUGEPA in Rotonda

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Keywords: storytelling, virtual reality, serious games.

Through digital transformation, museums can evolve from traditional repositories of artefacts to dynamic environments where individuals can actively engage and enhance their knowledge through discovery and self-challenge. In this regard, leveraging digital technologies and storytelling serves as an effective means to communicate ideas and beliefs, allowing visitors to immerse themselves in history and science through narratives that facilitate the creation of meaningful memories (Barbieri et al., 2017). Furthermore, digital technologies can help to enhance museum accessibility, embracing a wider audience.

With this goal in mind, the Geo-Paleontological and Archaeological Museum (MUGEPA) in Rotonda has undergone a complete revamp in its educational, cultural, and scientific offerings. This entailed a redesign of the exhibition display in terms of architectural layout and scientific content, as well as the implementation of several multimedia installations involving computer graphics, virtual reality (VR), digital storytelling, and serious games. The overarching aim was to seamlessly merge physical and digital content into a unique exhibition that guides visitors through the scientific, geological, paleontological, and archaeological richness of the Mercure's valley. The paleoenvironment is a perfect example, as it has been created from scientific content using the photobashing technique. It was then printed on a physical support and installed near to the remains of the animals.

The multimedia exhibits have been designed and developed using a multidisciplinary approach, combining scientific, creative, and artistic visions into interactive and educational experiences.

One of the most challenging tasks was to design and implement interactive experiences that catered to the needs of younger audiences, both in terms of content and languages used. In particular, two different multimedia applications were developed. The first is a VR experience wherein participants are immersed in a futuristic lab, tasked with solving a 3D puzzle to reconstruct the skeletons of the straight-tusked elephant (*Palaeoloxodon antiquus*), the Hundsheim rhinoceros (*Stephanorhinus hundsheimensis*), and the hippopotamus (*Hippopotamus antiquus*) (Palombo et al., 2024). The second application consists of a collection of 3 mini-games (namely a visual quiz, a puzzle game, and a simulation of a paleontological excavation) that can be accessed via tablets at the end of the museum visit.

Moreover, interactive experiences were designed and developed for the general audience, including a VR application that provides visitors with a virtual walkthrough of the Middle Pleistocene landscape of the valley, completed with reconstructed and animated 3D animals. Additionally, a touch-screen table offers users access to 3D models of animal remains, additional content, and insights. Lastly, a mobile application will assist all users during their visit by providing a multimedia audio guide.

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Enhancing the accessibility of the Herbaria of the University of Florence by reducing mercury contamination due to historical conservation treatments

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Keywords: natural history museums, mercury pollution, biodiversity.

The Herbaria of Natural History Museums preserve exsiccated plant specimens gathered from different parts of the world over the centuries and act as a source of invaluable importance for biodiversity studies. However, access to these repositories of dried plants is partially hindered by the past use of the corrosive sublimate, a highly toxic solution of mercury dichloride (HgCl2HgCl_2) employed worldwide as a pesticide to preserve the collections. The reduction of the Hg2+Hg^{2+}of HgCl2HgCl_2 to Hg0Hg^0 has led to the contamination of the herbaria halls (e.g. Briggs et al., 1983). In the Herbarium of the University of Florence (Italy), both gaseous elemental mercury (GEM) and particulate Hg are present in the halls and in the historical wooden cabinets where the plant samples are stored (Ciani et al., 2024). The present project aims to reduce the Hg contamination at the Herbaria of the University of Florence, which are among the largest and most ancient worldwide, to favour the fruition of the collections for both research and dissemination purposes. In this framework, a purpose-made steady-state flux chamber was set up and connected with a Lumex RA-915M analyzer to determine the GEM degassing rate from both a herbarium sample (dry plant + paper support sheet) and a wooden support. GEM fluxes (ng m-2h-1ng m^{-2}h^{-1}) were calculated following Floreani et al. (2023) and measurements were repeated at different relative humidity (RH) conditions to check the influence of this parameter on GEM emissions. RH was varied by inserting water-filled containers (wet conditions) or silica gel (dry conditions) in the flux chamber and monitored with a datalogger in continuum during the experiment. GEM fluxes at the RH typically detected in the herbarium (c. 60% RH) showed average values of 18±4 n gh-2h-1ng h^{-2} h^{-1} for the herbarium sample and of 17±1 n gh-2h-1ng h^{-2} h^{-1}for the wooden tablet. The RH increase (to c. 80% RH), led to a strong increase in the GEM fluxes (to c. 100 ng h-2h-1ng h^{-2} h^{-1} for the wood support and c. 1000 ng h-2h-1ng h^{-2} h^{-1} for the herbarium sample). On the contrary, drying the sample (to c. 30-40% RH) the GEM emissions dropped significantly down (herbarium sample: 8±2 ng h-2h-1ng h^{-2} h^{-1}; wood support: 1±0.3 ng h-2h-1ng h^{-2} h^{-1}). The present work confirmed that both herbarium samples and museum wooden cabinets are currently releasing GEM in the museum halls and allowed us to quantify the contribution of both sources. Moreover, a prominent role of relative humidity in the release of GEM was highlighted by these tests. These results suggest that both a decontamination treatment of the cabinets and the optimization of the indoor climatic conditions can help in minimizing the Hg pollution of the University of Florence Herbaria and, thus, favouring the fruition of their remarkable collections.

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From a XIX century museum to a 3D digital experience: the challenges of making a geological museum appealing to modern audience

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Keywords: historical museum, digitization, virtual reality.

The Geological Collection "Giovanni Capellini Museum" officially opened to the public in 1881 during the Second International Geological Congress hosted in Bologna, and at the time was the major geological museum in Italy. The geological and paleontological specimens currently on exhibition have been collected since the XVI century and represent one of the oldest and richest geological collections in Europe. Wood cabinets date back to the mid XIX century and are still on display today, making the collection fascinating, but very difficult to read for a modern audience.

In 2023, the Collection was identified as a case study for the PNRR Spoke 4 "Virtual technologies for museums and art collections". Among other targets, the project aims to investigate how a digitalized cultural heritage can improve the comprehension and narrative of museums. Although outcomes are expected by mid-2025, here we want to share our ideas on how technology can aid a geological museum narrative and how virtual reality, augmented reality, gamification, 3D models and video storytelling can expand the current space-time perception of geology among general audience and people with disabilities. Our main goal is to expand the knowledge and narratives by recreating objects and even localities that no longer exist, fostering citizens participation and social inclusion and bringing inside the museum people that usually do not attend such institution, with a particular focus on teenagers and young adults, an audience familiar with technology, but not so interested in museums.

The Arab-Norman itinerary stones: where geological history meets the local artistic heritage

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Keywords: scientific collection, exhibition, education.

The role of scientific museums in disseminating Earth Sciences is a basic requirement for enhancing public awareness on natural conservation and protection. Especially natural history museums educate visitors by showing the wonders of ancient organisms, ecosystems and environments. The link between the geological history of an area and its urban monumental and artistic heritage is largely overlooked, though it should be well within its educational mission. The Geological G.G. Gemmellaro Museum has recently acquired the "Sicilian Marbles" and the "Sicilian Petrographic Collection". These are historical rock collections, the second one coming from G.G. Gemmellaro's research, aimed at the production of the first Sicily Geological Map. The "marbles" are exhibited following their own compositional and chromatic differences, with the blatant indication to their use in the Arab-Norman itinerary architecture (two palaces, three churches, a cathedral and a bridge in Palermo and the Cathedral Churches of Cefalú and Monreale), which is UNESCO World Heritage. The monumental and artistic heritage of a territory mirrors the geological history itself, through the use of materials they are built with. Architecture, geology and history are merged, as starting point for a multidisciplinary approach to citizen science, scholastic and touristic activities, especially for high schools (PCTO).

A dual approach to enhance the Targioni Tozzetti collection, a little-known mineralogical heritage: digital and analytical methods

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Keywords: museum collection, mineralogical analysis, digitalization.

After approximately 20 years since the project that digitized 4500 documents and estimated 2687 surviving specimens (Cipriani & Scarpellini, 2007), the litho-mineralogical collection of Giovanni Targioni Tozzetti (1712-1798) has once again become the subject of study.

The collection is not solely composed of what we would consider minerals today, but it illustrates lithic materials in various manifestations. The collection follows the Linnaean logic that distinguishes nature among Animal, Vegetable and Mineral (Lapideum) Kingdom, placing itself in the latter. Giovanni not only gathers minerals and rocks, which constitute the most abundant specimens, but also shells and fossils. Furthermore, embodying the spirit of the experimental scientist in service of the nation, he collects samples during his territorial research aimed at discovering raw materials useful for the technological development of the Grand Duchy of Tuscany and provides information on origins, suppliers, and uses of different materials. The samples are document of the exploitation of ore deposits, lithic samples for construction, along with objects that testify the use of different materials (e.g., an armed magnet, made of magnetite), etc. Moreover, although the concept of a collection as a gathering for wonder and aesthetic contemplation had been surpassed, the separation between scientific and artistic value was not yet fully accomplished, hence there are also valuable artifacts such as worked stones or a lithic head of Etruscan manufacture.

To preserve, enhance, and transmit to future generations the values and the data contained in this 18th century document of scientific and technological relevance, a dual approach has been taken.

Firstly, 287 artifacts were inventoried (~11% of the total), among which 154 were catalogued following ICCD criteria. Consequently, 109 BNM (Beni Naturalistici-Mineralogia), 39 BNPE (Beni Naturalistici–Petrologia), 1 BNZ (Beni Naturalistici–Zoologia), and 5 PST (Patrimonio scientifico e tecnologico) cards were produced, accompanied by high-resolution images. The project is part of the Tuscany Region's program which has led to the creation of an online portal dedicated to the digital fruition of Tuscan heritage.

Simultaneously, an analytical campaign aimed at the correct mineralogical attribution of various specimens and a survey of their places of origin is underway. Specifically, 67 gems, both rough and cut, were analysed with optical microscope and μ-Raman to identify their mineral species (Fabrizi et al., 2023). In addition, 8 massive samples containing metallic minerals catalogued as "Stannum" and 11 as "Plumbum" underwent to optical microscope and SEM-EDS analysis for identifying the paragenesis and compare it with the deposits of origin.

Some noteworthy pieces have been identified during these studies and exhibited for the first time in the new exhibition dedicated to mineralogy, at the "La Specola" museum of the University of Florence Museum System.

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Fabrizi L. et al. (2023) - La collezione mineralogica Targioni-Tozzetti del Museo di Storia Naturale dell'Università di Firenze: indagini e approfondimenti su una raccolta naturalistica settecentesca, Museologia Scientifica Memorie (23/2024), 79-83, ISBN 978-88-908819-7-8.

Stories for the future. The cataloging of the Italian geo-mineralogical heritage

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Keywords: cataloging, museum collection, astromaterial curation.

The Italian geo-mineralogical heritage, a treasure trove of our national geological history and geoscientific cultural knowledge, is primarily housed in natural history museums. The preservation, study, and valorization of this unique resource, which stands as irreplaceable evidence of our past, is a shared responsibility of scientists and museologists. It is imperative that they unite under common standards and practices to ensure its preservation and accessibility for scholars and the general public for the years to come.

This research is designed to present the current state of Italian geo-mineralogical heritage cataloging according to the ministerial catalographic standards issued by the Istituto Centrale per il Catalogo e la Documentazione (ICCD). The data for this study are sourced from the Catalogo Generale dei Beni Culturali website (Veninata, 2020), a database managed by the Ministry of Culture that provides open access to cataloging records on the entire Italian cultural heritage. The analysis focuses on mineralogical and petrographic specimens cataloged according to the BN-M and BN-PE national standards (Pratesi & Franza, 2021), as well as meteorite collections cataloged using the BN-PL standard (Franza et al., 2022). This review will demonstrate the active involvement of natural history museums in the national cataloging system and the implications for advancing museum studies and scientific knowledge. Specifically, it will delve into the role of cataloging meteorite specimens according to the BN-PL national standard in the advanced curation of astromaterials, an interdisciplinary and cutting-edge field of research to improve curation practices (e.g., sample handling, cataloging, characterization, distribution, and valorization) in the existing collections and for future sample return activities (e.g., McCubbin et al., 2019).

In conclusion, this work will highlight how cataloging the Italian geo-mineralogical heritage according to the ICCD national standards represents an effective strategy for correctly preserving and valorizing the Italian geo-mineralogical heritage kept in natural history museums from a scientific, juridical, and managerial perspective. These cataloging procedures also enable diverse audiences to improve their awareness and understanding of the Italian geo-mineralogical heritage along with past, present, and future challenges and opportunities for geoscience research.

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McCubbin F. et al. (2019) - Advanced curation of astromaterials for planetary science. Space Sci. Rev., 215, 1–81, https://doi.org/10.1007/s11214-019-0615-9.

Pratesi G. & Franza A. (2021) - Mineralogical, petrological and planetological heritage. The (Italian) story so far. Rend. Fis. Acc. Lincei, 32, 95–116, https://doi.org/10.1007/s12210-020-00970-2.

Veninata C. (2020) - Dal Catalogo generale dei beni culturali al knowledge graph del patrimonio culturale italiano: Il progetto ArCo. DigItalia, 15(2), 43–56, https://doi.org/10.36181/digitalia-00013.

Taxonomic diversity of fossil vertebrates from the quaternary deposits of the Karst Pit of Cà Negra (Croatia)

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Keywords: Cà Negra, paleofauna, paleoenvironment.

In 1932, quarrying operations in an chalk quarry named Cà Negra (in the Gulf of Piran, Croazia), revealed a karst sinkhole containing countless fossil specimens of macro- and micromammals. About 20,000 fossil specimens were collected and initially classified by Franco Anelli, a speleologist who was working on Italian Cave Registry. His studies were interrupted in 1939 due to the outbreak of World War II. Carefully packed in newspapers, the specimens were sent to Bologna, where they remained unstudied to these days. Along with these specimens, also their packaging made of newspaper sheets and the correspondence of letters between Professor Michele Gortani and Franco Anelli provided a significant amount of historical information that enriched the museum's collection. As the site is no longer accessible due to massive quarrying activities, data housed in Bologna represent a pivotal tool to infer palaeobiological data from this unique Quaternary site.

The Cà Negra sinkhole was 15 meters deep, an horizontal stratification revealing five distinct levels based on filling type could be distinguished, two of which bearing the majority of fossil remains. In addition to typical carnivores, large herbivores, and micromammals, non-mammalian microvertebrates such as amphibians (Bufonidae), reptiles (Lacertidae), fish (Esocidae), and birds (Corvidae) have also been identified. A comparison of the fauna identified at Cà Negra with other karst fossil deposits in the Istrian peninsula has revealed some fundamental differences, thus adding an unusual dimension to the site biodiversity. These differences consist in the absence of proboscideans, the presence of non-mammalian microvertebrates and the presence of the gastropod Pomatias elegans, a good palaeoenvironment indicator.

Furthermore, of particular interest is the discovery of human remains, along with signs of manipulation such as cutmarks and fractured or burnt bones. These fossil specimens suggest direct involvement of Homo in the Quaternary ecosystem, opening new perspectives on his relationship with local fauna and evolutionary dynamics of the period.

The cataloguing of the scientific instruments of the University of Catania: research and prospects

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Keywords: cataloguing, university museums, scientific heritage.

Long mistreated, the scientific and technological heritage in Italy has obtained the recognition of 'cultural heritage' only since 1999 with the Testo Unico on the legislative provisions on cultural and environmental heritage and then, officially, with the Code of Cultural Heritage and Landscape since 2004 (Canadelli, 2019). Thanks to its qualities, this heritage is transversal and allows multiple stories to be told, not only the one of the individual artefact, but also that of the collection that hosts it, of the scientists who used it and more generally of the evolution of science. In order to adequately protect and enhance scientific heritage, it is necessary to start from a solid knowledge of it; therefore, it was necessary to adapt the regulations on cataloguing for it too, through a specific standard sheet drawn up by the Central Institute for Catalogue and Documentation (Vannozzi, 2014; Ferrante, 2018).

Aware of the importance of cataloguing as the first and fundamental step for a correct enhancement of the heritage, in recent years the University Museum System of the University of Catania has launched an impressive cataloguing campaign of the movable heritage kept in its various locations. Among these, within the PhD research project entitled "Cataloguing and enhancement of scientific instruments of historical interest of the University of Catania", financed by Sicilian region, more than 520 scientific instruments were registered, of which 93 pertaining to the Collection of minero-petrographic, geophysical, and geochemical measuring instruments (scientific responsible: professor Rosolino Cirrincione) present within the Museum of Mineralogy, Petrography and Volcanology, 309 to the Collection of ancient physics instruments (scientific responsible: professor Elena Geraci), 34 to the Museo dei Saperi e delle Mirabilia siciliane (scientific responsible: professor Germana Barone), 18 to the Museo della Fabbrica (scientific responsible: professor Federica Santagati), 26 to the science centre Città della Scienza (scientific responsible: professor Alessia Tricomi) and 40 to the Museo di Anatomia (scientific responsible: professor Velia D'Agata). This intervention therefore aims to illustrate the work carried out during the compilation of these technical data sheets, highlighting the methodology used, the conservation issues and the results obtained. Starting from this work, a reflection will also be conducted on how this activity can help improve the use of the instruments, seen both in their nature as museum items and as tools especially in relation to the geological and mineralogical samples present therein.

Canadelli E. (2019) - Il patrimonio storico-scientifico italiano: alcune riflessioni tra passato e presente. Museologia Scientifica Memorie, 20, 16-19.

Ferrante F. (2018) - Normativa PST- Patrimonio Scientifico e Tecnologico. Versione 4.00. Istituto Centrale per il Catalogo e la Documentazione, Roma, 186 pp.

Vannozzi F. (2014) - Catalogare il patrimonio scientifico e tecnologico: da SIC a STS a PST, storia di un percorso (e di una collaborazione). In: Pratesi G., Vannozzi F. (Eds), I valori del museo. Politiche di indirizzo e strategie di gestione, Franco Angeli, Milano, 98-101.

The Angelo Da Costa mineral collection: a new acquisition of the Natural History Museum of the University of Pisa

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Keywords: Angelo Da Costa collection, mineral acquisition, mineralogical museum.

The mineralogical collections of the Natural History Museum of the University of Pisa consist of more than 25,000 specimens. Among them, mineral specimens from Tuscany are well represented, owing to the long-lasting interest of mineralogists of the Pisa University in sampling and studying mineral occurrences from this region. Over the last thirty years, the improvement of the Tuscan collection has continued thanks to the acquisition of specimens belonging to some renowned collections (e.g., Cerpelli Collection, 1999; Del Taglia Collection, 2015). Recently, a suite of mineral specimens belonging to the Angelo Da Costa collection were acquired (Mauro et al., 2023).

Angelo Da Costa (1940–2022) was one of the most important Tuscan mineral collectors. He was a curious explorer and an excellent mineral digger. He began to collect minerals in 1973. During his 50 years of collecting activity in several Tuscan localities (i.e., Apuan Alps, Monte Pisano, Campigliese, etc.), he discovered some new mineralogical localities and found outstanding specimens of minerals. A peculiar feature of the Angelo Da Costa mineral collection, composed by more than 600 samples, was that most of his specimens were self-collected (Lorenzoni & Dini, 2023). The Natural History Museum of the University of Pisa acquired a selection of 33 specimens. Among them, some aesthetic samples of quartz from some classic Tuscan localities, i.e., Apuan Alps, Monte Pisano, Campiglia Marittima, Val Castrucci, and Gavorrano. It is worth noting that, among them, there is also the sample of smoky quartz with baryte from the Pollone mine (Apuan Alps) exposed during the XVI General Meeting of the International Mineralogical Association which took place in Pisa in September 1994. Other interesting samples were representative of his findings of hematite crystals from Gorfigliano (Apuan Alps) and of goethite after iron carbonates from the Monte Pisano, as well as other classic findings, such as arsenopyrite, allanite-(Ce), and fluorite from the Botro ai Marmi area (Campiglia Marittima) and aurichalcite from the Buche al Ferro, still in the Campigliese region. This suite of the Da Costa specimens is a further addition to the mineral collection of the Natural History Museum, but it also honours the memory of Angelo Da Costa and his passion for mineralogy, hoping that his life and his specimens may be a source of inspiration for the future generation of geoscientists.

Lorenzoni M. & Dini A. (2023) - Angelo Da Costa - Un pioniere del moderno collezionismo mineralogico in Toscana. Rivista Mineralogica Italiana, 47(1), 8-14.

Mauro D. et al. (2023) - La collezione Da Costa - I campioni acquisiti dal Museo di Storia Naturale dell'Università di Pisa. Rivista Mineralogica Italiana, 47(1), 16-33.

The mineralogical collections at the Earth's Science Department, University of Milano: history, conservation, digitization, and valorization

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Keywords: minerals, collection, history.

The Museo delle collezioni mineralogiche, gemmologiche, petrografiche e giacimentologiche at the University of Milano has a rich history dating back to 1939 when Professor Emanuele Grill acquired the prestigious collection of Ing. Eugenio Bazzi. Over the years, under the direction of Professor Giuseppe Schiavinato, the collections expanded significantly through donations, acquisitions, and contributions from the Institute's personnel. Noteworthy additions include the Sala dei Minerali delle Alpi, dedicated to Ing. Magistretti, and a collection of mineral deposits curated by Professor Dino di Colbertaldo.

Currently, the museum houses over 30,000 specimens, including minerals, gemstones, and rocks, displayed across showcases and corridors. Notable exhibitions include the prestigious demantoide samples from Luigi Magistretti collections, as well as notable hystorical specimens from Baveno and other alpine localities. The museum also preserves historical analytical instruments, archival material, and educational resources.

Ongoing efforts focus on updating and digitizing the inventory, alongside the creation of multimedia materials. Conservation activities involve assessing the overall condition of specimens, with some undergoing restoration processes to enhance their display quality. The collections serve educational, scientific, and public engagement purposes, including teacher training and outreach activities with primary and secondary schools. Recognized as a Museal Collection by the University in 2004, the museum plays a vital role in preserving and disseminating scientific and cultural heritage.

Museums for the development of inclusive education practices: a case study in the Earth Sciences Museum - University of Bari Aldo Moro

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Keywords: museum, accessibility, inclusion.

The social role that museums play in the global community constitutes a distinctive element of contemporaneity, assuming the relevant role of intermediary between culture, well-being and inclusion. The need therefore emerges for heritage mediation paths in a multi-dimensional key (physical, but also social, cognitive, sensorial-perceptive, emotional etc.) to encourage participation and awareness of its value by all citizens, through the widest accessibility to its contents. Accessibility to cultural heritage has long been a topic of great interest for the Università degli Studi di Bari (UniBa), implemented in particular thanks to SIMA (Sistema Museale di Ateneo). This following the indications of the Convention for rights for Persons with Disability (ONU, 2006, art. 30) which recognizes their right to participate to cultural life, by enjoying access to places for cultural performances or services, such as the museums.This research work starts from the synergy created between different professional figures within the scope of the UniBa transversal skills course "NO ONE EXCLUDED: from university classrooms to inclusive cultural and museum fruition" held at Earth Science and Geo-environmental Dep. and at the Earth Sciences Museum at the beginning of the current year. A new collaboration between some geologist and naturalist researchers and experts in scientific museology already engaged for years on this front with psychologists and pedagogists has been started in order to propose a holistic approach to museum fruition of indoors and outdoors itineraries. The educational activities through frontal teaching and laboratory group works were aimed at: i) provide an overview of the main SLD (Specific Learning Disorders) and forms of disability; ii) deal with the topic of inclusion with an operational approach; iii) enhance the adaptive capabilities of people with SLD/disabilities by enhancing their individual resources; iiii) raise awareness among all participants of a broader concept of "active citizenship". The laboratory activities carried out at the UniBa Earth Sciences Museum, allowed the participants to benefit from inclusive museum itineraries, such as "Museums in the Dark" in the Geological-Paleontological Section (through the use of 3D technologies for the prototyping of fossil samples made fully accessible to video impaired people; Francescangeli & Monno, 2010; 2011; Montenegro, 2024) and "Aural Structures" in the Mineralogical-Petrographic Section (through two sonification cabins in which it will be possible to "listen" to the symmetries of the crystals; Monno et al., 2024).The active involvement of young people and adults with sensory disabilities (blindness and hearing loss) and autism spectrum disorders coupled with the attention to their specific needs allowed participants to gain real experience of good practices for accessibility and inclusion.

Francescangeli R. & Monno A. (2010) - Il Museo di Scienze della Terra dell'Università di Bari Aldo Moro. In: Pegorari L.M. (FaLvision Editore), Museo al buio. Sperimentazioni didattico-museali per i videolesi, 7-39, ISBN:978-88-96931-08-0.

Francescangeli R. & Monno A. (2011) - Le tecnologie 3D per la comunicazione nei musei scientifici: l'esperienza del Museo di Scienze della Terra dell'Università di Bari. Museologia Scientifica 8, 86-88, ISSN:1123-265X.

Monno A. et al. (2024) - Sonificazioni delle strutture cristalline per la didattica museale. Museologia Scientifica, 162-166, ISBN 978-88-908819-7-8.

Montenegro V. (2024) - Speciali visite guidate presso i musei di scienze naturali dell'Università degli Studi di Bari. Museologia Scientifica Memorie, 23, 132-135, ISBN 978-88-908819-7-8.

From the past to the future: the new exhibition of the Mineralogical collection of the Florence University Natural History Museum and its relocation to the "La Specola"

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Keywords: mineralogy, Medici collection, "La Specola" museum.

The Mineralogy and Lithology Collection of the Florence University Natural History Museum represents, in terms of origin, quantity and quality of the specimens owned, one the most important mineralogical collections in Italy. (Pratesi, 2012). It is enough to remember how the "Imperiale e Regio Museo di Fisica e Storia Naturale di Firenze", inaugurated in 1775 and from which the present Museum originates was the first naturalistic museum open to the public in Europe. In the museum, a central role was assigned to the mineralogical collections which reflected not only the scientific interests of the Grand Duke itself, but also the ever-increasing importance assigned to the study of minerals (Cipriani, 2011). Its relocation within the La Specola Museum represented therefore a considerable challenge from a museologic and museographic point of view, that was overcome through an approach respectful of the characteristics of the other parts of the Specola complex (Moggi Cecchi et al., 2022). The exhibition itinerary starts with a fascinating environment in which the visitor is totally projected into a "spatial" context in which specimens of meteorites are exhibited, to remember the origins of the Earth. It continues with showcases dedicated to the development of our planet - observed from a geological point of view - during its 4.5 billion years of life. A connecting room illustrates some old instruments and the scientific figures that have characterizing the history of mineralogy at the "La Specola" museum. In the next room the fundamental concepts of the general mineralogy are presented, starting from the evolution and differentiation of terrestrial rocks and going on with the concepts of crystal growth, habit, polymorphism and isomorphism, the basic principles of crystallography and the physical properties of minerals. The systematic collection is also exhibited in the same room. Another connecting room displays the exceptional tourmaline specimens from Minas Gerais, Brasil, belonging to the former Ponis Collection and the unique pink morganite crystals, flagships of this collection. In this room are also exhibited the huge beryl and topaz specimens, well known as amazing masterpieces of the Museum. The path continues with the exhibition of the carved stones belonging to the Medici Collection and of the precious stones, with a showroom that presents many references to the historicity of the samples on display. The next room is dedicated to the exhibition of the mineralogical regional collections, first of all the worldwide famous Elban collection, with its extraordinary polychromatic tourmaline specimens and the huge ilvaite aggregate of crystals, considered one of the largest in the world. A corner of this room is dedicated to fluorescent minerals glowing in the dark. The final part of the itinerary is dedicated to the exploitation of mineral resources and the consequences of this human activity from a social and environmental point of view.

Cipriani C. (2011) - Le collezioni mineralogiche del Museo di Storia Naturale dell'Università di Firenze dalle origini a oggi. L.S. Olschki, Firenze. XVI-238 pp., https://www.olschki.it/libro/9788822260024.

Moggi Cecchi V. et al. (2022) - Nuove esperienze per nuovi pubblici: la nuova esposizione della collezione mineralogica del Museo "La Specola". Museologia Scientifica Memorie, N. 22/2022 pp. 148-152, https://www.anms.it/upload/rivistefiles/92a665a7875ad1fd8b22869f70741728.pdf.

Pratesi G. (2012) - Il Museo di Storia Naturale dell'Università degli Studi di Firenze. Le collezioni mineralogiche e litologiche. Firenze University Press, Firenze. 336 pp., https://books.fupress.com/catalogue/il-museo-di-storia-naturale-delluniversit-degli-studi-di-firenze-le-collezioni-mineralogiche-e-litol/2351.

The late Cenomanian Aigialosaur (Reptilia, Squamata) exposed in the Earth Science Museum of Bari University (Italy)

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Keywords: late Cenomanian Aigialosaur, Apulia platform limestones, Earth Science Museum of Bari university.

Remains of an upper Cenomanian reptile were found during 1995 on a limestone slab collected in the "Ruvo di Puglia" quarry district (Murge, SE Italy), and stored in the Earth Science Museum of Bari University (Italy). These remains correspond to the anterior half of a partially articulated skeleton of a squamate, and represent one of the few Mesozoic reptiles coming from the Apulia Carbonate Platform, part of the tethyan periadriatic domain. A multidisciplinary research, based on paleontological, stratigraphic, geochemical, and 3D methods, was performed on these remains. Geochemical components of bones, such as apatite, phosphate, and organic material residues, recognized through the use of UV contrast light, micro Raman spectrometry, and XPS laser ablation mass spectrometry, indicate that bone material is excellently preserved. Stratigraphy, microfacies analysis, and taphonomy suggest that the reptile body was non promptly buried when it was in a warm and protected shallow-marine environment. This datum agrees with data coming from several bones features, ascribable to a marine reptile living in a shallow sea. The 3D reconstruction highlighted the presence of both bones and natural casts profiles, and led us to obtain a virtual fossil. This helped to attribute the studied squamate remains to Aigialosauridae on the basis of : i) the cranium base structure, ii) the cervical and ventral vertebras shape, iii) the humerus and rib morphologies, and iv) the total body size.

The mineralogical and petrographic collections of the Regional Museum of Natural Sciences in Turin, Italy: a dazzling journey through the wonders of nature

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Keywords: historical, wonders, explorations.

The MRSN reopened to the public on January 12, 2024 after over a decade of closure due to an accident in the summer of 2013. Three halls in the newly designed layout: - the Historical Museum of Zoology, where naturalised specimens from historical collections of the the University of Turin are displayed; - the Ark of Explorations, an ideal route through past and present naturalistic journeys; - the Hall of Wonders, a careful selection of specimens and samples held in the museum's collections. The MRSN was established in 1978. Pursuant to a specific agreement, the museum acquired the zoological, mineralogical, petrographic and palaeontological collections of the University of Turin, being committed with preserving, studying and enhancing them. To mark the reopening to the public, the Department of Mineralogy and Petrography contributed to the setting up of the Hall of Wonders and the Ark of Exploration by selecting unique samples of aesthetic, scientific and historical value. The historical core of the collections comes from the Museum of Mineralogy and Petrography and the Museum of Geology and Palaeontology of the University of Turin. From 1980 to the present day, the Museum has developed its own collection to complement the university ones (which had not been enriched since the first half of the 20th century). More than 20000 aesthetically appealing minerals and rocks from the latest mineralogical discoveries worldwide have been acquired. The Hall of Wonders was set up by selecting samples with high visual impact, and emphasising the size, colour and morphology of the crystals. The history of the collections is recalled by the display of samples from the Traversella mines and the mineralogical sites of the Val d'Ala. The Ark of Explorations houses specimens and samples from scientific explorations carried out from the first half of the 1800s to the early 1900s. The 1836 exploration of Egypt of the engineer Carlo Boreani, who had been sent out in search of precious metals by the Italian Royal Household. General La Marmora's journeys to Sardinia. He donated three copies of its own collection of rocks to the Turin, Cagliari and Paris Museums. The Ruwenzori expedition carried out by the Duke of the Abruzzi in 1906. The 1899-1900 'Polar Star' expedition to the North Pole made it possible for the crew to reach a record latitude and for the Museum to acquire another 300 mineral and rock samples of outstanding scientific and historical value. The study of these samples made it possible to trace the geological structure of the remote regions reached by the expedition. An old granulite bears testimony to an orogenesis that occurred in those areas around 1.3 billion years ago.

A multi-sensory experimental laboratory for Earth Sciences at the Museum of Sicilian Knowledge and Mirabilia of the University of Catania

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Keywords: university museums, accessibility, Earth sciences.

The University of Catania, through the Sistema Museale d'Ateneo (SiMuA), is significantly committed to promoting initiatives that - by combining audience development and audience engagement strategies - favour not only an enhancement of its rich heritage, but also a greater involvement of different audiences in its cultural offer (Barone et al., 2023). The multisensory workshop to discover geology and mineralogy recounted in this abstract had a dual purpose: on the one hand, to bring young students in Catania closer to STEM subjects, towards which there is a growing disaffection, through an experimental approach (Scippo et al., 2020); on the other, to sensitise them to the theme of inclusivity by placing them on the side of less fortunate visitors, blind or visually impaired, who are used to enjoying collections through all the senses (Bollo et al., 2017; Da Milano & Gariboldi, 2019). Sicily, after all, is a geological laboratory in continuous evolution and with which the territory is in constant dialogue: the Museum of Sicilian Knowledge and Mirabilia's repertoire of samples is very extensive and consists mainly of minerals from Sicilian solfares, systematic mineralogy, Sicilian rocks, volcanology, with samples from Etna, the Aeolian Islands and the Vesuvian area, rocks used in construction and precious rocks, gems and ambers, all samples coming from the Museum of Mineralogy, Petrography and Volcanology at the same university. This vast repertoire also made it possible to explain historical events, settlements, economies, offering the possibility of a direct and highly educational experience. For the participants (students aged 9-11) this represented a new environment, never seen before, but also for those who had already experienced it, the museum was perceived as a place of growth and discovery. A stimulating process was therefore set in motion that involved obscuring the sense of sight and at the same time stimulating the sense of touch, thanks to the possibility of touching the specimens on display, as well as the sense of smell and taste for some specimens with specific peculiarities, following a common narrative line, born from the union of all the stories created by the working groups, specifically homologated from a lexical, syntactic and content point of view. These stimuli were then taken up, discussed, evaluated and used at school and included in an elaboration work that allowed knowledge and skills to be refined in order to connect them to other contexts and uses.

Barone G. et al. (2023) - Un approccio sperimentale multisensoriale per le Scienze della Terra. Museologia scientifica, 17, Firenze, 73-83, https://doi.org/10.53246/ANMS0037. ISSN 1123-265X.

Bollo A. et al. (2017) - Glossary. Study on Audience Development – How to place audiences at the centre of cultural organisations, Commissione Europea B-1049, Brussels, 1-9.

Da Milano C. & Gariboldi A. (2019) - Audience Development: mettere i pubblici al centro delle organizzazioni culturali, FrancoAngeli, Milano.

Scippo S. et al. (2020) - STEM disciplines teaching in Italy. Italian Journal of Educational Research, 25, 35-48.

Mèmora: a showcase for the cultural heritage of Piemonte Region

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Keywords: ornamental stones, Piemonte region, digital archive.

The Regional Museum of Natural Sciences of Turin (NW Italy) has created, since the end of the 20th century, a collection of stone materials of particular importance; the collection is represented by a petrotheque of natural materials, both raw and in slabs with various processes (polished, smoothed, bush-hammered, split, chiselled), coming from all over the world, but with the prevailing objective of representing the materials in the best possible way, of Italian or foreign origin, marketed on the national trade. This nucleus is also accompanied by a series of specimens of "extinct" rocks, materials whose quarries have been closed or have long been abandoned. The objective of the collection is to be able to provide specialized users (architects, engineers, researchers, historians, quarrymen and other operators in the sector) with a consultation, study and research tool for current lithotypes and, at the same time, to have a comparison for rocks no longer commercialized, but often still present in architectural works. Based on a collaboration developed over twenty years, the entire collection is available for consultation by the Department of Earth Sciences (DST) of the University of Turin for the mineralogical and petrographic study of stone materials. Recently, some historical stone materials from the Piemonte region have been selected and studied by the DST for an in-depth petrographic characterization and for their enhancement in the field of cultural heritage. The results of these studies are progressively included in the Mèmora catalogue. Mèmora is the tool used by the Piemonte Region for cataloging the cultural heritage, including naturalistic heritage. Mèmora consists of two components, Memora Back End which allows operators to catalogue and describe the heritage, and Memora Front End for the publication, consultation, fruition and use of data on the web. It describes the objects being catalogued in an integrated way using national descriptive standards (ICCD). Textual content can be accompanied by images, digital documents, audio and video and offers the possibility of geolocating and viewing resources on maps. The data can be exported in the most popular formats (XML, Excel, PDF etc.) guaranteeing high interoperability. The Mineralogy, Petrography and Geology section completed the data migration into the new application and began using it during 2021, also cataloguing the samples selected for the research project with the Department of Earth Sciences. Through Mèmora, by means of thematic insights, cultural heritage can also be read by a wide audience and not just specialists.

"Fauglia... un mare di anni fa": a new palaeontological exhibition and an example of valorization of the palaeontological heritage in the Fauglia Municipality (Pisa Province, Italy)

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Keywords: cultural heritage, museum, palaeontology.

The Lower Pleistocene sediments exposed at Montalto, near Fauglia (Pisa Province), have yielded a remarkable fossil assemblage, including an exquisitely preserved seagrass (*Posidonia oceanica*) meadow and an extensive coral (*Cladocora caespitosa*) bank, which on the whole provides valuable insights into the paleoenvironmental conditions and palaeodiversity of the Mediterranean Sea during the Calabrian age. The high diversity of the fossil assemblage (which includes pinnipeds, sharks, rays, bivalves, gastropods, barnacles, echinoids, corals, foraminifera and ostracods) and the many different fossilization styles observed at Montalto (which witnesses to a complex and peculiar diagenetic history) makes this locality much remarkable as well as worthy of conservation and valorization (Bosio et al., 2021). What is relevant here is that the main palaeontological outcrops at Montalto occur within a large quarried area that is not subject to any special protection measures, which means that the locality is bound to undergo progressive destruction due to quarrying activity. With the aim to showcase and give a platform to this threatened palaeontological heritage, a new palaeontological exhibition – "Fauglia... un mare di anni fa" – was established thanks to the collaboration between professional paleontologists of the University of Pisa, avocational paleontologists of the Gruppo AVIS Mineralogia e Paleontologia Scandicci (GAMPS) and the local Municipality. The long-term goal of this exhibition is to establish a site museum to provide a permanent home for many valuable fossils. By curating and exhibiting a good deal of representative specimens from the various different facies and taphofacies observed at Montalto, we hope to raise awareness on the natural heritage of the Fauglia area as well as on the urgent need for sustainable practices to safeguard these and other remarkable localities.

Bosio G. et al. (2021) - Exceptionally preserved coral bank and seagrass meadow from the lower Pleistocene of Fauglia (Tuscany, Italy). Alp. Mediterr. Quat., 34(2), 237-256.

Unveiling Earth' archives: harnessing Earth Science collections to navigate modern challenges

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Keywords: collections, data, standards.

Earth Science Collections, housed within European institutions, represent invaluable data repositories encompassing the Earth's formation, physical attributes, geosphere, atmosphere, and the evolution of all life. These collections offer profound insights into past extinction events and climate fluctuations that are key for comparing and predicting forthcoming environmental challenges as well as for deciphering their underlying causes. They are also essential to the development of sustainable resources. However, many of these resources remain untapped by researchers across diverse disciplines grappling with present-day sustainability, climate change, and biodiversity loss. The Earth Science Group (ESG) within the Consortium of European Taxonomic Facilities (CETAF) aims to promote the significance of these collections in enhancing our comprehension and prediction of the present environmental and biodiversity crisis. This talk showcases a selection of examples from CETAF member institutions where Earth Science Collections have played a pivotal role in advancing our understanding of hazards, resource management, climate shifts, and biodiversity decline. Moreover, it addresses the challenges inherent in integrating these collections into modern scientific frameworks and facilitating interdisciplinary collaboration. Efforts to enhance the accessibility and interoperability of Earth Science Collection data are underway through initiatives such as the Geoscience Collections Access Service (GeoCASe) portal, developed to promote universal online access to mineral, rock (including borehole cores), meteorite, and fossil specimens. Programmes such as DiSSCo will increase the level of specimen digitisation (MIDS level) and collaborative endeavors with organizations like the Biodiversity Information Standards (TDWG) aim to refine metadata standards for digitization and publication, fostering harmonized understanding and facilitating scientific research and collaboration on a global scale. Through these endeavors, Earth Science Collections emerge as reservoirs of invaluable data and as catalysts for multidisciplinary scientific advancement and international cooperation.

Falsification techniques and materials in Geoheritage

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Keywords: geological forgeries, μ-Raman, UV luminescence macro photography.

Natural geological samples have always exerted a deep fascination on human mind. The symmetry and optical properties of minerals and gemstones quickly attracted the attention of humans, inducing Homo Sapiens to transform these into amulets as well as pigments in wall paintings.

Hence, natural specimens should be considered as part of humankind cultural heritage because of their intrinsic aesthetic value as well as their contribution to expand hominids technical skills as well as their abstract thinking.

Such a geoheritage maieutic role needs to be strengthened nowadays, especially in light of the rapid environmental change we are experiencing now. In this context, one of the most important goals that the scientific community must fulfil is in promoting society's increased awareness of and comprehension of natural processes (Artioli, 2022).

Geological forgeries identification play a crucial role in educating people because they might incorrect information upon geological processes. Indeed, manufactured minerals are created as a way to be aesthetically attractive although they frequently haven't any geological consistency as for natural forming minerals remounted on incompatible matrices and crystals dyed with the aid of unnatural dyestuff (Calik et al., 2019).

For such a reason, we'll discuss some case studies involving dyed samples and original specimens that have been remounted on matrix from both contemporary and historical collections. We propose to combine the macroscopic investigation with microscopic and spectroscopic methods in order to positively identify counterfeiting and materials involved in the forgery. First of all, digital photos are taken exciting specimens at UV frequencies, in order to highlight potential inhomogeneity in the chemical composition. Subsequently, an exhaustive characterization by means of μ-Raman vibrational spectroscopy is conducted to thoroughly identify incompatible phases (Bernardino, 2016).

μ-Raman are favoured over alternative analytical methods because to its non-invasiveness, high specificity and versatility that allows to clearly detect both organic and inorganic, amorphous and crystalline compounds.

This macro-micro incorporated method allows us to undoubtedly discover the compounds utilized in counterfeiting the analysed samples. Moreover, it may be implemented domestically in Natural History Museums because of transportability capabilities and in situ appearing of those techniques, training people in faking minerals detection and in familiarizing with scientific methods.

Artioli G. (2022) - Authentication and the perception of fakes. forgeries of natural specimens. In: Salvadori M., Bernard E., Zamparo L., Baggio M. (Eds), Beyond forgery – Collecting, authentication and protection of cultural heritage, Antenor Quaderni 52, Padova University Press, Università degli Studi di Padova, 67-77, ISBN: 978-88-6938-292-5.

Bernardino N.D.E. et al. (2016) - Fake turquoises investigated by Raman microscopy. Forensic Sci. Int., 262, 196-200, https://doi.org/10.1016/j.forsciint.2016.03.041.

Calik A. et al. (2019) - Fake and Synthetic Minerals; A Way to Sustain the Gem Supply. In: Agnihotri, A., Reddy, K., Bansal, A. (Eds), Environmental Geotechnology. Lecture Notes in Civil Engineering , 31, Springer, Singapore, 319-328, https://doi.org/10.1007/978-981-13-7010-6_30.

Digitalization and reconstruction of Pleistocene vertebrates from Museo di Scienze della Terra (University of Bari Aldo Moro) for the valorization of the Apulian paleontological heritage and territory

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Keywords: digitalization, paleontology, Pleistocene.

The MuSTe (Museo di Scienze della Terra) of the University of Bari Aldo Moro houses a rich paleontological heritage which tells the history of our territory over geological time and testifies to the changes in biodiversity in relation to climate changes and natural processes . To enhance the exhibitions and involve a wider public in the natural history of the region, the University of Bari Aldo Moro, in collaboration with CETMA (European Research Center for Design Technologies and Materials), has carried out a project supported by the Apulia Region (POC Puglia FESR ESF 2014-2020-action 10.4), based on the use of digital technologies. In particular, the project was aimed at the digitization of two of the most important Pleistocene vertebrate fossils from Apulia housed at MuSTe: an almost complete fossil skeleton of Balaenoptera sp. and a Coelodonta antiquitatis partial skull. The two specimens were digitalized through photogrammetry and laser scanner, the missing parts of the skeletons were digitally reconstructed and then a scientifically accurate life-reconstruction was created through 3D graphic softwares. The models thus obtained were animated and inserted into digital dioramas, which include palaeoenvironmental reconstructions. Final digital diorams are aimed to be played or projected in a permanent exhibition. The present project represents the first step towards a progressive digitalization of the museum collections and updating of the MuSTe exhibitions which will hopefully be able to integrate other specimens from the museum collections in the future.

S7.

Vibrational spectroscopy studies of geomaterials: case studies and new perspectives

CONVENERS & CHAIRPERSONS

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Investigating corrosion systems in archaeological artifacts from Motya (Sicily, Italy): a micro-Raman spectroscopy and correlative imaging approach

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Keywords: micro-Raman spectroscopy, X-ray microscopy, corrosion.

Raman spectroscopy is a non-destructive technique which can provide a unique fingerprint of the corrosion products embedded within the patina of archaeological artifacts, leveraging molecular vibrational modes analysis. Its sensitivity and capability for discriminating between corrosion products make it a valuable tool, particularly due to its ability to delve into structural characterization at the microscale and produce qualitative phase distribution maps.

In this research, we employed micro-Raman spectroscopy in combination with correlative imaging techniques and imaging tomography to investigate corrosion phenomena in nails from the Phoenician-Punic site of Motya (Sicily, Italy). To accomplish this, we used correlative light and electron microscopy, micro-Raman spectroscopy, and X-ray microscopy. This approach involves the integration of complementary investigation techniques to perform multiscale and multimodal experiments, all focused on the same area of interest.

The aim of this study is to investigate the stratification of corrosion layers and the mechanism of transformation of Fe products formed under specific conditions that occurred in lagoon-like environment. Recognizing the spatial distribution and interconnectivity of mineral phases and cracks within corrosion layers was crucial for comprehending the corrosion process's evolution. The results showed remarkable differences in the condition of the nails and provided 3D imaging of the internal structures, revealing cracks and the original shape of the nails.

Archaeological mortars under IR light: application of IR spectroscopic techniques for the study of hydraulic Roman mortars

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Keywords: IR spectroscopy, ancient hydraulic mortars, geomaterials in cultural heritage.

The aim of this work is to apply different IR-based spectroscopic techniques for the study of mortars (Jordan et al., 2018), to evaluate pros and cons of each analytical procedure and the possibility to obtain an effective grouping of samples. The object of the study are ancient Roman mortars coming from hydric structures (mainly aqueducts and cisterns), which have been analyzed with thermogravimetric analysis (TGA) to assess their hydraulic nature. Thanks to the use of a multi-analytical approach which comprises optical microscopy (OM) scanning electron microscopy with microanalysis (SEM-EDS) and X-ray powder diffraction (XRPD), the characteristics of the aggregate (predominantly pozzolanic) and the binder have been inferred (Botticelli et al., 2021; Calzolari et al, 2023a; Calzolari et al., 2023b). Fourier-transform infrared spectroscopy (a) in attenuated total reflectance (ATR) and reflectance mode have been applied to evaluate the possibility of grouping mortars samples by PCA, checking the results by the comparison with the characterization obtained with OM, SEM-EDS, XRPD and TGA.

Botticelli M. et al. (2021) - Aqua Traiana, a Roman infrastructure embedded in the present: The mineralogical perspective. Minerals, 11(7), 703, https://doi.org/10.3390/min11070703.

Calzolari L. et al. (2023a) - Aqua Alexandrina and Fragole cistern: characterization of mortars from Roman constructions, Rome (Italy). Archaeol. Anthrop. Sci., 15(12), 183, https://doi.org/10.1007/s12520-023-01885-3.

Calzolari L. et al. (2023b) - Insights on the Mortars of Ancient Roman Aqueducts: Aqua Virgo and Aqueduct Y, Rome (Italy). Buildings, 14(1), 69, https://doi.org/10.3390/buildings14010069.

Jordán M. M. et al. (2018) - Mineralogical analysis of historical mortars by FTIR. Materials, 12(1), 55, https://doi.org/10.3390/ma12010055.

An Archaeometric Investigation to analyze some medieval rings from Cencelle (Tarquinia, VT)

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Keywords: spectroscopy, gems, archaeometry.

The city of Leopoli-Cencelle, founded by Pope Leo IV in 854 A.D., is located in the Tolfa Mountains in the territory of Tarquinia (Viterbo, Italy). Between the 12th and 13th centuries the city underwent a radical restructuring with an overall redesign of the "forma urbis" according to the dictates of the time. Cencelle represents a unique opportunity for the archaeological study of a medieval urban centre since, having its development stopped at that time without any other reuse during centuries, it can be investigated in its entirety (Stasolla et al., 2011; Somma, 2014).

The present research focuses on the analysis of 3 gem-set rings, which can be dated between the 13th and 15th centuries, and a cameo, dating from the Etruscan period with a subsequent reuse during the Middle Age. All these samples have been recovered from funerary contexts. Rings found as part of grave goods often serve as significant indicators of social status and personal identity. Indeed, items buried with the deceased frequently reflected their status and/or their role in society (Marshall, 1907; Pollio, 2018). In particular, the inclusion of precious materials, elaborate designs, or engraved symbols on the rings provides useful insights that offer important information about the social position of their owners. The aim of this study was to determinate the nature of the gems through a non-invasive and non-destructive multi-analytical approach that involved the use of Fourier Transform Infrared Spectroscopy (FTIR), Raman Spectroscopy and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS). The results of the archaeometric investigations have made it possible both to delineate some traits of their production processes, which is still poorly understood, and to obtain useful information to understand the social and gender differences that may have existed among the inhabitants of Cencelle.

Marshall F.H. (1907) - Catalogue of the Finger Rings, Greek, Etruscan, and Roman: In the Departments of Antiquities, British Museum, order of the Trustees.

Pollio T.N. (2018) - Ancient Rings: An Illustrated Collector's Guide. McFarland (eds.).

Somma M.C. (2014) - I cantieri di Cencelle: maestranze, materiali e tecniche. In Forma e vita di una città medievale: Leopoli-Cencelle. Fondazione Centro di Studi sull'alto medioevo. Spoleto, pp. 63-65.

Stasolla F.R. et al. (2011) - Materiali, tecniche costruttive e fonti di approvvigionamento a Leopoli-Cencelle. Risorse naturali e attività produttive: Ferento a confronto con altre realtà. Atti del II Convegno di Studi in memoria di Gabriella Maetzke (Viterbo, 27-28 aprile 2010), 299-340.

The Deposition by Raffaello: a rediscovery of old cross-sections through vibrational spectroscopies

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Keywords: Raffaello Sanzio, Raman, FTIR.

The Deposition, dated 1507 and located at the Borghese Gallery of Roma, represents one of the masterpieces by Raffaello Sanzio. This painting was subjected to a remarkable series of non-invasive diagnostic campaigns over the years (Miliani et al., 2007; Alberti et al., 2023), exploiting X-Ray Fluorescence, both in standard and mapping modes, UV-Visible Light Reflectance and mid-InfraRed Reflectance spectroscopies . The analytical results provided by these techniques allowed characterizing the palette of the Urbino Master in a totally non-invasive way, but some uncertainties about the compositions of the pigments remained unsolved. In 2020, the year celebrating the 500th anniversary of Raffaello Sanzio death, the altarpiece has been subjected to conservative revision and preventive conservation project: on this occasion, an in-depth study was conducted on cross sections prepared between 1966 and 1972, during an older restoration intervention conducted by the Istituto Centrale per il Restauro (ICR) (Ferrara et al., 1972). The ethical and sustainable choice of investigating stratigraphic sections from the 1960s was adopted because these represent a powerful documenting evidence of the original pictorial film and restoration repaintings before intervention of 1966-1972, in order to both reconstruct the conservation history of the painting and to achieve new information on the materials composition.

For the characterization of materials, with reference to the complexity of species hypothesized on the base of previous non-invasive analyses, a combination of vibrational techniques was applied, taking into account of the versatility and the informative power of these analytical methods for the identification of chemical species belonging to different classes. Fourier-Transformed InfraRed and Raman spectroscopies were exploited in different setups and methodologies, in order to provide a complete characterization of inorganic, organic and "hybrid" pigments. The presence of very fine-grained particles in the film and the low concentration of some species represented a challenge to respond through the coupling with microscopies and with the support of Scanning Electron Microscope with Energy Dispersive X-Ray analysis. The adopted multi-technical diagnostic approach has made it possible to recognize the pigments employed in the different pictorial layers, including those in traces and those based on organic materials, responding to open questions from previous investigations and deepening further aspects of Raffaello's palette and painting technique.

Alberti R. et al. (2023) - La Deposizione Baglioni: studio dei materiali attraverso le mappe di concentrazione degli elementi ottenute con la tecnica MA.XRF. In: M. Minozzi M. (Ed.), Raffaello nella Galleria Borghese. Nuove indagini e un progetto di conservazione programmata, Silvana Editoriale, 108-117, ISBN: 8836646050.

Ferrara L. et al. (1972) - Storia e restauro della Deposizione di Raffaello, Museo e Galleria Borghese, Roma.

Miliani C. et al. (2007) - The Deposizione Baglioni (1507), Non-Invasive Study of Raphael's Palette by Complementary Molecular Spectroscopic Techniques from X-Rays to the Near Infrared. In: Conference: Proceedings of the Workshop "Raphael Painting Technique: Working Practice before Rome", Volume: Quaderni di Kermes, Nardini Press (AGU), 107-112, ISBN-108840442928.

Raman spectroscopy reveals pigments on ancient Sicilian inscriptions

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Keywords: Raman spectroscopy, pigments, ancient epigraphy.

Within the interdisciplinary project "Crossreads: Text, materiality, and multiculturalism at the crossroads of the ancient Mediterranean" (https://crossreads.web.ox.ac.uk/), a full work package is dedicated to materials of ancient Sicilian inscriptions, alongside palaeography and linguistics, for the study of the epigraphic culture of the island (c. 5000 inscriptions). Within the project, detailed knowledge of the pigments used in epigraphy complements the ongoing characterization of the stone supports (including marble provenance), which will provide the first systematic account of the material aspects of epigraphic culture. Pioneering results are being obtained on polychromy through a multi-analytical approach, where Raman spectroscopy plays a dominant role.

The poor preservation of so-called rubrication is due to both the action of environmental factors and to human intervention, as inscriptions have been thoroughly cleaned to increase their readability and subjected to squeezing (i.e. applying pressure to damp paper applied to the surface to obtain a 3D reproduction of the text). This means that often the only traces of pigments are in the deepest part of the grooves, which makes focussing directly on the paint particularly challenging during in situ analyses. On the other hand, collection of minute samples by rubbing cotton swabs in the grooves of ancient inscriptions, or by gentle scraping with a scalpel has been allowed by museums and conservators. These samples are then brough to the laboratory for micro-spectroscopic analyses. X-rays fluorescence analyses are also being applied in situ to areas showing traces of colours, and the elemental information is considered for a full characterization of the pigments.

The most widely used colour in Greco-Roman epigraphy appears to be red, followed by blue and others, seemingly corresponding to the ancient palette used in sculpture and architecture. Pliny suggests the use of expensive minium (the mineral cinnabar, HgS) for painting letters, on walls, tombs and monuments. However, its occurrence is exceptional and related to specific contexts. The other reds used in antiquity (ochres and red lead Pb_3O_4) are also identified, with further details on iron oxides and oxyhydroxides (e.g. Fe_2O_3, FeOOH, Fe_3O_4) present in the mixture coming from Raman spectroscopy.

Although the identification of pigments, especially the red ones, is a straightforward task for Raman spectroscopy, it appears that the topic has not been explored in a systematic way. The possibility of obtaining precise mineralogical information on pigments provides interesting information on many aspects of manufacturing of ancient inscriptions, such as the choice of expensive vs. readily available pigments and the use of mixtures, chronological or local patterns both for pigments use and for specific pigment – support combinations.

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Advanced deep Raman Spectroscopy methods for the non-invasive investigation of materials subsurface: impact on Heritage Science

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Keywords: deep Raman, heritage science, inorganic scattering materials.

One of major outstanding and only partially addressed needs in conservation and material sciences is the non-destructive and non-invasive analysis of subsurface components with molecular specificity at micrometre scales. This capability is just in part fulfilled by confocal Raman microscopy, since its depth–resolving power is restricted to depths at which sample is transparent or semi–transparent. In case of highly diffusely scattering materials, i.e. pigments, powders, tissues, and many inorganic compounds, the restriction can be very severe and, although it is highly undesirable and, in many cases, impossible as in the case of precious objects of art, cross section sampling becomes the only available recourse.

This presentation will focus on recent technological and methodological developments of advanced Deep Raman Spectroscopy methods at the Raman Spectroscopy Laboratory of ISPC-CNR for the non-invasive investigation of deep portions of highly diffusely scattering materials in Cultural Heritage. Micro Spatially Offset Raman Spectroscopy (micro-SORS) is the proposed approach developed in 2014 for non–destructive probing in turbid media (Conti et al., 2014; Mosca et al., 2021). The method involves separating the laser illumination and Raman collection zones from each other on sample surface to facilitate deeper recovery of sublayer signals than with confocal Raman microscopy and identify their chemical makeup. First, the principles of micro-SORS and the existing instrumental modalities will be presented; then, the analytical capabilities of two benchtop and portable micro-SORS prototypes (Lux et al., 2024), recently developed at ISPC laboratory, will be demonstrated on mock-ups mimicking situations encountered in art field with the aim of identifying non-invasively the molecular composition of the compounds and their mutual position. The coupling of micro-SORS with imaging/mapping modalities will be also presented for studies of high-resolution molecular distribution of compounds hidden by external opaque layers in art objects (Botteon et al., 2024). Finally, limitations as well as case studies will be depicted through case studies within the network of the European research infrastructure for heritage science (E-RIHS).

Botteon A. et al. (2024) - Advanced Microspatially Offset Raman Spectroscopy for Noninvasive Imaging of Concealed Texts and Figures Using Raman Signal, Fluorescence Emission, and Overall Spectral Intensity. Anal. Chem., 96, 11, 4535-4543, https://doi.org/10.1021/acs.analchem.3c05249.

Conti C. et al. (2014) - Subsurface Raman analysis of thin painted layers. Appl. Spectrosc., 68, 686-691, https://doi.org/10.1366/13-07376.

Lux A. et al. (2024) - Advanced portable micro-SORS prototype coupled with SERDS for heritage science. Analyst, 149, 2317-2327, doi:10.1039/D3AN02215C.

Mosca S. et al. (2021) - Spatially offset Raman spectroscopy. Nat. Rev. Methods Primers, 1, 1, https://doi.org/10.1038/s43586-021-00019-0.

Characterization of chert raw material using a non-invasive approch: the case of Hyblean foreland (South-Eastern Sicily)

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Keywords: chert, hyblean foreland, Raman spectroscopy.

During Prehistory, chert was the most used lithic material to produce stone industry. Chert is a sedimentary rock composed of mostly microcrystalline silica (about 95%) in addition to minor oxides and trace elements. The petrographic, micropaleontological and geochemical features are related to the depositional environment and the diagenetic evolution and represent an essential database to determine artifacts' provenance.

The Hyblean foreland (South-Eastern Sicily) has been known for its abundance of chert outcrops. Regarding the primary deposition, raw material occurs as nodules and lists in limestones of Amerillo Formation and Ragusa Formation (in the Leonardo Member). During the Prehistory, this resource played an important role in the economy of Hyblean area, indeed some researchers hypothesize about the presence of a "chert network" ("network della selce"- Scerra S., 2023). In fact, the strategy of the mining activity is not yet clear and the area is currently investigated by different research groups. In the Comiso town the discovering of a mining complex (e.g. Monte Tabuto and Contrada Coste mines) attests to the systematic exploitation of the raw material in this district.

In this work, we present preliminary data about the characterization of the Hyblean chert, through the use of non-invasive investigation analyses. While there have been preliminary studies on source catchment areas (Barone et al., 2018; Chatyimpaloglou et al., 2020), the current study aims to collect and analyse geological samples from a large area, with the aim to create a related lithotheque.

For this study we follow a non-destructive and multi-parametric protocol involving macroscopic observation, microscopic description and chemical analysis. Here we show results of Raman spectroscopy to characterize the collected chert samples and determine the presence of specific minerals (Moscone et al., 2020). As an example, this kind of analysis is often useful to distinguish two polymorphs of silica, quartz and moganite. For each sample, different spots were analysed on areas with different colours and morphological characteristics, to achieve a representative description (Moscone et al., 2020). Finally, Raman spectroscopy was coupled with portable X-ray Fluorescence (pXRF), in order to obtain a chemical characterization of the investigated samples (Barone et al., 2018).

Barone G. et al. (2018) - Portable XRF analysis for the study of Sicilian flint archaeological tools. In: Congresso congiunto SGI-SIMP, Abstract book, Catania 12-14 settembre 2018, 598, https://doi.org/10.3301/ABSGI.2018.02.

Chatyimpaloglou P. et al. (2020) - Connecting chert sources of Sicily with Neolithic chert artefacts of Malta. J. Archaeol. Sci. Rep., 29, 102-111, https://doi.org/10.1016/j.jasrep.2019.102111.

Moscone D. et al. (2020) - Compositional features of cherts from the Jebel Zawa mines (Dohuk, Kurdistan Region of Iraq) and implications for exploitation strategies during the Late Chalcolithic/Early Bronze Age. J. Archaeol. Sci. Rep., 29, 102086, https://doi.org/10.1016/j.jasrep.2019.102086.

Scerra S. (2023) - Un decennio di ricerche di preistoria negli Iblei ragusani: recenti acquisizioni sulle età del Rame e del Bronzo antico. In: Cannata A., Cugno S.A., Scaravilli M.S. (Eds), HYBLAEA Studi di archeologia e topografia dell'altopiano ibleo, vol. 1, 23-40, ISB1 978-1-80327-315-0 (e-Pdf).

Evaluation of an IR multi-methods protocol for the study of Cultural Heritage

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Keywords: IR-spectroscopy, geomaterials, diagnostic.

The PNRR project "CHANGES" was conceived to establish a multi-technological network in the Cultural Heritage, with a particular attention to the transdisciplinary. A key section of this project, the Spoke 5, focuses on the development of new scientific methods and approaches to deepen the study of cultural artefact materials and their historical context. Within this framework, a new protocol for the analysis and data interpretation of Cultural Heritage studies has been developed.

To validate and refine this protocol, several natural and artificial geomaterial samples were chosen and treated by both natural and artificial ageing. Samples of marble, travertine, wakestone, hydraulic and aerial mortars were exposed to open environment and analysed at intervals of three months, in order to evaluate variation in their infrared signal responses. In particular, the samples were studied applying three different Fourier transform infrared spectroscopy methods: attenuated total reflectance (FTIR-ATR), µTransmission (µ-FTIR) and external reflection (ER-FTIR) were employed for this purpose (Brunello et al., 2019). The first two methods are deemed micro-invasive, whereas the third is entirely non-invasive, which is a fundamental feature for the study of cultural heritage.

Subsequently, a multivariate statistical elaboration of the data collected from the samples with different analytical methods was applied, aiming to evaluate the efficacy of the protocol also to define the origin of raw materials and production techniques.

In conclusion, the project represents a significant step forward for the preservation of Cultural Heritage. Pioneering new scientific methods and the development of a novel protocol for analysing ancient geomaterials will marks a crucial advancement in the field with minimum or no damage to the finds. The ongoing testing and refinement of the protocol here described will provide further insights into material behaviour over time, ensuring the preservation and understanding of our cultural heritage for future generations.

Acknowledgements: This project was funded by PNRR PE05 – CHANGES_SPOKE-5-DST; CUP B53C22003780006 Medeghini.

Brunello V. et al (2019) - Non-invasive FTIR study of mortar model samples: comparison among innovative and traditional techniques. Eur. Phys. J. Plus, 134, https://doi.org/10.1140/epjp/i2019-12667-1.

The evolution of the corrosion process of medieval objects through IR-spectroscopy

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Keywords: IR-spectroscopy, corrosion product, degradation processes.

The investigation of the chemical composition and microstructure of archaeological metal artifacts is essential for understanding degradation processes, with a particular attention to the corrosion, often triggered by prolonged periods of burial.

This study focuses on the characterisation of the metal structure of a set of agricultural tools remains dating from the 13th to 14th centuries, unearthed in the site of Cencelle, a medieval settlement near the Tolfa Mountains (central Italy), founded in the 9th century and abandoned since the 17th century AD (Annoscia, 2016). The main objective is to understand the underlying causes of degradation, assess conservation status, and unravel the composition of patinas and corrosion products formed during and after burial period (Grevey et al., 2020).

To achieve these objectives, a comprehensive multi-analytical approach has been adopted, encompassing techniques such as Optical Microscopy, Electron Microscopy coupled with Energy Dispersive X-ray analysis, and Infrared spectroscopy. Significantly, infrared spectroscopy plays a crucial role in identifying both organic and inorganic materials within the samples, as well as to identify the nature of the patinas and the corrosion products growth on the samples surfaces also after their preparation.

By analysing data acquired through Infrared spectroscopy, it becomes possible to identify compounds present in corrosion products and determine their implications on the conservation status of metal artifacts. This methodological framework offers detailed insights into the nature and composition of materials within the samples, enhancing understanding of degradation mechanisms, and guiding the formulation of conservation and restoration strategies.

In conclusion, integrating Infrared spectroscopy with complementary analytical methodologies provides a robust approach for the systematic examination of archaeological metal artifacts and their associated degradation processes. The outcomes of this investigation provide substantive contributions towards the preservation and valorisation of medieval cultural heritage.

Annoscia G. M. (2016) - Per una storia agraria di Leopoli-Cencelle: gli attrezzi agricoli (XIII-XV secolo). Scienze dell'Antichità 22.1, 177-187.

Grevey A. L. et al. (2020) - Microstructure and long-term corrosion of archaeological iron alloy artefacts. Herit. Sci., 8(57), https://doi.org/10.1186/s40494-020-00398-9.

Pros and cons on the investigation of geopolymers through micro-Raman spectroscopy

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Keywords: geopolymers, micro-Raman spectroscopy, XRD.

Geopolymers are inorganic materials obtained through alkaline activation of aluminosilicates. After a consolidation phase at RT, geopolymers can be used as restoration or construction materials. Geopolymers production may represent a promising alternative to traditional binders, reducing the CO_2 footprint in the building sector. Recent works showed that geopolymers have suitable properties for application in conservation/restoration (Fugazzotto et al., 2024). The use of waste materials (sawing sludges, Construction and Demolition Waste,…) as precursors is currently encouraged in a circular economy perspective (Portale et al., 2023; Volpintesta et al., 2024).

In this work, two sawing sludges were tested to produce geopolymers, consisting of basalt (Etna volcano, Italy), (FB), and granite from pink porphyry quarry (Cuasso al Monte, Varese, Italy), (FC). In the synthesis, metakaolin, Na hydroxide and Na silicate were used. Carbon fibers were added in the FB-geopolymers, to evaluate their effects on the structure.

Geopolymers were characterized through Polarized Light Microscopy (PLM), micro-Raman spectroscopy and X-Ray diffraction (XRD).

PLM observations highlighted the different mineral species in the products, which were confirmed by XRD and by micro-Raman spectra, acquired on the same crystals observed with PLM. Crystalline phases, typical of the precursors were distinguished: mainly feldspars, pyroxenes and olivines in FB-geopolymers; feldspars, quartz and micas in FC-geopolymers. In the case of olivines, the change in colour within a single crystal observed in PLM was correlated with a change in composition, evaluated from the positions of the two main Raman peaks (in the ranges 817.5-822.5 cm-1 and 847.5-852.5 cm-1, respectively): a contribution of forsterite between 60% and 80% was estimated.

In addition, through micro-Raman spectroscopy, the geopolymers were analysed both on the internal and the external parts: a uniform mineral composition was observed. Micro-Raman analyses revealed the nature of efflorescences which can form on the external surfaces by carbonation due to Na excess, consisting of trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), gaylussite ($Na_2Ca(CO_3)_2 \cdot 5H_2O$)/pirssonite ($Na_2Ca(CO_3)_2 \cdot 2H_2O$), natrite ($Na_2CO_3$).

XRD analyses revealed the amorphous content, amounting to ~25% and ~30% for FB- and FC-geopolymers, respectively. The amorphous content was not detected by micro-Raman analyses, probably due to the submicrometric size of the amorphous regions, whose signals could be covered by those related to the coexisting crystalline phases.

Overall, micro-Raman is a powerful technique to investigate the morphology and the mineralogical composition of geopolymers. A complete description of the residual phases from the precursors and the newly formed phases could be obtained from the Raman results. The combination of micro-Raman spectroscopy with XRD is fundamental to reveal the amorphous content of geopolymers, in addition to crystalline phases.

Fugazzotto M. et al. (2024) - Creating mortars through the Alkaline Activation of ceramic waste from construction: case studies on their applicability and versatility in conservation. Sustainability, 16(3), 1085, https://doi.org/10.3390/su16031085.

Portale S. et al. (2023) - Feasibility study about the use of basalt sawing sludge in building and restoration. Mater. Lett., 333, 133624, https://doi.org/10.1016/j.matlet.2022.133624.

Volpintesta F. et al. (2024) – Compositional differences in Construction and Demolition Wastes (CDWs) for geopolymer mortars: a comparative study using different precursors and alkaline reagents. Minerals, 14(4), 376, https://doi.org/10.3390/min14040376.

A multi-technique investigation for provenance determination of white marbles from the Roman villa in Fiumana (Forlì-Cesena, Italy)

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Keywords: marble, micro-Raman spectroscopy, stable isotopes.

During the recent archaeological excavations in the site of the Roman villa in Fiumana (Forlì-Cesena, Emilia Romagna, Italy), several white marbles were discovered. They are decorative elements, consisting of fragments of reliefs and slabs for floors and walls. The determination of the provenance of marbles is of great interest to identify marble quarries and trade routes in the antiquity.

In this work, white marbles were investigated by a multi-technique approach, by using polarized light microscopy (PLM), X-ray powder diffraction (XRPD), micro-Raman spectroscopy and stable isotope ratio analysis (δ18O and δ13C). PLM observations on thin sections revealed the mineralogical-petrographic features, in terms of microstructure and mineral phases. XRPD confirmed the mineral composition of the marbles, also distinguishing some accessory minerals (e.g. micas), in addition to calcite. Interestingly, all these features were highlighted by micro-Raman analyses, through the use of a single technique. Micro-Raman spectra were collected on different crystals on the thin sections and the mineral phases were identified in terms of both main and accessory species. Further, δ18O and δ13C were evaluated for the marbles and some possible provenance sites were suggested, by comparing the obtained results with the international databases and the available studies about Mediterranean white marble quarries used in antiquity (Capedri et al., 2004; Antonelli & Lazzarini, 2015; Taelman et al., 2020).

The combination of the isotopic results with the mineralogical and petrographic features was essential to define the provenance of marbles and decisive information to archaeologic investigations were revealed.

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Capedri S. et al. (2004) - Accessory minerals and δ18O and δ13C of marbles from the Mediterranean area. J. Cult. Herit., 5(1), 27-47, https://doi.org/10.1016/j.culher.2003.03.003.

Taelman D. et al. (2020) - Archaeology and archaeometry of marbles in Roman central Adriatic Italy. Proceedings of the 2020 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage, Trento, Italy, 22–24 October 2020, 404-409.

Proposal of an interdisciplinary protocol for the archaeometric study of mosaics by spectroscopic methods and history of art

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Keywords: spectroscopic techniques, medieval mosaics, multidisciplinary.

The integrated development of scientific research, promoting the value of mutual complementarity of human and hard sciences, has a paramount importance on the studies of cultural heritage. Considering both cultural and material aspects of artefacts is mandatory to reveal and precise chronology, provenance, workshops practices and to protect and transmits their material and cultural value. This paper describes an ambitious multidisciplinary research project aimed at the establish an in situ, non-invasive and non-destructive physico-chemical protocol (Tempesta et al., 2018; De Ceglia et al., 2024), to improve the knowledge, the conservation and the valorisation of the Apulian mosaic heritage.

This project considers the medieval floor mosaics (6^{th}-13^{th} centuries AD) in the Adriatic area. The historical-artistic and documentary study, fundamental for a coherent and correct interpretative definition of the mosaics examined will be carried out. The characterisation of the geo-materials and synthetic glasses, constituting commonly the mosaic tesserae, by means of complementary spectroscopic techniques (FORS, RAMAN, XRF) will carried out using portable instruments. A detailed mineralogical characterisation, that can contribute to obtain information on the source of materials, will be performed on symbolic regions of the mosaics, chosen valuating their historical, liturgical and artistic impact. The statistically significant chemical and mineralogical data will be completed by laboratory analyses on the most representative tesserae. The extensive data collected will constitute original content and will be made available to the scientific community on an open database. The study with the material information acquired will allow the identification of most suitable techniques for the optimal conservation of mosaic heritage. The extensive data that will be collected in situ will constitute original content and will be made available to the scientific community. The study also aims to develop a protocol for the archaeometric investigation of mosaics that can be applied in different contexts and that will allow for a proper comparison of the data. The study will allow the identification of more suitable techniques for the optimal conservation of mosaic heritage. Furthermore, the results of physico-chemical analyses on the Apulian mosaics will make it possible to identify the provenance of the raw materials, to precise the chronology, to understand the procedures used for the processing the tesserae and to distinguish the original ones from later replacement. (Neri, 2016). Finally, the research will promote knowledge and valorisation of the Apulian mosaic heritage to improve its fruition and public use.

De Ceglia F.P. et al. (2024) - In Search of the Phoenix in Eighteenth-Century Naples. Raimondo di Sangro, Nature Mimesis, and the Production of Counterfeit Stones between Palingenesis, Alchemy, Art, and Economy. Nuncius (published online ahead of print 2024), https://doi.org/10.1163/18253911-bja10097.

Neri E. (2016) - Tessellata vitrea in età tardoantica e altomedievale: produzione dei materiali e loro messa in opera. Considerazioni generali e studio dei casi milanesi. Brepols Pub, 398 pp.

Tempesta G. et al. (2018) - The "Exultet 1" of Bari: multi-methodological approach for the study of a rare medieval parchment roll. Period. Mineral., 87(2), 93-102.

Novel hybrid materials inspired by ancient technologies: the case of 'PALY@DAPI'

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Keywords: palygorskite, DAPI, hybrid nanocomposite.

Maya Blue is a famous and extremely stable pigment used in Central America (VIII/ XV Century AD) for mural paintings, statues and pottery. The secret of its stability lies in the indissoluble 'marriage' between palygorskite – a fibrous and highly-hydrated microporous clay mineral – and the frail indigo dye – responsible for the blue colour. A heating-induced sorption and bonding of the dye in the inner tunnels and surface grooves that permeate the clay framework allows indigo to be aptly shielded from external agents, preventing its decay. Due to this, Maya Blue is duly considered an ancestor of hybrid nanocomposite materials. The proverbial 'dice' had been cast: borrowing the stimulus from the ancient Mayas, novel compounds may be thus be prepared by coupling the host palygorskite to other guest molecules, so as to obtain hybrid materials with peculiar features useable in the Materials Science and/or Cultural Heritage fields – valid and sustainable surrogates for other polluting compounds used nowadays.

DAPI is a fluorescent stain capable of binding to the major groove of DNA, thus allowing an imaging of the genetic material. Since the major groove of DNA and the superficial grooves of the palygorskite fibrils bear some similarities, we explored the possibility of synthesizing a stable fluorophore by trying to fasten the DAPI molecule on the hosting clay framework, following the ancient Mayan recipe (grinding, heating at 160°C and washing in water).

The obtained 'PALY@DAPI' composite was investigated with a multi-analytical protocol (FE-SEM-EDS, BET-SSA/micropore volume measurements, thermogravimetry, UV-vis, fluorescence and FT-IR spectroscopies), which proved that grinding involves at first an evident solvation of the guest in the host structure. Interactions between the clay and the dye tend to form already after grinding – being favoured by an incipient electrostatic attraction between the cationic guest molecule and the diffuse negative charge of the palygorskite fibrils surface. These preliminary interactions are also corroborated by H-bond formation between the dye amine groups and the zeolitic and structural water molecules occupying the host superficial grooves, which contribute to stabilize the composite and ensure a significant raise in the quantum yield (QY). Curiously, the following synthesis steps (heating and washing) – which are fundamental for Maya Blue to gain its stability – do not either improve the composite performances or strengthen the previously formed interactions, rather worsening both its stability and QY.

In light of its reactivity and structural features, this 'PALY@DAPI' hybrid composite may find application in the production of tailored, metal-free, fluorescent materials for sensors and optical devices, as well as in the field of imaging or design-targeted drug-delivery systems.

Answering archaeometric questions on technology and provenance relative to emblematic ancient ceramic productions in Basilicata by combining micro-Raman spectroscopy, micro X-ray fluorescence and micro X-ray diffraction to the study of pigments

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Keywords: pigment technology and provenance, archaeometry, archaeology of production.

In the present paper are showed the results of micro-Raman spectroscopy, micro X-ray fluorescence and micro X ray diffraction relative to ceramic artefacts from emblematic archaeological contexts in Basilicata region (southern Italy) as innovative, effective and sustainable solutions to answer questions on technology and provenance for pottery production. The compositional characterization of ceramic decorative elements (e.g. pigments and glazes) in quite different ceramic productions exhibiting an important change in technology and raw material supply in the Lucanian area will be investigated in the diachrony and the adjustment of tools and solution to the specific questions for the different ceramic production (e.g. presence of glaze) will be exerted. Regarding the matt painted pottery analyzed (V-VI B.C.), in order to understand pigment technological aspects, it is necessary to combine analysis of red and brown pigments using micro-Raman spectroscopy and powder/micro X-ray Diffraction as well as micro X-ray fluorescence. The 532 e 785 nm lasers can be alternatively adopted, depending on the portion of ceramics to investigate. Combination of spectroscopic and diffrattometric techniques thus allowed to detect, in the brown pigment the presence of jacobsite ($MnFe_2O_4$) (Lubraco et al., 2024). As the jacobsite formation is consequence of firing in an oxidant environment of manganese oxides (mainly MnO_2) and iron oxides (Fe_2O_3), a mixture of these oxides was used for the black pigment and the artefact was fired at temperatures ranging from 900-1000°C (Schweizer & Rinuy, 1982). A "before firing" application of the decoration can be hypothesized as well as the use of the well-known "manganese black technique". The manganese source for the jacobsite formation may be identified in the black sand from Mt. Vulture (PZ). The presence of glaze and different colored pigments in the Graffita ware (XII-XV A.C.) – with the presence of a large number of chromophores - necessitates a part from the use of new integrated methodology developed for the micro X-ray fluorescence (Lubraco, 2023) also the adoption of specific expedients in the use of micro-Raman spectroscopy, e.g. the compulsory analysis of the portion below the glaze to decipher the contribution of glaze to the spectra. Different technologies seem to have been adopted to produce Graffita ware from Moliterno Castle (PZ) in the diachrony. There is a Graffita ware characterized by a lead coating with traces of tin, containing abundant quartz and cristobalite, implying firing at high temperatures. The green decoration consists of a Cu pigment (likely the verdigris pigment) with aggregates of cassiterite (SnO2) (Annunziata et al., 2022; Lubraco, 2023). The olive-green decoration consists of bivalent and trivalent iron. A Graffita ware with arsenic in the glaze and in the blue pigment suggests postdating them to early 16th century. Besides, there is evidence that animal bone dust was intentionally used to make the engobe. A possible non-local provenance can be hypothesized for a fragment of Graffita ware.

Annunziata E.M. et al. (2022) - Archaeometry of Basilicata Graffita ware: provenance and technology 2022 IMEKO TC-4. Proceedings of the International Conference on Metrology for Archaeology and Cultural Heritage University of Calabria, Italy, October 19-21, 2022.

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Gemstone, treatments and imitations in medieval goldworking: a gemmological and spectroscopic combined approach

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Keywords: gems, gemmology, spectroscopy.

Raman spectroscopy is a well-established method for the analysis of gemstones, allowing the identification of minerals without the need for sample handling, which is particularly important in the case of precious goldworks.

Within the framework of an extensive project on the study of medieval goldsmithing (Martiniello, 2022), nineteen among relics, reliquaries, religious and imperial insignia preserved in Tuscany Museums, dating from the 10th to the 16th centuries and produced both in Italy and abroad (from Northern Europe to Byzantium) were studied, and a total of 850 gems and gem-like materials were analysed with a strict link between gemmological analysis and spectroscopic examinations.

Overall, the study showed the great advantage of such a multidisciplinary approach, demonstrating the fundamental role of gemmological analysis, intertwined with analytical investigation methods and art historical/archaeological evaluations, also as a tool for analysing the chaîne opératoire underlying the creation of jewellery, the provenance and circulation of gems and objects themselves (Martiniello et al., 2023). In fact, the preliminary step of identifying the materiality of the gemstones by means of spectroscopic methods must be accompanied by the analysis of the inclusions in gems, their cutting and setting, as well as the treatment of the gemstones, which are not always detectable by spectroscopic techniques. These are essential for a global interpretation of their historical significance and cultural context of gems and goldworks analysed.

The research project, which is still underway, has made it possible to reflect on the economic and philosophical value of gems and gems-like materials, by identifying a large number of natural gems from both European and Oriental regions, often reserved for religious or imperial ornaments, and often used in combination with glass. The study also provided an opportunity to identify and observe various types of treatment, among which the composite gemstones stand out for their peculiar manufacturing technique, which is only documented from the 16th century onwards, but which has now been discovered in the analysed 13th century goldworks (Martiniello et al., 2023).

This contribute intends to present a rich repertoire of evidence of gemstones and treatments, with a diachronic approach that also highlights aspects of economic history, considering how the trade in gemstones has evolved over time and tracing its trajectory from ancient practices to more recent ones. This longitudinal perspective allows the study of continuity and change in terms of gem technology, trade routes, consumption patterns and symbolic significance across different historical periods.

Martiniello S. (2022) - Le analisi gemmologiche a supporto della storia dell'oreficeria: cinque casi studio. In: Annali di studi umanistici, X, 171-226, ISBN: 9788879235044.

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Phoenician seeds are rich in minerals: a multi-analytical study of mineralised archaeobotanical remains from the archaeological site of Motya

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Keywords: archaeobotanical remains, mineralisation, FTIR.

Although most of the botanic remains recovered from archaeological sites in the Mediterranean area are constituted by charred samples, mineralized macro-remains obtained from excavations represent interesting case studies, because their actual chemical composition could be related to the archaeological context, while the chemotaxonomic data deriving from the identification of mineral phases could be used for the identification of fossil plant taxa, enriching the interpretations deriving from the morphological analysis (Vajda et al., 2017). In this study, a multi-disciplinary protocol combining Optical microscopy, Variable Pressure Scanning Electron Microscopy supported by dual-Energy Dispersive X-ray spectroscopy (VP-SEM-dEDS) and Fourier Transformed InfraRed spectroscopy (FTIR) was applied to investigate the fossilization of selected fruits and seeds retrieved in the Phoenician-Punic site of Motya (Sicily, Italy; Moricca et al., 2023). In the first steps, the archaeological remains were identified through a stereomicroscope using atlases (Neef et al., 2012; Sabato & Pena-Chocarro, 2021), while their mineralization conservation state was assessed. After this procedure, the carpological remains have been compared to those of their modern counterparts: both the archeological and modern samples were subjected to imaging, elemental and molecular analysis, in order to highlight processes attributable to biomineralization and to replacement mineralization. VP-SEM-dEDS was applied to observe the seed structure at higher magnification and to obtain elemental maps -both on the outer surface and on the cross section of archaeological and modern samples- to highlight the main differences in their elemental composition. In order to individuate the molecular compounds deriving from mineralization, FTIR spectroscopy was applied by means of two different approaches. Specular FTIR reflectance provided the fingerprints modern seeds and fruits and the chemical modifications on archaeobotanical remains. Besides, diffuse FTIR spectra on powdered samples revealed their bulk composition and the presence of organic residues in archaeological samples. The combination of the results obtained from microscopic and spectroscopic techniques resulted generally coherent in providing information about the chemical and mineral composition of the analyzed fossils, while the comparison with the imaging data provided preliminary hypotheses on the mineralization process, extending also the actual knowledge on the preservation condition of archaeobotanical materials from Motya.

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Neef R. et al. (2012) - Digital Atlas of Economic Plants in Archaeology. Barkuis Pub, 724 pp., https://doi.org/10.2307/j.ctt20p56d7.

Sabato D. & Pena-Chocarro L. (2021) - Maris Nostri Novus Atlas. Seeds and fruits from the Mediterranean Basin. Ediciones Doce Calles, 452 pp., http://hdl.handle.net/10261/266042

Vajda V. et al. (2017) - Molecular signatures of fossil leaves provide unexpected new evidence for extinct plant relationships. Nat. Ecol. Evol., 1, 1093-1099, https://doi.org/10.1038/s41559-017-0224-5

Analyzing the structure and chemical composition of an Etruscan bronze fibula from Tomb Number 129 at Vulci (VT, 1Italy) through a non-destructive multi-analytical approach

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Keywords: bronze corrosion, XRM, brochantite-sampleite.

This study examines an Etruscan bronze fibula dating back to the 8th century BC, which is part of the grave goods found in tomb number 129 from the Archaeological Park of Vulci (VT, Italy). The investigations were conducted using a multi-analytical approach based on non-destructive techniques, i.e., Energy Dispersive X-ray fluorescence (ED-XRF) combined with Monte Carlo simulation (MCS) (Golosio et al., 2014), micro-Raman spectroscopy, and X-ray microscopy (XRM). The results revealed that the fibula was produced in a single casting event with a ternary Cu-Sn-Pb alloy. XRM enabled 3-D reconstructions of the fibula, which allowed the investigation of its internal structure (Bernabale et al., 2023), production technology, and preservation state by distinguishing the metal core from the corrosion layer and highlighting areas of fragility. The patina was evenly and compactly distributed over the entire surface, with a thickness between 100 and 400 μm. Micro-Raman spectra indicated the presence cuprite (Cu_2O), malachite ($Cu_2CO_3(OH)_2$), brochantite ($Cu_4(OH)_6SO_4$) and sampleite ($NaCaCu5(PO_4)4Cl•5H_2O$). These latter two phases were also found in another tomb under similar environmental conditions. Indeed, the formation of sampleite and brochantite is promoted by the presence of bacteria and organic matter within burial environments (Muros & Scott, 2018).

Bernabale M. et al. (2023) - 3D imaging of micro-segregation and corrosion behavior of alloying elements in archaeological artefacts from Motya (Sicily, Italy). Corros. Sci., 211, 110900, https://doi.org/10.1016/j.corsci.2022.110900.

Golosio B. et al. (2014) - Monte Carlo simulation of X-ray imaging and spectroscopy experiments using quadric geometry and variance reduction techniques. Comput. Phys. Commun., 185, 1044–1052, https://doi.org/10.1016/j.cpc.2013.10.034.

Muros V. & Scott D. A. (2018) - The occurrence of brochantite on archaeological bronzes: a case study from Lofkënd, Albania. Stud. Conserv., 63(2), 113-125, https://doi.org/10.1080/00393630.2016.1264179.

Microstructure, chemistry and corrosion products of copper and copper alloys of artefacts from Pyrgi (Italy) through a multi-analytical approach

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Keywords: copper alloys, etruscan metallurgy, corrosion processes.

In this study, several archaeological artifacts, i.e., arrowheads, nails, and aes rude, made of copper or copper alloys were examined (Esposito et al., 2019). They were found at the Etruscan site of Pyrgi (Santa Severa, Italy), dating back to the 6th to 4th century B.C. We explored the microstructure and composition of each sample, considering its relationship to the environmental storage, and the possible corrosion phenomena triggered on its surface. Such phenomena can produce irregular multilayer structures (patina) and possible selective enrichment or depletion processes of alloying elements. A multi-analytical approach, based on Scanning Electron Microscope, X-ray maps, and μ-Raman spectroscopy was used. The chemical composition of nails and aes rude is pure copper, while arrowheads are made of a ternary Cu-Sn-Pb alloy. In addition, it was possible to distinguish artifacts produced by simple casting from those that underwent additional processing. The μ-Raman spectra of the surface of the artifacts indicated the occurrence of cuprite, malachite, and copper trihydroxy-chlorides, indicating the occurrence of type I and type II patinas (Robbiola et al., 1998). The presence of chlorine even within the cores in some samples indicates a very corrosive environment. The chemical and microstructural information allowed hypotheses on the production and metallurgical processes of the artifacts and their application. The choice of using copper nails was quite unusual, but as reported in the literature (Dilo et al., 2010; Pomey et al., 2013), it could be due to their use in ship carpentry. As for the arrowheads, the data suggest that they are votive objects as their composition and structure would make them not particularly suitable as weapons. The aes rude, almost all composed of pure copper, represent one of the earliest forms of coinage. They are semi-finished products, rich in inclusions due to the process of smelting raw materials. These data provide valuable information on the processing techniques and materials used by the Etruscans, contributing to the understanding of their technological capabilities and conservation processes of artifacts found in a coastal archaeological context such as Pyrgi.

Dilo T. et al. (2010) - Archaeometallurgical characterization of some ancient copper and bronze artifacts from Albania. AIP Conference Proceedings, 1203, 985-990, https://doi.org/10.1063/1.3322596.

Esposito A. et al. (2019) - The production of metal artefacts in Southern Etruria (Central Italy): Case studies from copper to Iron Age. Sci. Technol. Archaeol. Res., 5.2, 64-84, https://doi.org/10.1080/20548923.2019.1660496.

Pomey P. et al. (2013) - On the transition from Shell to Skeleton. Int. J. Naut. Archaeol., 42(2), 434-438.

Robbiola L. et al. (1998) - Morphology and mechanisms of formation of natural patinas on archaeological Cu–Sn alloys. Corros. Sci., 40(12), 2083-2111, https://doi.org/10.1016/S0010-938X(98)00096-1.

Application of infrared external reflection spectroscopy in the identification of emerald provenance

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Keywords: emerald, spectroscopy, provenance.

Throughout the history, emerald has always had an economic and religious importance, as evidenced by its widespread diffusion even far from its mines. Emerald belongs to beryl-group minerals with a general formula $Be_3Al_2Si_6O_{18}$, where tetrahedra form six-member rings filled by Si, whereas Al and Be ions are located at the octahedral and tetrahedral sites, respectively, which link together the columns of rings of six Si-O tetrahedra. The green color is due to the presence of Cr and/or V which replace Al at the octahedral site (Aurisicchio et al., 2018). Recent studies have proved that spectroscopies can be a useful non-invasive approach in the identification of emerald provenance. In particular, thanks to the shape and position of vibrational modes associated with the Si-O stretching (main peak ~1200 $^{cm-1}$ and shoulder at ~1140 $^{cm-1}$) and the bands associated with the OH stretching mode of water (in the range 3500-3800 $^{cm-1}$) of FTIR spectra, it could be possible define the genetic model for each deposit (Giuliani et al., 2019) and consequently their provenance. The present work reports for the first time the results of infrared external reflection spectroscopy on emerald samples from the main deposits exploited in antiquity such as Malyshevsk (Russia), Jos (Nigeria), Pajshir Valley (Afghanistan), Habactal (Austria), Sikait, Zabara (Egypt) and Swat Valley (Pakistan**).** The results are compared with FTIR spectra acquired in transmission mode to identify spectroscopic "markers" which could help in the reconstruction of the provenance.

Aurisicchio C. et al. (2018) - Major and trace element geochemistry of emerald from several deposits: Implications for genetic models and classification schemes. Ore Geol. Rev., 94, 351-366, https://doi.org/10.1016/j.oregeorev.2018.02.001.

Giuliani G. et al. (2019) - Emerald deposits: A review and enhanced classification. Minerals, 9(2), 105, https://doi.org/10.3390/min9020105.

Precious votive offerings in 17th- and 18th-century Sicilian production: non-invasive gemmological analyses

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Keywords: Raman spectroscopy, x-ray fluorescence, ecclesiastical jewellery.

There is a vast production of ecclesiastical artefacts traceable in Sicily between the 17th and 18th centuries, a period in which there was a blossoming of the arts related to the creation of silverware, as well as goldsmithing of the highest level. The repertoire of objects also includes beautiful jewellery and ex votos of incredible richness. This vast corpus can be admired in many Diocesan Museums and Museums of Sacred Art in the area, known for exhibiting important collections marked by precious objects with refined decorations and gems set in the mouldings. But beyond the undisputed devotional value and historical document value that characterises these artefacts, it is necessary to understand whether the information reported is reliable. Traditional survey methodologies and autopsy observations do not allow for the classification and characterisation of gems of interest, and scientific studies are rarely used. Thanks to the investigations conducted with non-invasive and non-destructive portable instruments, it is possible to study these works in situ: the combined approach of portable Raman spectroscopy (with an excitation wavelength of 785 nm) and portable X-ray fluorescence (XRF), allowed for the exact identification of the gems (Barone et al., 2015) on some considerable works. The analyses, in some cases, confirmed what was stated in the caption, while in other cases they contradicted the information, revealing, however, lesser-known aspects. This method has made it possible, for example, to thoroughly analyse an ex voto erroneously attributed to the baroness Giovannella De Quadro, today known as De Quatris (1444 - 15 July 1529) (Mollica, 2015), who left all her possessions to the Church of Santa Maria Assunta in Randazzo (Italy). The jewel is not coeval to the reference chronological horizon and is rather associated with the model known as 'fiocco de Savignè' (Di Natale, 2008). In fact, the object follows a traditional Sicilian production type of Franco-Austrian derivation in vogue especially in the 18th century. The gems mentioned must have been rubies, garnets and diamonds, as in a similar specimen already studied in a previous campaign of analysis and currently included in the bust of the simulacrum of the Madonna Immacolata of Caltagirone or like some pendants currently exhibited in the Museum of Sacred Art of S. Nicolò in Militello in Val di Catania (Italy).

Barone G. et al. (2015) - Nondestructive investigation on the 17-18th centuries Sicilian jewelry collection at the Messina regional museum using mobile Raman equipment. J. Raman Spectrosc., 46(10), 989-995.

Di Natale M.C. (2008) - Gioielli di Sicilia. Gemme e ori, smalti e argenti, coralli e perle, uno scrigno preziosissimo ricolmo di monili. Palermo: Flaccovio Editore.

Mollica E. (2015) - De quadro. Una storia prende vita. Autopublishing, Randazzo.

Non-invasive combined FT-IR and NMR protocol to assess the cleaning action of a lignin-based hydrogel on stones

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Keywords: lignin-based hydrogel, portable FT-IR, single-sided NMR.

Lignocellulosic biomass is found on top of agricultural waste and includes cellulose, lignin, and hemicellulose. Of the three polymers, only lignin is considered inexpensive and 98% is burned to generate energy (Vásquez-Garay et al., 2021). Lignin is also an important by-product of paper industry. Due to the growing interest in converting waste into high-value-added products and thanks to the key properties of lignin, such as biodegradability, biocompatibility, thermal stability, antioxidant and antimicrobial properties, several procedures have been developed to regenerate lignin into advanced materials, including hydrogels, nanotubes, films, nanofibers, and nanoparticles (Akhtar et al., 2016). These are suitable for a variety of applications, such as drug delivery systems for agriculture or medicine, in water remediation applications, and in sensors since they can serve as absorbents for heavy metal ions, controlled release agent for controlled delivery and water retention, smart materials for stimuli response, and biosensors and electrodes (Rico-Garcìa et al., 2020). In this scenario, a novel emerging application of lignin-based hydrogels could be in the cleaning practice of cultural heritage stones. This work aimed to evaluate the cleaning potential of a PVA-lignin hydrogel to remove metal ions from stone surfaces using a non-invasive protocol based on the combination of single-sided NMR and portable FT-IR (Stagno et al., 2021). Different stones were artificially stained with copper corrosion products and then cleaned using the lignin-based hydrogel. The spin-spin relaxation time (T2) and the IR spectra were collected on the stone surface before and after the artificial staining, as well as after the application of the lignin-based gel. Moreover, FT-IR spectroscopy was also used to study the changes in bonds within the PVA-lignin system before and after being used to clean the stone.

Akhtar M.F. et al. (2016) - Methods of synthesis of hydrogels... A review. Saudi Pharm. J., 24(5), 554-559, https://doi.org/10.1016/j.jsps.2015.03.022.

Rico-Garcìa D. et al. (2020) - Lignin-Based Hydrogels: Synthesis and Applications. Polymers, 12(81), 1-23, https://doi:10.3390/polym12010081.

Stagno V. et al. (2021) - Non-Invasive Assessment of PVA-Borax Hydrogel Effectiveness in Removing Metal Corrosion Products on Stones by Portable NMR. Gels, 7(4), 265, https://doi.org/10.3390/gels7040265.

Vásquez-Garay F. et al. (2021) - A review on the lignin biopolymer and its integration in the elaboration of sustainable materials. Sustainability, 13(5), 2697, https://doi.org/10.3390/su13052697.

On site analyses of geomaterials in Sansevero Chapel Museum (Naples)

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Keywords: ultramarine, fluorite, vermillion.

Raimondo di Sangro (1710–1771), Prince of Sansevero, is renowned for having made experiences on mineral palingenesis, among other things, using his creation for the embellishment of his masterpiece, the Sansevero Chapel. This multidisciplinary study led by Francesco Paolo de Ceglia within the project promoted by the Interuniversity Research Center "Seminario di Storia della Scienza" called "The uncertain borders of nature. Wonders and miracles in early modern Naples" allow, during two distinct surveys at Sansevero Chapel Museum, to identify geomaterials used or created by Raimondo to adorn the Chapel (de Ceglia et al., 2024). The results obtained by the analyses performed on-site on the cushion of St. Oderisius' statue, on St. Oderisius' Cardinal Hat and on the blue frame on the high altar, executed by means of portable Raman spectroscopy, Ultraviolet, Visible and Infrared spectroscopy (UV-VIS-NIR) and Ultraviolet luminescence are presented. The cushion, described as amethyst in an old guide of the Chapel, appears to be an aggregate (like breccias) consisting of centimetre-sized clasts that shows a strong blue fluorescence. Raman analysis confirmed the assumptions made from the appearance and the observed characteristic fluorescence with UV light, identifying the mineral as fluorite (CaF). As regards the traces of red pigment remains on the cardinal hat the VIS-NIR analyses show that Francesco Queirolo used vermilion, a mercury sulphide (HgS) mineral, to colour the white marble. Raman analyses confirmed the presence of cinnabar. The blue pigment of the frame, that looks like made by a slice of lapis lazuli rock, was analysed through the VIS-NIR spectrum. The analyses demonstrated its compatibility with ultramarine. This pigment was made of lazurite, a mineral responsible for imparting the characteristic blue hue to the natural rock lapis lazuli. It was a precious pigment more expensive than gold, at that time. Further, detailed analyses on micro-fragments of the pictorial layer were performed in the laboratory by means of Optical Microscope (OM), Scanning Electron Microscopy coupled with Energy Dispersive Spectroscopy (SEM-EDS), Ultraviolet, Visible and Infrared spectroscopy (UV-VIS-NIR) coupled with OM. Our analyses confirm for the first time that the Prince of Sansevero was able to create artificial ultramarine 50 to 70 years before Guimet's ultramarine synthesis. As of today, this seems to be the earliest ever recorded example of the production of this artificial pigment. Consequently, this study suggests that historical sources documenting di Sangro's experiences should be seriously reconsidered.

de Ceglia F.P. et al. (2024) - In Search of the Phoenix in Eighteenth-Century Naples: Raimondo di Sangro, Nature Mimesis, and the Production of Counterfeit Stones between Palingenesis, Alchemy, Art, and Economy. Nuncius (published online ahead of print 2024), https://doi.org/10.1163/18253911-bja10097.

Spectroscopic studies of white and black pigments in a Dalì painting

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Keywords: Dalì, white pigment, spectroscopy.

To get preliminary insights on a paint panel signed by Salvador Dalì, spectroscopic data from various techniques were acquired. In the specific case, Fiber Optic Reflectance Spectroscopy (FORS), portable Raman spectroscopy, portable X-ray fluorescence spectroscopy (PXRF) and infra-red spectroscopy with Fourier Transformed-Attenuated Total Reflectance (FTIR-ATR) were performed. The paint realized with a black pigment on a white substrate shows warp and cracks damages due to the ages on the wood panel. No references about diagnostic on Dalì paints were easily found, probably due to the existence of the "Gala - Salvador Dalí Foundation" that exclusively analyzes and verifies the attribution to the artist, not publishing and sharing the analytical data. So, the color palette of the artist is unknown. Only one study on the white zinc-oxide degradation was found (Keune & Boevé-Jones, 2014). The Raman spectroscopic data collected allow us to identify a white pigment, homogenous on all the panel, made by a mix of barium sulphate and titanium oxide. This pigment is different from zinc white described in literature, but this composition belongs to a white pigment produced in the early 20th century. These findings corroborate the paint datation suggested by the owner to 1936. The black pigment belongs to organic matter. Only a large black blemish on the upper right side of the panel has been distinguished by FORS from the other black paint. It probably belongs to an acrylic paint sprayed afterward. FTIR-ATR data permitted to recognize the presence of plastic matter on the edge and to assess the likely attribution of organic binder to plant gum. Due to the importance of this Dalì's panel, these first preliminary results need further investigation with innovative approach based on the use of highly retentive hydrogels and/or organogels for non-invasive analysis of organic binders, working as smart micro-reactor and micro-extractor directly on the object, followed by mass spectrometric acquisitions.

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Keune K. & Boevé-Jones G. (2014) - Its Surreal: Zinc-Oxide Degradation and Misperceptions in Salvador Dalí's Couple with Clouds in Their Heads, 1936. In: van den Berg, K., et al. Issues in Contemporary Oil Paint. Springer, Cham, https://doi.org/10.1007/978-3-319-10100-2_19.

S8.

Geodiversity, Geoheritage and Geotourism: wondering about awareness for a sustainable Planet

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Virtual geological walk to discover the historical-artistic heritage of Rome and its lithoid resources: the Basilica di San Paolo fuori le mura

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Keywords: geotourism, geological heritage, geodiversity.

Rome, the Caput Mundi in the imperial age, now the fourth among the one hundred european cities that the tourists visited most for its rich historical-cultural and natural heritage. A city whose territorial, political and economic growth is due to the Geo-diversity and the resources of the area on which it was expanding. These features need to be disseminated to raise awareness among citizens toward a more sustainable development. Among the resources to be protected, there are the lithotypes, both those quarried for a long time from the local geological formations, and those from the Mediterranean Basin, that during the centuries came to Rome, to build and decorate great works of historical-artistic interest in the City. A heritage to be safeguarded and handed down, to "tell" during geological walks in presence, outdoor and indoor, but also, thanks to the modern technologies, through virtual tours: from the recognition of the rock, to the geological formation and the country where it comes from; from the quarries to the evolution of the extractive techniques, up to the use and their expression in the historical monuments of the city, passing through a dense network of economic and social relationships. An example of "geological" Virtual Tour is that realized for the Basilica di San Paolo fuori le mura, selected among the numerous monuments of Rome for its long history, from the palaeo-christian age to nowadays. This history is made of reconstructions and structural and decorative readaptations, in response to natural and anthropic changes of the territory in the surrounding area, but, above all, for the variety and beauty of its "marbles", that contribute to the narration of its transformations and to its valorization.

URGERE: URban GEodiversity for a Resilient Environment

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Keywords: geomorphometry, multiscale analysis, urban areas.

The URGERE project is concerned with resiliency of cities and urban areas in Italy (Alvioli, 2020a), with respect to geo-hydrological hazards and environmental impact on ecosystem services, human life and infrastructure. To do that, it first focuses the variety of the abiotic parameters, mostly geomorphological: namely "geomorphodiversity" (Melelli et al., 2017) , as a measure of the potential of morphological evolution of the landscape. Human presence contributes substantially to the modification of the landscape, especially in urban areas.

Urbanization is a growing phenomenon, and human presence and activities enhance environmental fragilities in cities. We propose a quantitative geodiversity index, GmI, focused only on geomorphological parameters, and with a high-resolution set of elevation and thematic data, homogeneously available all over Italy (Burnelli et al., 2023).

The focus is mostly on the use of digital elevation data, for they are the basis for geomorphometric analysis and for an automated classification of landforms, in addition to thematic information. Interpretation of the resulting index is straightforward, allowing a wide range of applications, at relatively low cost. Implications of different values of the index, in combination with geo-hydrological hazard, are prominent within urban areas. To this end, we single out urban areas with a novel, parameter-free technique, and we aggregate results of statistical models for geohazards at slope unit level (Alvioli, 2020b). Within this framework, we can describe geodiversity, the degree of urbanization, and hazards, at comparable resolution at the national level.

At intermediate/regional and local/urban level we investigate the possibility of relying on a different class of data, stemming from advanced use of aerial photographs and LiDAR measurements with airborne drones, exploiting existing datasets and newly acquired data at very high resolution, in selected locations. Recently developed photogrammetry techniques applied to historical aerial photographs provide digital models of vegetation surface, showing its change in time in the last century and allowing study of the links with local geodiversity and hazards.

We match the national GmI and local analysis in data rich locations thanks to the high-resolution of GmI, providing a truly multi-level and validated approach. Geomorphological mapping and numerical modeling of hazards with very-high-resolution data in selected urban areas elucidates the role of geodiversity and its impact on the environment and human life for a meaningful planning of urbanization and infrastructure. A public release of the software to obtain GmI in GIS using a collection of morphometric, geologic and environmental data is under way.

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Melelli L. et al. (2017) - Geomorphodiversity index: Quantifying the diversity of landforms and physical landscape. Sci Total Environ., 584, 701-714, https://10.1016/j.scitotenv.2017.01.101.

Exploring geodiversity through historical fountains and ancient springs: geotouristic paths in the Premurgia Region for sustainable development (Puglia, Southern Italy)

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Keywords: geodiversity, Premurge, springs.

Geodiversity can be defined as the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (land form, physical processes), soil, water and environmental features. It includes their assemblages, relationships, properties, interpretations and systems (Gray, 2013).

According to the Sustainable Development Goals of the 2030 Agenda, protection of geodiversity guarantees an essential framework for ensuring the conservation of biodiversity, the responsible management of natural resources, the reduction of natural hazards and the promotion of sustainable development models. Premurge area (Puglia, Southern Italy) offers a good opportunity to show how geodiversity could influence the development of historical settlements and enrich the biodiversity of a territory. Representing the transitional sector between the Apulian Foreland and the Bradanic Trough, this area includes the geological feature of both domains, respectively foreland and foredeep related to the evolution of the Southern Apennines Chain. The foreland (locally the Murgia Materana region), characterized by topographical up and down, is made up of fractured Cretaceous limestones which represent also the substrate of the foredeep (locally the Premurge region, Here the Cretaceous rocks are covered by Quaternary deposits. The latter, from the bottom to the top, comprise: coarse-grained calcarenites (Calcarenite di Gravina Fm) passing to clays (Argille subappennine Fm), in turn covered by sands and gravels (Regressive Deposits of the Bradanic Trough). The key position of clays below coarse-grained porous deposits favours the presence of local surface aquifers and several shallow springs. To discover these different geological features, it could be possible to promote a geotouristic itinerary along the old towns of Laterza, Gravina in Puglia, Matera, Poggiorsini and Spinazzola. Towns with different landscapes, from rugged and barren (such as the rock towns of Laterza, Matera and Gravina in Puglia) to humid and hilly (Poggiorsini and Spinazzola), are indeed linked by an important element: the water. The accessibility of surface water resources, fundamental in pre-modern times for the development of human settlements, is the important difference between the Premurgia area and the top of the Murge area, where towns lack.

The objective of the geotouristic itinerary is to outline how geodiversity enriches both the landscapes and resources of an area. Furthermore, promoting geotourism in these communities provides an opportunity to revitalise historic springs and restore access to drinking water sources, in line with the principles of sustainability and environmental management. By using geodiversity as a tool for education and cultural enrichment, these geotourism trails not only preserve the legacy of our ancestors, but also open the way for a more sustainable future. Targeted investment in the conservation and enhancement of geodiversity is therefore crucial to ensuring a equitable future for present and future generations.

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High-resolution geomorphodiversity and anthropization indices of Italy for urban geomorphology

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Keywords: geomorphodiversity, multiscale analysis, urban geology.

Urban geomorphology analyses morphological and topographic arrangement caused by human activity in urban areas. Urban sprawl modifies ecosystems, but most of the global actions for future sustainability focus on the biosphere, overlooking the role of the abiotic components, embedded in the geosphere. The geosphere and its diversity support natural processes and human health through a range of ecosystem services (Melelli et al., 2017).

Here, we propose the joint study of indicators of land surface variability and of anthropic modifications. We consider geomorphodiversity as a discrete measure of richness of abiotic components, previously obtained for the whole of Italy at high resolution (Burnelli et al., 2023), and a newly defined index describing the degree of human impact inferred from observed land cover classes. We specifically study the combination of the two indicators within urban areas of different sizes across Italy. Results show that the geomorphodiversity indexes are possible at large scale, using public datasets and consistently at high resolution, which permits simultaneously to study the national scale, and the local scale, within individual urban areas. The use of geomorphodiversity and anthropization indices is complementary, in that they describe different quantities whose change in time due to natural and anthropic actions occurs at completely different time scales.

We show that urban development in Italy was fostered in areas where the land surface is characterized by lowlands, alluvial plains or hills. Urban areas with large values of geomorphodiversity host larger numbers of natural areas. Studying ensembles of urban areas, we show that the particular shape and size of different definitions of urban boundaries are essential to investigate different aspects of human impact on the landscape (Alvioli, 2020).

We suggest that quantitative geomorphodiversity in combination with time–dependent indicators of land cover changes and of human impact may represent an additional tool to study the inherent relationship between the geosphere, the natural environment, and the anthropic modifications on the landscape (Del Monte et al., 2016). Our results provide a new approach to urban planning that considers the diversity abiotic parameters as a fundamental reference point for shaping future city development.

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Geomorphodiversity in urban areas and the role of geomorphological maps: the study case of Perugia (Central Italy)

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Keywords: geomorphodiversity, geomorphological map, urban geomorphology.

Geomorphodiversity, as an element of the geodiversity assessment, is defined by the variety of landforms and processes of a landscape resulting from the interaction between the lithological types, the surface processes and the climatic variables . The quantitative assessment of geomorphodiversity produces numerical indices objective, reproducible and scalable to different spatial resolutions (Melelli et al., 2017) as for the Land surface diversity index (GmI, Burnelli et al., 2023). It is assessed within a GIS-based approach using topographic variables derived from a Digital Elevation Models (DEM), and geological and hydrological data. The validation of the GmI is fundamental for the worth of the output data which depend on the type and spatial resolution of the DEM, the algorithms that process the attributes, and the moving windows radius for the variety. To date an effective validation method is the comparison with geomorphological maps.

This approach is particularly pertinent in urban environments and on high resolution analysis where anthropogenic transformations due to urbanization and human activities can significantly modify the early morphology over time. Geomorphodiversity indices assessed using high-resolution and relatively recent DEMs, are unable to depict the pre-settlement topography.

The case study in this work is Perugia, the capital city of the Umbria region (central Italy). The city's geological history and geomorphological conformation provide a clear example of how these factors have conditioned the expansion of the urban fabric for centuries.

The first geomorphological map of the city historical center is presented here , it summarizes the natural landforms and the anthropogenic transformations to the topographical surface from around the 3rd century B.C. to the present day.

The aim of this work is to compare the map and the GmI assessed using both the current DEM and the pre-settlement DEM, obtained combining geognostic surveys and historical-archaeological data (Vergari et al., 2022).

The results are two different geomorphodiversity indexes pre- and post- urbanization. A comparison with the geomorphological map allows for timely validation. The mapping of the variation of geomorphodiversity over time due to anthropogenic transformations is original and incisive for the evaluation on the human impact on geodiversity.

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Unveiling the interplay of mining activities and geo-tourism: an analysis in the Northern Italian region

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Keywords: industrial tourism, geo-tourism, mining tourism.

Mining activities leave a lasting imprint on the landscapes they inhabit, manifesting in a multitude of ways. Physically, their presence is marked by tunnels into the earth, extractive waste facilities, and industrial dressing plants. Yet, their impact extends beyond the tangible; they weave a complex web of economic, social, and environmental consequences.

In the context of the Germanasca Valley, nestled within the majestic embrace of the Alps, mining has been an enduring companion to both the landscape and the local population for centuries. It has entrenched itself as an integral facet of the region, intricately interwoven with its economic and social fabric. The symbiotic relationship between mining and the valley has fostered a sense of interconnectedness, shaping the landscape and the livelihoods of its inhabitants.

As mining operations gradually migrated to lower altitudes, they left behind a tapestry of historic mining structures. Remarkably, these remnants have found new purpose, albeit partially, as catalysts for emerging forms of industrial and geo-tourism (Ólafsdóttir & Tverijonaite, 2018). This adaptive reuse stands as a testament to the resilience of the local community and their ability to harness the legacy of their mining heritage (Jelen, 2018) for contemporary endeavors.

Closely, the technological advance and the evolution of mining production, towards a higher quality product, with a consequent reduction in the quantities exploited has led over time to a progressive reduction in the number of miners employed.

The contraction of work in the mine has been partially absorbed by transforming former miners in tourist guides and increasing the activities induced, passing from the previous model “in house” to an “outsourcing” model, where many mine-related activities are outsourced.

The transformation of old mines into museums has certainly contributed to the development of the area, particularly considering a rediscovery tourism that has little to do with the “fast and junk” tourism that has grown lately.

The allure of the Germanasca Valley lies not only in its scenic vistas but also in the intricate tapestry of its mining legacy. It serves as a microcosm, a living laboratory, where the dynamic interplay between active mining endeavors and territorial development unfolds before our eyes. Here, mineral extraction and geo-tourism converge, shaping the landscape and enriching the human experience.

Indeed, the Germanasca Valley stands as a compelling case study, illuminating the profound interdependence between mining activities and the holistic development of a region (Moyle et al., 2018). It underscores the symbiotic relationship between resource extraction and the burgeoning geo-tourism industry, underscoring the imperative of sustainable practices and mindful stewardship of our natural and cultural heritage.

This flourishing form of geo-tourism stands in stark contrast to the superficial allure of mass tourism, offering a nuanced exploration of the valley’s cultural and geological heritage (Varriale et al., 2023), beckoning travelers seeking more profound and authentic experiences.

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The PanAfGeo Project: the role and experience of ISPRA, Geological Survey of Italy for the enhancement and protection of geological heritage

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Keywords: geoheritage, Africa, training.

In April 2024, ISPRA participated in a training program on Geoheritage in Lobatse (Botswana) in the framework of the EC PanAfGeo-2 Project.

The project, started in 2014, is aimed at strengthening the relationship between EU and African countries and providing a set of training sessions to geoscientific staff from African Geological Surveys on several topics related to Geosciences for e.g. sustainable mineral exploitation and related infrastructures, natural disaster prevention and mitigation, geoscientific mapping, and conservation and enhancement of geological heritage.

As a matter of fact, the African continent is particularly rich in geological diversity. Presently, the main efforts are being devoted to exploitation of mineral raw materials; nonetheless, this does not sufficiently contribute to the improvement of the overall living conditions of the African population. Being either still unexplored or unclassified, most of the continent's mineral resources are still widely under-exploited.

Detailed and reliable geological data and information are vitally important to the economy of African countries as well as to the protection of its bio and geodiversity and population. In this regard, Geological Surveys can provide services that can be used by state agencies, consultants, industry, developers and the public as key input for local and regional socio-economic development plans, being of support to the achievement of objectives related to, among others, environmental protection (especially water and soil), natural and anthropogenic hazards, energy and mineral resources, land-use planning, agriculture, economic development, earth resources development, climate change, sustainability, and tourism.

In Botswana, seminars with practical desk and field activities were held, attended by 45 geologists from African and European Geological Services, during which the state-of-the-art on geological heritage was presented, based on distinct experiences and methods. A specific effort was done to identification of sites of high geological interest (geosites) and implementation of national inventories as well as supporting sustainable management of territorial resources to promote geological culture and develop potential geotourism routes in Africa. The systematic identification of "geosites" will also assist in UNESCO Geoparks nominations which, in Africa, are very few and highly underestimated. During the training, some potentialities of open-access Lidar remote sensing tools were also applied, tested, and shared with local Geological Service; actually, ISPRA is applying such tools as part of the EC-funded GeosciencesIR- PNRR project for the digitalization of geosites, and precisely to promote and make the geological heritage more accessible to specialists, stakeholders and public.

Geology and cultural heritage in Petra (Jordan): evolution and degradation in relation with tourism management

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Keywords: geotourism, Petra WH site, geological risks.

Tourism plays a significant role in enhancing destinations' economies, social life, culture, and the environment. On the other hand, unplanned and uncontrolled tourism growth can lead to negative outcomes and harmful influences, not only upon the destination environment but also on the social and cultural values of a community. The case of Petra (Jordan) a World Heritage site since 1985 can well encompass and represent the positive and negative impacts of tourism development on this worldwide known 'marvel' of the modern World. As a matter of fact, the tourism in Petra provided job opportunities to local people, alleviating poverty, improving infrastructures, tourism investments, and greatly supports the GDP of Jordan. At the same time, the excess of tourism capacity recorded in the last decade in Petra has caused also negative impacts on the conservation of the monuments as well as on the natural, and geological environments.

The archaeological site of Petra is characterized by Nabataean monuments, hand-carved in the local sandstone rock. From a geological point of view, Petra's tangible cultural heritage suffers from several natural and human-induced hazards, such as earthquakes, landslides, floods, weathering that pose a threaten to the site and visitors. The major risk for the tourists is represented by the occurrence of flash-floods and rock falls in the 'Siq', a 1.2 km natural gorge which serves as to main entrance to the site. The consciousness of this permanent danger in the Siq resulted in the implementation of the 'Siq Stability Programme', a series of UNESCO project initiatives started in 2009 in cooperation with the Jordanian authorities, scientifically coordinated by ISPRA, Dept. for the Geological Survey of Italy. This initiative was also in line with the Hyogo Framework for Action 2005-2015, the main UN-wide policy on Disaster Reduction, which encourages the awareness of the importance of disaster reduction policies as a key objective to ensure the substantial reduction of disaster losses and enhance the resilience of local communities.

The 'Siq Stability Programme' was then implemented with the main objective to ensure that preventative measure were in place in the main tourist areas for the protection of the Petra's cultural heritage again natural risks and the safety of thousands of tourists who visit Petra each year.

The programme included a phase of preliminary multi-discipline studies, implementation of landslide mitigation works including rock slope consolidation with a team of expert rock climbers with the involvement of the local community and park rangers. Several scientific and technical trainings were also organized for Jordanian technicians, and a series of awareness campaigns addressed to the local community and visitors. This initiative can be considered as a best practice for the geological conservation in a UNESCO World Heritage site.

Multidisciplinary scientific investigation supporting assessment, valorisation, and management of geoheritage: lessons from CLIMATE@COA project

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Keywords: fluvial landscape, open-air prehistoric rock art, UNESCO world heritage.

The CLIMATE@COA project (COA/CAC/0031/2019) – '*Climate and human adaptation during the Last Glacial Period in the Côa Valley region (Portugal)*' is an integrated multidisciplinary scientific initiative funded by the Ministry of Science, Technology and Higher Education of Portugal (www.climatecoa.org). Its distinctive approach involves the analysis of various terrestrial records (natural and cultural) preserved in northeast Portugal's Côa River Valley region. This territory is not only home to exceptional open-air prehistoric rock art classified as a UNESCO World Heritage site since 1998 but also contains fluvial landforms and sediments that hold significant information concerning the climate evolution of the Last Glacial Period, as well as archaeological remains that allow us to understand coeval human occupation. The ongoing investigation is based on a multi-scalar analytical approach that utilises stratigraphical, sedimentological, geochemical, geomorphological, archaeological, and geochronological research to decipher long- and short-term landscape evolution and deduce the environmental forcing factors for such evolution, namely climate and ecosystem changes. The collected data also help us better understand the societies and behaviours of Middle-Upper Palaeolithic hunter-gatherer human populations in the Iberian Atlantic façade. The execution of this project highlights the importance of multidisciplinary scientific investigation in supporting the assessment, valorisation, and management of the geological, geomorphological, and archaeological uniqueness of the study area, as well as its history, scientific value, educational potential, and geotourism opportunities, encompassing a wide range of geodiversity (from local sedimentary outcrops to UNESCO recognition). Indeed, to properly appreciate and monitor its intrinsic geoheritage and geotouristic values, it is crucial to deeply understand the natural dynamics of the territories. Additionally, it is necessary to assess, classify, appreciate, and monitor these elements to ensure their preservation and promotion for future generations. In this context, the project's results and conclusions are valuable only if shared with stakeholders responsible for planning, management, conservation, culture, economics, and social issues. Thus, the information produced can provide original and valuable data that are scientifically valid and applicable in supporting territorial planning, environmental management, and geotourism. For instance, exploring the natural and cultural heritage and diversifying tourism can be improved through these data - e.g., revitalising scientific information and contents of the Côa Museum and associated Archaeological Park. This, in turn, can assist in defining strategies for a more integrated and sustainable local and regional development.

Degradation risk and sensitivity to climate change of geosites: a methodology for quantitative assessment

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Keywords: geosites, degradation risk, vulnerability.

In recent years, research on geoheritage has gradually focused on the risk of degradation of geosites. The identification of threats to geoheritage, whether natural or anthropogenic in origin, and the consequent assessment of degradation risk, is considered a fundamental aspect in any geoconservation strategy. Several methodologies, both qualitative and quantitative, have been proposed in scientific literature to assess the degradation risk of geosites. In most cases, these assessments are incorporated into the general geosite value assessment procedure (e.g. Brilha, 2018), and revolve around the concepts of "fragility", "vulnerability", "sensitivity" etc., terms that have been used inconsistently over the years (Garcia-Ortiz et al., 2014).

In this paper, in addition to a brief review of specific terminology, a quantitative methodology is proposed for assessing the degradation risk of geosites. The procedure is divided into four blocks, concerning: i) fragility, dependent on the intrinsic characteristics of the geosite; ii) natural vulnerability, i.e. the sensitivity to degradation dependent on natural processes; iii) anthropogenic vulnerability, i.e. due to human action; iv) sensitivity to climate change. Each of these four blocks was assessed by means of a set of indicators, to which numerical scores are attributed.

The methodology was tested on two different inventories of geosites, the first concerning the Liguria region (North-Western Italy), the second in the Hérens Valley of the Pennine Alps (Valais, Switzerland). The methodology is structured to be easily replicable in other study areas and in different geographical-geomorphological contexts, and the results may constitute an important tool for the outlining of effective management and valorisation strategies for geosites.

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García-Ortiz E. et al. (2014) - Concepts and terminology for the risk of degradation of geological heritage sites: fragility and natural vulnerability, a case study. Proceedings of the Geologists' Association, 125(4), 463-479, https://doi.org/10.1016/j.pgeola.2014.06.003.

In search for a key area for geotourism? The example of "Sassi", the old town of Matera (Southern Italy)

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Keywords: geotourism, Sassi di Matera, rupestrian town.

The rupestrian old town of Matera (southern Italy) is an urban area included in the UNESCO World Heritage List since 1993 and designated as European Capital of Culture for the 2019. Since prehistoric times, the old town, called "Sassi di Matera" ("sassi" is the Italian word for stones), has been spectacularly dug in a "soft rock" (a quaternary calcarenite). This rupestrian settlement is perched in the upper part of the right side of the "Gravina di Matera", a canyon cutting the so called "Murgia Materana", the barren rocky high in front of the town.

An increasing number of tourists is attracted by itineraries crossing the "Sassi di Matera", and, due to the intimate connection between the old town and the geological anatomy of the area, each touristic itinerary could become an urban geotour or could be enriched by geological information (Tropeano et al., 2018). Therefore, tourists visiting the old town of Matera and admiring several amazing panoramic view from easy points, may be intrigued in understanding the development of the crossed landscape.

Tropeano M. et al. (2018) - "Sassi", the Old Town of Matera (Southern Italy): First Aid for Geotourists in the "European Capital of Culture 2019". Alp. Mediterr. Quat., 31, 133-145, https://doi.org/10.26382/AMQ.2018.09

Geotourism as a tool for geoheritage promotion: a geotrail project in Beigua UNESCO Global Geopark (Liguria, Italy)

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Keywords: geodiversity, european charter for sustainable tourism, geosites.

The geoparks contribution to the development of geotourism is widely recognized (Farsani et al., 2014; Albani et al., 2022) and the UNESCO Global Geoparks (UGGp) are among the most suitable place to perform geotouristic studies, to develop and to promote geotourism as well as to test innovative tools. The European Geoparks Network (EGN) guidelines (Zouros, 2004) stated the pivotal role of geoparks in the economic development through the enhancement of geoheritage and the development of geotourism. This study was performed in the Beigua UGGp, which is located in northwestern part of Italy, in the junction between the Ligurian Alps and the Northern Apennines. It covers 42,376 hectares and includes the whole territory of Beigua Regional Nature Park (8,791 hectares), straddling the provinces of Genova and Savona. The geopark area is mostly composed by metamorphosed ophiolites and their oceanic sedimentary cover, with minor occurrences of metamorphosed rocks of continental crust; in addition, all lithologies are covered by limited outcrops of clastic sedimentary rocks and Quaternary sediments. The outstanding geodiversity of Beigua UGGp is well represented in fifty-four geosites covering a wide number of geological aspects of the complex tectono-metamorphic evolution of the area.

Beigua UGGp is actively involved in the development of sustainable tourism, particularly geotourism, to create a virtuous circle leading to the awareness on the importance of geoheritage and nature conservation. In 2023, Beigua UGGp applied to the European Charter of Sustainable Tourism in Protected Areas (ECST) to integrate tourism development within parks with the protection of natural environment. An action plan including ninety actions, to be developed between 2024 and 2028, was submitted by Beigua UGGp and forty-four stakeholders comprising local authorities, tour operators, farms, museum, territorial associations, and university. The proposed actions are included in the following four strategic axes of the plan: biodiversity, geodiversity, landscapes, and sustainable tourism development. The action described in this works concern the "Geosites and geodiversity valorization" and aims to promote geoheritage in Beigua UGGp through the scientific investigation of the most representative geosites followed by the creation of innovative geotouristic tools and thematic geotrails.

Fifteen geosites, covering the most important geological features of the geopark, were chosen basing on several aspects, such as scientific and cultural importance, representativeness, didactic and touristic potential, scenery, accessibility as well as fragility and vulnerability. The geotrails were designed and mapped according to the existing network of hiking and biking trails within the Beigua UGGp that pass near the selected geosites. Moreover, the geotrails include several noticeable geological points of interest ("geostops") suitable to show peculiar geological insights.

Albani R.A. et al. (2022) - New approach on the quantitative assessment of geotouristic potential: A case study in the northern area of the Rio De Janeiro Cliffs and Lagoons Geopark project. Geoherit., 14(2), 72, https://doi.org/10.1007/s12371-022-00707-7.

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Zouros N. (2004) - The European Geoparks Network-Geological heritage protection and local development. Episodes J. Int. Geosci., 27(3), 165-171, https://doi.org/10.18814/epiiugs/2004/v27i3/002.

The role of geosciences to activate the virtuous circle: awareness of geodiversity values - enhancement of geoheritage - growth of sustainable geotourism - public engagement

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Keywords: geodiversity, geoheritage, geotourism.

Geosciences play a fundamental role in promoting awareness of geodiversity and its possible contributions to the enhancement of natural and cultural heritage. This is a fundamental role that can be strengthened by territorial policies that develop geoheritage assessment and at the same time promote sustainable use of the environment, particularly through environmentally friendly geotourism.

The GeoSIT-Piemonte team has developed an innovative -conceptual and operational- "circular, approach" to the geoheritage in the Piemonte region: 1) to use digital knowledge for assessing geodiversity, useful for 2) inventorying geosites and enhancing geoheritage, therefore allowing 3) growth of sustainable geotourism, and 4) public recognition of the whole "virtuous circle", also by means of adequate administrative and policy actions, culminating in the L.23/2023 Regional Law on geoheritage conservation, management and valorization.

Comparative analyses of scientific literature on the rich Piemonte geodiversity lead to the identification of the most representative geothematic areas and related geosites, including landforms, geological units and processes of different ages and environments. Description and interpretation forms on scientific and additional values of geosites, related to educational, cultural, aesthetic and other interests, allowed comprehensive assessments of natural and cultural heritage; these are supporting promotion and management initiatives in the regional territory. To ensure a balance between the protection of Nature and the need for local economic development, we aim at a sustainable use of geosites of high scientific value for educational activities, geotourism itineraries, cultural proposals, thus enhancing their local economic resources.

For effective activation of the virtuous circle, some important issues of the public engagement on geodiversity and geoheritage of the territory were taken into consideration:

In order to spread information and geoscience knowledge, the geotouristic offers need to be for everybody, with the planning of paths to be accessible to people with disability and specific itinerary adapted for blind and/or deaf people, in which other senses can be used.

For enhanced link between cultural and geological heritage, a central role is played by the self-guided tours and itineraries. In this way, the geotourist is guided during the visit of the cultural and geological sites in the identification of the connection between the geoheritage and the cultural heritage.

Furthermore, local communities usually preserve original ideas, stories, and customs that have been transmitted along over decades. These contributions help to deepen understanding of a certain area's geological history and significance while underscoring the intimate relationship between humans and their environment. Incorporating local knowledge improves understanding of geoheritage, generating a sense of caring and community among both inhabitants and tourists. Thus, it is critical for geoheritage to recognize and appreciate local and vernacular knowledge.

Dynamic geodiversity and environmental sustainability within alpine glacial areas: educational values for the secondary schools

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Keywords: sustainability, glacial areas, education.

Due to the present day accelerated climate change, Alpine environments are experiencing increased warming, resulting in a rapid change of the interaction of landforms, rocks, soils, water, air, and living organisms. This in turn is causing accelerated geodiversity changes within mountain glaciated areas. Therefore the concept of dynamic geodiversity is of increasing importance for enhanced awareness on sustainability issues, both in educational plans, and environmental management.

Based on data on dynamic geodiversity (from the historical archive of the Italian Glaciological committee) we proposed a laboratory activity targeted to the analysis of some of the most clear example of the interaction of the planet and climate change: glaciers (SDG 13 of the Sustainable Development Goals; UN Agenda 2030). In particular, we analysed data from the northernmost valleys of Piemonte region: the Lepontine Alps (Ossola valley).

We worked with 16 students aged 17, and offered them with a selection of glaciological data (description and measurement from the reports of the annual glaciological campaign) and related images (terrestrial and aerial pictures of glaciated areas). The students accessed this material online and were asked to create diagrams and make interpretation for describing the dynamic evolution of glaciated areas within a time interval of several decades (1970-2022).

Students could recognize some relevant facts of climate-glacier interaction: the progressive but uneven withdrawal of glaciated areas related to temperature rise, the pulsed behaviour of glacial masses, the accelerated glacial instabilities during last decades.

For highlighting the relationship within dynamic geodiversity and sustainability, we tested student knowledge on these concepts before and after the laboratory activity, thus proving the virtuous outcome of working on the natural environment to increase the awareness of young generations on the current climate crisis, its effects on the mountain areas and its resources, and stimulating good practices for mitigating impacts and climate hazards, and enhancing resilience.

Geosites as a tool for climate change education: a case study in Piedmont, IT

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Keywords: geodiversity, outdoor education, sustainable development.

The objective of raising awareness on geodiversity cannot be fully achieved without a strategy that involves schools of all levels as much as possible: in particular, to use geosites in school education is one of the important ways to promote geoheritage values (Zgłobicki et al., 2024). This is why, for example, in Piedmont the recent regional law on geodiversity (LR Piemonte 23/23) stipulates that the inventory of geosites must also indicate their possible educational value: this potential does not always correspond to their scientific importance, as the visibility and comprehensibility of the phenomena are more important for didactic purposes (Drápela, 2022). This study presents the results of an analysis conducted among the students of 3 classes of I grade secondary schools that took part in an outdoor activity entitled "Earth Sciences and climate change", in which, after an introductory meeting held in the classroom, a didactic excursion was planned to the Spiaggia dei Cristalli (Verduno, CN), an important outcrop allowing to explore Messinian deep marine sediments and gypsum deposits and to unravel the paleoclimatic clues they record. Here, an inquiry-based method was adopted through a sensory exploration of the area that prompted participants to reflect on their own relationship with Nature and the role of humans in the current ecological crisis. The students' answers to the pre- and post-experience questionnaires show that the visit to the geosite was fundamental for learning some basics of stratigraphy, paleoceanography, paleoclimatology and sedimentology, as well as for effectively understanding how Earth Sciences systemic thinking applied to the study of past climatic changes helps to compare them with those taking place today and to address their causes and impacts. Our suggestion is therefore to enhance the use of geosites as a teaching tool, as they allow for a transdisciplinary and transformative outdoor education approach, which aligns geoscience education with the goals of education for sustainability: this will make it even more evident the extremely important and unique contributions of Earth Sciences for the understanding of Earth's past, clearly connected with a sustainable future for both humankind and non-humans (Gerbaudo et al., 2022).

Drápela E. (2022) - Assessing the Educational Potential of Geosites: Introducing a Method Using Inquiry-Based Learning. Resources, 11, 101, https://doi.org/10.3390/resources11110101.

L.R. Piemonte 23/23, Disposizioni per la conservazione, gestione e valorizzazione del patrimonio geologico. Legge Regionale del 06/10/2023, N. 23. B.U.R. Piemonte Suppl. Ord., 2023, 3.

Gerbaudo A. et al. (2022) - Comment on "Gerbaudo et al. Are We Ready for a Sustainable Development? A Survey among Young Geoscientists in Italy. Sustainability, 14, 7621, https://doi.org/10.3390/su142316101.

Zgłobicki W. et al. (2024) - The Use of Geosites in Education—A Case Study in Central Poland. Resources, 13, 15, https://doi.org/10.3390/resources13010015.

Geosites inventory and territorial planning

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Keywords: geodiversity, geoconservation, inventory.

The geological heritage, by its intrinsic nature, holds scientific, environmental, cultural, and tourist-recreational value. Fundamental elements of geological heritage are geosites. Geosites represent a distributed archive of non-renewable natural resources that allow for the recognition, study, and interpretation of the evolution of Earth's geological history, particularly within the area they are located in, to the extent of determining an interest in their conservation. These are "geological singularities" (sites rich in fossils, minerals, landscape morphological elements, etc.) that, due to their rarity, scientific value, scenic beauty, cultural and educational usability, can be considered true geological "monuments" to be protected, safeguarded, and enhanced (APAT, 2005).

Thanks to its geological and geomorphological peculiarities, Italy is particularly rich in geodiversity, which is closely linked to biodiversity. The geological characteristics of the substrate influence the diversity of life and are in turn influenced by it. The state of conservation of geodiversity thus affects that of biodiversity and must therefore be protected to ensure the balance of the environmental system. Often, but not always, geosites are found within protected areas; however, this does not exempt them from dangers, just as those outside naturalistic areas are certainly more exposed.

Their correct cataloging allows both long-term protection and potential enhancement in the case of possible tourist-recreational use, making them an absolute testimony of the landscape of which they are part.

Geosites constitute the geological heritage, a component of natural heritage, the protection of which is provided for in legislation on protected areas, cultural heritage, landscape protection, and also in the Constitution (Fabbri et al., 2014). Once geosites are identified, it is necessary to adequately plan the geoconservation process, for example through a series of procedural phases: geosite proposal; geosite validation; insertion of the geosite into the database; establishment of territorial management models aimed at environmental protection; incorporation of the database into higher-level territorial planning; incorporation of the database into local territorial planning.

The inventory of Geosites, implemented by the Italian Geological Survey (ISPRA), is an indispensable knowledge tool for their enhancement and protection, also through the promotion of local development forms such as geotourism.

Their census also contributes to increasing awareness of the natural risks to which the territory is exposed, giving local administrations the opportunity to take them into account for the purpose of better territorial planning.

APAT (2005) - Patrimonio geologico e geodiversità. Rapporti - 51/2005, ISBN 88-448-0151-5.

Fabbri M. et al. (2014) - I geositi del territorio di Roma Capitale. Società Italiana di Geologia Ambientale. Supplemento al n. 3/2014 di Geologia dell'Ambiente, ISSN 1591-5352.

Geosites as natural scientific laboratory: investigating the links between geology, soil chemistry and botany

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Keywords: geodiversity, biodiversity, REEs.

Geosites are commonly considered as an expression of the geodiversity of a territory, as a range of geological, geomorphological and soil features. These characteristics are crucial for the different species that live in these areas. Consequently, the conservation of geodiversity and geological heritage contributes to the integrity of the ecosystems combatting the loss of biodiversity.

The present research starts from a competitive call promoted by the University of Bari, Horizon Europe Seeds 2021, within the project "Rare earths, geochemical elements of strategic importance: presence in subsoil and soil, and effects in model organisms". This project aims to synthesize the literature data about the occurrence of REEs in abiotic matrices (rocks and soils) and to unravel their mechanisms of transfer in biological ones (microalgae, terrestrial and aquatic plants), their environmental behavior and potential toxicity in biological matrices. Rare earth elements (REEs) playing an important role in several industrial and chemical applications are extracted from rocks and minerals in large quantities. Overuse promotes their increase in ecosystems with effects on the environment and on the biotic communities that still partially escape our knowledge.

The investigation of the distribution and the behavior of some minor and trace elements (with particular attention to REEs) in karst limestones during progressive chemical alteration processes is proposed as a case study. We present and discuss the first evidence from a geosite selected as a natural scientific laboratory along the Apulian Murge Area (southern Italy).

Preliminary data indicate that the karst alteration process on limestone was promoted and accelerated by allochthonous siliciclastic material supply and silicate solution circulation between the carbonate bedrock and the overhead pelite material (Micheletti et al., 2023). These processes seem to favor mobility and increase of REEs contents from the carbonate substrate to the residual deposits ("terra rossa" and bauxites).

Ongoing experiments aim to evaluate the adverse and/or positive effects of REEs exposures in plants, soil-borne plant-pathogenic fungi and animal models and their physiological/molecular evidence. The overall information points to shifts from toxic to favorable effects in model systems according to their concentrations, suggesting the occurrence of hormetic behavior (Gjata et al., 2022; Tommasi et al., 2022).

Understanding the transfer mechanism and the behavior of REEs on some model organisms may be useful to better define the close relationships between abiotic and biotic factors. This analytical approach will be easily extended to anthropic sources of contaminant elements such as active or inactive mining/industrial sites.

This research also has an educational value as it was the inspiration for joining the "GeoEventi 2022" call promoted by the aspiring UNESCO Geoparck "Alta Murgia National Park" through didactic walks favoring Citizen Science.

Gjata I. et al. (2022) - Cytological alterations and oxidative stress induced by Cerium and Neodymium in lentil seedlings and onion bulbs. Front. Environ. Sci., 10, https://doi.org/10.3389/fenvs.2022.969162.

Micheletti F. et al. (2023) - Petrographic and Geochemical Inferences for Genesis of Terra Rossa: A Case Study from the Apulian Karst (Southern Italy). Minerals, 13(4), 499, https://doi.org/10.3390/min13040499.

Tommasi F. et al. (2022) - Evaluation of rare earth element-associated hormetic effects in candidate fertilizers and livestock feed additives. Biol. Trace Elem. Res., 1-9, https://doi.org/10.1007/s12011-022-03331-2.

Urban geology and geoheritage conservation: enhancing aspiring UNESCO geopark development in the Gargano promontory

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Keywords: urban geology, geoheritage, geoparks.

The Gargano Promontory is an ideal candidate for UNESCO Global Geopark due to its size (about 2000 kmq), well-defined geographic boundaries, unique geology, partially distinct from the rest of the Apulia Region, rich biodiversity, and cultural heritage featuring significant archaeological sites (Morsilli & Gianolla, 2022).

Noteworthy geological features include internationally renowned sites like Punta delle Pietre Nere, showcasing the oldest rocks in Apulia, and Dolina Pozzatina, one of Europe's largest dolines. The region's geological composition spans from Upper Jurassic to Miocene carbonate rocks alongside prominent structural elements like the Mattinata Fault. These geological complexities have contributed to the creation of the region's captivating natural landscape, characterized by karst features, valleys, small canyons, rocky cliffs, sandy beaches, and lagoons. Sedimentological highlights encompass diverse settings from shallow-water to basin environments with inner-platform peritidal cycles, marginal facies with stromatoporoids or ooids, as well as well-exposed slope and base-of-slope facies showcasing a diverse array of gravity-flow deposits, and basinal white limestones with colored cherts and frequent slumpings (Morsilli et al., 2021).

In addition to its geological significance, the Gargano boasts a rich cultural heritage, including the legend of Archangel Michael's apparition, which has contributed to its historical and cultural amalgamation (Piccardi, 2005).

Furthermore, recognizing that many Apulian towns are situated on carbonate rock, this study will delve into the role of urban geology, and particularly the visible sedimentologic features, in geoheritage conservation and geotourism development thus adding an additional layer of significance to the region's geological and cultural assets.

Morsilli M. & Gianolla P. (2022) - Gargano Promontory (Apulia, Italy): a natural aspiring candidate for the UNESCO Global Geoparks network. Congresso della Società Geologica Italiana: Geoscience for a sustainable future, Torino, https://doi.org/10.3301/ABSGI.2022.02.

Morsilli M. et al. (2021) - A journey along the Gargano Promontory (Southern Italy): The Late Jurassic to Eocene Apulia Carbonate Platform evolution. In: Field guides to exceptionally exposed carbonate outcrops, International Association of Sedimentologists, 395-480, https://doi.org/10.54780/IASFG3/08.

Piccardi L. (2005) - Paleoseismic evidence of legendary earthquakes: The apparition of Archangel Michael at Monte Sant'Angelo (Italy). Tectonophysics, 408, 113-128, https://doi:10.1016/j.tecto.2005.05.041.

The new geosites identified by the Sezione Geologica regionale and the geological forms of the landscape in Umbria

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Keywords: geosite, landscape, geology.

The Sezione Geologica of the Regione Umbria has reviewed all the geosites that had been defined with article 86 of the Regional Law 21 January 2015 n. 1 which defines and protects the "Areas of particular geological interest and geological singularities". The complete review work began in 2021 and this activity was carried out in coordination with the thematic table "Geological Heritage" established by the Board of Directors of the State-Regions and Autonomous Provinces Geological Committee. In the review, the definitions and criteria that define the geosite were taken into account and all the areas of particular geological interest were reviewed, identifying the changes that needed to be made also following specific inspections and surveys. The work, compared to the 43 previous geosites, defined: 24 confirmed geosites; 8 unified geosites with changes to the perimeter; 3 new geosites; 8 geological singularities erased. For the geosites, in the descriptive sheets it has also been indicated in which domain of the geological forms of the Umbrian landscape they fall. In Umbria, detailed geological information is available for the entire regional territory and this has allowed the identification of 10 different domains of geological landscape forms which indicates the most prominent forms of the landscape that derive from the geological characteristics. Geological syntheses of Umbria were developed in 5 different geological domains in which the geological units were grouped. The geological-morphological characteristics of the Umbrian alluvial valleys were also considered, which vary depending on the size of the river. Globally, alluvial deposits of different ages occupy 36.3% of the regional territory, well over 1/3 of the entire region. Alluvial deposits are characterized by the characteristic of being lenticular; their thicknesses are very variable. The situation changes if we analyze the geological representativeness (ref. the geological Representativeness https://doi.org/10.13140/RG.2.2.15393.76642) of the different alluvial deposits, i.e. going to the geological representativeness of the current and terraced alluvial deposits is 0.56%, while that of the ancient and very ancient alluvial is 26%. These numbers indicate unequivocally that the current and terraced alluvial deposits have a different geological representativeness from the ancient ones: the former extend areally but are film-like with a shape factor of approximately 1/45, while the ancient ones sometimes have thicknesses even greater than their areal extension. In many cases there are inversions of the relief with areas that were previously depressed, i.e. occupied by alluvial valleys, now found high up, constituting a large part of the Umbrian hills and vice versa. The lithological characteristics of the rocks and ancient alluvial deposits are the main cause of the landscape shapes present in Umbria. Through selective erosion, the least erodible deposits have formed reliefs and most of the historic inhabited centers and localities of Umbria have been built on these reliefs. The detailed geological information available for Umbria allows us to have a very precise picture of the geological units, or parts of them, which are more resistant and those which are less resistant, allowing us to identify the forms which are in relief or very prominent from those which are valleys, in addition of course to the flat alluvial valleys.

Geotourism: empowering geologists or engaging the masses?

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Keywords: geotourism, geosite, heritage.

A geosite is a geological asset worthy of protection due to its representation of "geodiversity", showcasing the geological richness of a region and its intricate links with landscape, social, cultural, human, and economic aspects. Geotourism plays a pivotal role in appreciating and preserving geosites sustainably. The Sezione Geologica has established an online platform for proposing geosites to involve a wider audience, but minimal proposals have been received despite significant efforts in information dissemination. This highlights the perception that only industry experts possess the requisite knowledge for accurate identification and dissemination of geosites. Information provided by tourist operators or economic entities often tends to be biased, disseminating irrelevant or erroneous information. The challenge lies in balancing the expertise of geologists with engaging the broader community in identifying and promoting geosites. Collaborative efforts are needed to leverage both the specialized knowledge of geologists and the insights of local communities and tourists. To address the limited public response, the regional Sezione Geologica initiated a project to design the "Spoleto-Norcia geo-tourist route," accompanied by general and geological information, photos, and brief explanations accessible to non-experts. The project utilizes apps like Komoot and Conota Camera for route planning, photo capturing, and note-taking, enhancing user experience with additional data such as project details, GPS coordinates, and environmental information. The objective of this initiative is to enhance public understanding of the region's geological heritage by invoking emotions, imagination, and curiosity among hikers. Notable historical and artistic landmarks, as well as efforts aimed at preserving cultural heritage and public safety, are highlighted, with special attention to remnants of railway infrastructure. The former Spoleto-Norcia railway route is being traversed on foot, focusing on identifying visible geological features along 5 km segments. The project timeline includes 5 months for data acquisition and three additional months for finalizing products. In conclusion, the project aims to balance leveraging geologists' expertise with fostering community engagement in exploring and promoting geosites. Through collaborative efforts, sustainable management and appreciation of geological heritage for present and future generations are ensured.

The relevance and current state of the Villaggio del Pescatore lagerstätte (Campanian, Italy)

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Keywords: Villaggio del Pescatore, paleobiology, geosites.

Located in the Duino-Aurisina municipality, about 20 km to the north-west of Trieste, the Villaggio del Pescatore (VdP) paleontological site stands as the most informative early/middle Campanian lagerstätte in southern Europe. The site is geographically located in a territory that includes a remarkable number of geological, archaeological, and environmental gems and not by chance is formally included into the ISPRA Italian Geosites Inventory. Ever since the 1990's, fossil beds have resulted extremely productive, yielding an unparalleled sample of the diversity in the Cretaceous European ecoregion. In addition to multiple articulated hadrosauroid dinosaurs, crocodylomorphs and teleosts, abundant invertebrate and floral remains were recently reevaluated, revealing a greatly underestimated diversity. In particular, the systematic revision of historic, neglected, and newly acquired data into a unified framework (which include all stratigraphic, taphonomic, geochemical, palaeobotanical, micro-anatomical, and palaeoecological aspects) set the ground for determining lines of investigations with immediate effects. Relevant examples are new micro-tomographic and fluorescence analyses on vertebrate remains (in collaboration with the Elettra Synchrotron, Trieste), the identification of a diverse associated biota (including articulated insects, crustaceans and megafloral remains), and microbiological interactions as a key component on the taphonomy and genesis of the site. Furthermore, careful inspections at the quarry in 2024 allowed to identify and map many diagnostic, in situ specimens exposed to weathering agents. Unfortunately, the lack of fundings and the complex management requirements have hindered extracting activities, which are currently at a standstill. From a scientific perspective, the VdP stands as one of the most relevant geosites in Italy having, in addition, a potential for promoting educational activities related to geosciences and economic income related to cultural tourism. A clear stance by the scientific community may effectively trigger positive institutional actions toward its protection and promotion.

Geoheritage and cultural heritage in the Sesia Val Grande UNESCO Global Geopark (North-West Italy): new approach for monitoring and assessing geosites and cultural sites

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Keywords: geoheritage, geoparks, geosites.

UNESCO Global Geoparks (UGGp) are defined as single, unified geographical areas where sites and landscapes of international geological significance are managed in a holistic manner, i.e. with a comprehensive approach to protection, education, and sustainable development. The territory of a UGGp usually contains an extraordinary geodiversity, such as a great variety of abiotic natural elements and landscapes, deriving from different geological processes. The Sesia Val Grande UNESCO Global Geopark (SVUGGp) is recognised for its high geodiversity, but several sites with historical, cultural and archaeological interest can be found. However, while the scientific community acknowledges the significant cultural value of geosites, cultural heritage inside UGGps is usually undervalued, receiving insufficient attention in the context of UGGps, even though many cultural sites exhibit deep connections with geological features. Cultural sites are a valuable resource for the geopark, especially those showing strong relationships with geological features. Since currently no methodologies allow a comparable qualitative assessment between geosites and cultural sites, it is important to fill this gap in order to provide the SVUGGp and other geoparks with a tool for integrating the geoheritage and the cultural heritage in the administration of the territory. Therefore, we propose a specific assessment for cultural sites, including parameters that are comparable with those adopted for geosite assessments. The research aims to enhance knowledge on effectively safeguarding, preserving, and promoting cultural heritage within the framework of a UGGp. In order to successfully integrate cultural heritage within the SVUGGp management and promotion strategies, the assessment methodology developed by (Brilha, 2016) has been adapted for the cultural sites, including criteria of cultural significance. This allowed the comparison of the assessment of cultural sites with the assessment of geosites within a geopark. Due to its exceptional geodiversity and remarkable cultural heritage, the SVUGGp exemplifies the characteristics necessary for a first attempt at applying the modified methodology. A comparable number of geosites and cultural sites have been selected due to their high importance, and they have been equally considered during the assessment process. Finally, the comparison of the two types of sites allows the promotion of a comprehensive approach for the conservation and the management of both cultural and natural heritage, preserving the natural resources and safeguarding the cultural heritage of the area, by successfully incorporating cultural sites into the geopark management framework.

Brilha J. (2016) - Inventory and Quantitative Assessment of Geosites and Geodiversity Sites: a Review. Geoheritage, 8, 119–134, https://doi.org/10.1007/s12371-014-0139-3.

Geodiversity - biodiversity relationship for the identification and conservation of priority natural areas in urban ecosystems. The case study of the city of Rome

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Keywords: geo-biodiversity relationship, urban environment, anthropogenic erosion/accumulation impact.

The increasing cities' expansion and density of population poses many challenges upon sustainability of urban ecosystems. Scientific knowledge about urban habitats - species relationships became essential to improve biodiversity conservation success, ecosystem service provision, and human well-being. The recent trend in nature conservation studies considers the abiotic conditions of importance for the selection of areas for biodiversity conservation.

In such a context, the analysis of the urban geomorphology of Rome (Italy) highlighted how prevailing landforms and processes in the city current landscape are related to anthropogenic erosion and accumulation (Del Monte et al., 2016; Vergari et al., 2020; 2022) affecting the natural vegetation potential (PNV; Farris et al., 2010), because of the alteration in both structural and compositional terms, consequent to changing in outcropping lithologies and natural morphology.

The aim of this work is the analysis of natural and anthropogenic geomorphodiversity effects on PNV, based on urban geomorphological survey and geometric and morphometric analysis of the anthropogenic landforms.

The procedure to characterize anthropogenic landforms and study responses and adaptation of actual vegetation within them is illustrated here by means of specific case studies. Morphometric analyses first allow volumes of anthropogenic deposits to be quantified, intercepted lithologies to be recognised, and soil and drainage changes to be estimated. Following targeted vegetation surveys allow the shift from undisturbed successional models to be assessed.

Understanding where and how morphological alterations modify local PNV is crucial for planning and designing suitable geodiversity-biodiversity restoration actions and resilient Nature based Solutions.

Del Monte M. et al. (2016) - Geomorphological classification of urban landscapes: the case study of Rome (Italy). J. Maps, 12(1), https://doi.org/10.1080/17445647.2016.1187977.

Farris E. et al. (2010) - The power of potential natural vegetation (and of spatial–temporal scale): a response to Carrión & Fernández (2009). J. Biogeogr., 37(11), 2211-2213, https://doi.org/10.1111/j.1365-2699.2010.02323.x.

Vergari F. et al. (2020) - Geomorphology of the ancient historic centre of the Urbs (Rome, Italy). J. Maps, 17(4), https://doi.org/10.1080/17445647.2020.1761465.

Vergari F. et al. (2022) - Geomorphological classification of the landscape in urban areas: hints from some study cases in Italy. Rend. Online Soc. Geol. It., 57, https://doi.org/10.3301/ROL.2022.09.

Eastern side of Monte San Vicino: discovering its geo-environmental and architectural heritage

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Keywords: geo-environmental heritage, nature trails, religious tourism.

This contribution aims to disseminate some geological, naturalistic, and historical-cultural aspects of a rural area with low population density and for many years the subject of progressive depopulation, falling within the seismic crater of 2016 and little known, in which it is necessary to conserve the environment and enhance territorial resources. A first element of interest is represented by the ancient Ginocchielli mine located near the municipality of Poggio San Vicino (MC), subject to limited exploitation of manganese, in which atypical mineralogical species were found in the sedimentary environment of the region. The deposit is in an external position of the Umbria-Marche thrust system, in the Mesozoic limestone succession adjacent to the External Marche Basin, in the central Ancona sector between the Esino and Musone rivers. Based on the mineralogical studies carried out (Cozzupoli & Matteucci, 1983), the origin of the mineralizing fluids of probable epithermal origin should be traced back to a crystalline basement, the position, nature, and depth of which are still unclear. Between the Upper Messinian and the Upper Pliocene-Lower Quaternary, regional-scale extensional tectonics (Centamore et al., 1980) would have induced hydrothermal manifestations of deep origin also in the Marche, which led to the deposition of singular mineralization otherwise found in the Tyrrhenian margin. The former mining site is located adjacent to the Gola della Rossa Natural Park - San Vicino and Canfaito Mountains Nature Reserve, which together constitute the largest protected area in the Marche (~12,000 ha). The territory, being characterized by limestone gorges alternating with small areas of the valley floor, reveals a notable naturalistic value due to the fauna, the conservation of plant environments and their extension, together with the presence of biological corridors (Biondi et al., 2008). We must then include the numerous monuments and places of worship present in the area, some of which are characterized by millenary stories and legends (Castagnari, 1990), whose architecture is closely connected to the use and processing of native stones and materials. Among these we note the Abbey of San Salvatore di Valdicastro (AN), the Benedictine Abbey of Sant'Urbano all'Esinante (MC) and the Sanctuary Madonna della Grotta (AN). The objective of this work is to promote the territory and avoid further depopulation by virtue of the huge heritage present. Being also connected by a network of routes and paths, the area lends itself to naturalistic hiking activities involving flora, fauna, geology, environment and culture, a territory in the past the subject of pilgrimages and religious walks.

Biondi E. et al. (2008) - Tesori naturalistici. Alla scoperta dei paesaggi e della biodiversità, dalla montagna al mare nelle province di Belluno, Vicenza, Mantova e Ancona. A cura di Cesare Lasen, Editore: Fondazione Cariverona, 383-499.

Castagnari G. (1990) - Abbazie e castelli della Comunità Montana alta Valle dell'Esino. Comunità Montana Alta Valle dell'Esino.

Centamore G. et al. (1980) - La tettonica recente nell'arco appenninico umbro-marchigiano. Contributi alla realizzazione della Carta Neotettonica D 'Italia. Pubbl. n. 316, Prog. Fin. Geodinamica, sottoprog. Neotettonica CNR.

Cozzupoli D. & Matteucci R. (1983) - Primi dati sulla mineralizzazione manganesifera di Poggio San Vicino (MC). Boll. Soc. Geol. It., 102, 557-572.

The Italian Geosites Inventory: making travellers aware through knowledge of geodiversity

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Keywords: geoheritage, geodiversity, geosciencesIR.

Since the early 2000s the Italian peninsula geoheritage has been catalogued to promote the conservation and the dissemination of geological knowledge (Giovagnoli, 2023). The Italian Geosites Inventory is a free access geodatabase, in which users can consult, around them and in the territories they wish to discover, places where it is possible to appreciate geological characteristics.

An interactive map and a search service is available in the Inventory for searching information about approximately 3000 geosites registered across the national territory. This is a number that is continuously updated as the work proceeds simultaneously with the insertion of new geosites, with the revision and if necessary, the elimination of geosites already present in the database, or outdated.

Each user can actively participate in the database growth and maintenance proposing new geosites by the submission to ISPRA (Italian Institute for Environmental Protection and Research), of a form template with the relevant descriptions. The geologists of the Geological Survey of Italy will deal with the proposal and in some cases the Italian Geological Surveys Network (RISG) could even be involved.

In some cases, in fact, the collaboration between ISPRA and the Geological Regional Surveys will lead to shared inventories at a regional level. This kind of interchange of information has already led to the drafting and implementation of some regional laws that have been approved to protect and enhance the regional geological heritage. The geoheritage is in fact not protected in Italy by national law yet.

In the year 2023, a total of approximately 12.000 accesses on the National Geosite Inventory were detected by the ICT systems, with an average of 1.000 accesses per month. Only accesses via the homepage were considered. Furthermore, the pages visited were almost 42.000 with a daily average of 115 pages (3.450 per month).

To reach even as many citizens and professionals as possible, on the occasion of the GeoSciencesIR project, a harmonized GeoSciML/INSPIRE compliant database will be published.

The INSPIRE Consolidated UML model for geosites is the application schema Geology (GE). The semantic harmonization will take place through the use of code list. The dataset will be harmonized and shared in compliance with the FAIR (Findable, Accessible, Interoperable, Reusable) principles.

A work of updating is being carried out and all the records will agree with the recently revised and validated geosite definition. The first update concerns the integration with the information deriving from the national coverage of the geological cartography at the 1:100,000 scale, the CARG cartography with the related explanatory notes, and the information deriving from the reports filled by the proposers themself, attached within each form of the Italian Geosites Inventory.

Giovagnoli M.C. (2023) - The Italian Geosite Inventory: Past, Present, and Future. Geoherit., 15(2), 69, https://doi.org/10.1007/s12371-023-00843-8.

Gabara Park: a magic place to recall sicilian mining history

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Keywords: geoturism.

The "Gabara" sulfur mine area, dates to the early 19th century, and is located within the Municipality of San Cataldo (CL) on the western side of Gabara Mt, about 3.5 km north-west of the village.

It lies in a Protected forestry eucalyptus area, with trees planted during the late 1950s.

At least ten mining concessions, rich in about 30 underground tunnels allowed the sulfur mineralized layer to be reached via stairways carved into the rock. The rock was then transported on the shoulders of young guys, "carusi", or carried on inclined slopes by wagons pulled by winches. Some tunnels "discenderie" are today still accessible. "Calcaroni" and Gill ovens, for separating the sulfur from the gangue, are also scattered around the park. Remains of old buildings, used as residences for the sulfur mine operators, rooms for steam winches, stables for the mules used to transport the mineral to the town, and roast waste are present.

Gabara is starting to become a popular geo-mining park since has a particular charm testifing to an almost family-run sulfur extraction activity. It preserves the memory of past generations for the benefit of the present and future ones. Thanks to the active collaboration of several institutions (municipal administration, mining district, Superintendence of the BB.CC., Forestry Company and Forestry Inspectorate) and the donations of many entrepreneurs, artisans and artists it is possible to transform a place of memory in an exciting tourist route, capable of telling the story of a ancient mining civilization.

A tourist route called in memory of the the early twentieth century Pirandello novel "Ciàula scopre la Luna makes known the story of the sulfur – called devil's gold - which for over two hundred years was the driving force of the national and Sicilian economy national.

The site, whose valorization started in April 2015 and still ongoing, is today an exciting journey into the world of sulfur, between geology, mining archaeology, anthropological history, literature, contemporary art and theatre.

The geology is clearly readable in the rocks, which tell the history of the "Messinian salinity crisis of the Mediterranean"; mining archeology is present with the remnants of sulfur mines, historical photos tell the anthropological life in the sulfur mine. Along the tracks you will also encounter writers who gave voice to the sicilian mining world, such as Sciascia, Verga, Consolo, Hamilton, Bonavia, Pirandello and poets such as Giuliana, Buttitta, Lo Presti Russo. The park is also enriched with installations of contemporary art works by Giuliana, Barba, Politano. During the visit, some actors recall the terrible illegal sale or rental of boys and actresses portray mothers who accept to give a child to the picconiere or perform the desperation after an underground accident.

Today, Gabara has been included in the National Network of Museum and Mining Parks ReMi_ISPRA and an agreement for fruition and valorization has been signed with the University of Catania , Department of Biological, Geological and Environmental Sciences.

Paintings and writings by Carlo Levi: an unlikely combination with geology?

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Keywords: dissemination, geotourism.

Portions of the three orogenetic elements (foreland, foredeep and chain) characterizing the geology of southern Italy can be observed in the Matera Territory. These elements are represented by the Apulian Foreland, the Bradanic Trough and the southern Apennines. It is possible to briefly outline the evolution of this orogenic system by tracing an itinerary that starts from the city of Matera (located within the Apulia Foreland), continues in the small town of Grassano (within the Bradanic Trough) and then reaches the small town of Aliano (within the Apennines Chain). This proposed itinerary connects three places linked together by the presence in the '30s of Carlo Levi, political exile during the fascist regime in such localities. This artist, who came from a big and modern city, Turin, narrated and painted places of the "deep South", capturing not only relevant aspects of Lucanian cultural anthropology but also the geological ones, almost unconsciously. Indeed, the people and the landscape are often the protagonists of his paintings and of the well-known book "Christ Stopped at Eboli" (Levi, 1945; 1947).

A selection of Levi's artworks can be utilized to guide tourists along a journey (Tropeano et al., 2011; Sabato et al., 2019), illustrating the geology of the area through the eyes (i.e. the paintings), and, above all, the words (i.e. the book) of Carlo Levi.

Levi C. (1945) - Cristo si è fermato a Eboli. Einaudi, Torino

Levi C. (1947) - Christ Stopped at Eboli. FSG, New York

Sabato L. et al. (2019) - Following Writings and Paintings by Carlo Levi to Promote Geology Within the "Matera-Basilicata 2019, European Capital of Culture" Events (Matera, Grassano, Aliano - Southern Italy). Geoherit., 11(2), 329-346, https://doi.org/10.1007/s12371-018-0281-4.

Tropeano M. et al. (2011) - Geoturismo in Basilicata: il Parco Letterario "Carlo Levi" ad Aliano quale veicolo di divulgazione di elementi di geologia del sedimentario. Rend. Online Soc. Geol. It., 17, 195-198, https://doi.org/10.3301/ROL.2011.55.

Evidences of geodiversity in Murge and Premurge territories (Southern Italy), potential training grounds for geotouristic experiences

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Keywords: Adria, Murge and Premurge, southern Italy.

In southern Italy, the Puglia Region and the estern part of the Basilicata Region, as a whole, correspond to the largest in situ remnant of the Adria Plate, the old continental plate almost entirely squeezed between the Africa and Eurasia Plates. In such a context, Puglia and estern Basilicata respectively represent the foreland and the foredeep of the Southern Apennines Chain. Both are virtually undeformed sectors of Adria (where the crust is still rooted to its mantle), while other territories of the plate are and/or were involved in subduction/collision processes. Such a worldwide geological uniqueness can be geotouristically appreciated in the Murge territory, where a Cretaceous sector of the Apulia Carbonate Platform (one of the largest peri-Tethys carbonate platforms) crops out, and in the adjacent Premurge territory, where the southwestward lateral continuation of the same platform (being flexed toward the Southern Apennines Chain) is covered by thin Plio-Quaternary foredeep deposits.

An "anomalous" regional middle-late Quaternary uplift led to expose both a thick Cretaceous succession in the Murge area, where shallow-water carbonates of the Apulia Platform crop out and record part of the ancient evolution of the continent, and a Plio-Quaternary covering succession, recording the outer Southern Apennines foredeep development.

Despite the presence of numerous geological singularities of international relevance, it would be important, from a geotourist point of view, to propose a regional framework of the geology of the area before introducing visitors to the significance of the individual geosites, whose importance could be amplified if included in the geoevolutionary context (Tropeano et al., 2023).

Tropeano et al. (2023) - Geological uniqueness and potential geotouristic appeal of Murge and Premurge, the first territory in Puglia (Southern Italy) aspiring to become a UNESCO Global Geopark. Geosci., 13, 131, https://doi.org/10.3390/geosciences13050131.

Heritage stones: the case of Aurisina Limestone to promote geodiversity in the Classical Karst cross-border area

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Keywords: Kras-Carso, Aurisina limestone, heritage stone.

The Classical Karst Region (Kras-Carso) is a cross-border area shared by Italy and Slovenia, from which the international scientific term "karst" was adopted (Jurkovšek et al., 2016). The geodiversity of the Classical Karst is expressed by superficial and underground features, a particular hydrogeological network and a rich paleontological record correlated to the Cretaceous-Paleogene evolution of the former Adriatic-Dinaric Carbonate Platform (Jurkovšek et al., 2016; Bensi et al., 2022). The Cretaceous-Paleogene sedimentary succession comprises the Upper Cretaceous, rudist-rich and shallow water "Aurisina Limestone" (Bensi et al., 2022), which has historically played a significant role in the Karst region. Indeed, it has been used since Roman times for construction purposes, due to its geotechnical and ornamental attributes. This is confirmed by evidence of quarrying activities and by the widespread use of this material on both regional and extra-regional scales (Previato, 2015). The export of the Aurisina limestone re-experienced a significant growth in the 18th and 19th century with the establishment of the free-trade port of Trieste and the construction of the Austrian Southern Railway, linking Vienna to the Adriatic Sea (Carulli & Onofri, 1969) and continues nowadays worldwide. The preservation and promotion of the geodiversity of the Classical Karst Region has been the object of European cross-border projects for at least two decades. Following the definition of the Kras Carso Geopark within the KRAS-CARSO 2007-2013 project, the 36 months long Interreg project Kras-Carso II (2023-2026) was funded. The project partners, belonging to local administrations and scientific institutions, are involved in the creation of the EGCT (European Group for Territorial Cooperation). As one of the project partners, the Department of Geosciences of the University of Padova has two main objectives: the listing of the Aurisina Limestone among the Heritage Stones recognised by the IUGS (International Union of Geological Sciences) and the scientific support to the creation of educational contents. The ratification as an IUGS-Heritage Stone is subordinated to the submission of a detailed report of quarry exploitation and architectural use through time. Here we present a first dataset from the literature and the historical archives. Additionally, as part of a wider network of integrated tourism products, we display a collection of artistic photomicrographs of rocks, representing the geological uniqueness of the Classical Karst Region. This collection will be the focus of a series of traveling exhibitions for the general public.

Bensi S. et al. (2022) - The Classical Karst geopark. Geological Survey - Central Directorate for Environmental Protection, Energy and Sustainable Development of the Autonomous Region of Friuli Venezia Giulia, 164 pp., https://hdl.handle.net/11368/3053480

Carulli G.B & Onofri R. (1969) - I marmi del Carso, Del Bianco Editore, 102 pp.

Jurkovšek B. et al. (2016) - Geology of the classical karst region (SW Slovenia–NE Italy). J. Maps, 12(sup1), 352-362, https://doi.org/10.1080/17445647.2016.1215941

Previato C. (2015) - Aquileia. Materiali, forme e sistemi costruttivi dall'età repubblicana alla tarda età imperiale, Padova University Press, 638 pp., https://hdl.handle.net/11577/3147546.

The Water and the Rock: a geotouristic route through the geology of springs and fountains in Matera (Basilicata, Southern Italy)

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Keywords: Sassi di Matera, springs, geotourism.

The old town of Matera is one of the most known tourist destinations in Italy, since his complex network of caves, tunnels, cisterns, houses, and churches, dug in carbonate soft-rocks is a worldwide example of perfect and unique integration between human urban development and natural abiotic background. This bond lies not only in the excavation of the stunning landscape of the "Sassi" (the local name of the old town) in the outcropping calcarenite rock, but also in the capacity of the local population to manage and exploit the natural source of water occurring near the town and in the surroundings. In this work we propose a geotouristic route to discover this bond, showing some historic fountains present in the town centre (Fontana Ferdinandea) or in the surroundings (Fontana di Vite, Fontana Santa Candida and Fontana Cilivestri) and enhancing the geological settings that determine the presence of the water. This fountains in fact are built in correspondence or near natural springs, often located at the top of clay hills overlied by sandy and gravelly (and then porous) deposits. Once captured, the water was used in place or displaced to the town, where was stored both in domestic cisterns and in a very big public one, called "Palombaro lungo", now already become a tourist attraction.

Starting from the countryside, the path will conduct the visitors to a journey within the geology of the area until the deep heart of the town. On this way, the visitors will better understand why and how the Sassi could have been habitable from ancient times to the modern era.

Promotion and enhancement of the geoheritage of the Dindéfélo Geopark Project of the Dindéfélo Community Nature Reserve (Kédougou, Senegal)

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Keywords: Senegal, geo-development, geopark.

In 2020, the Ministry of Mines and Geology, through the Directorate of Prospecting and Mining Promotion (DPPM) and the National Geological Servey of Senegal (SGNS) implemented a geo-development strategy for exceptional geosites, aimed at the conservation and enhancement of Senegal's geological heritage. The pilot site of the project as a potential Geopark is Dindéfélo, a Community Natural Reserve (RNCD) created in 2010 and located in the Bassari Country (Kedougou region), declared a UNESCO World Heritage Cultural Landscape. The development of this geoheritage will promote economic growth in this area below the poverty line.

This reserve has a geological history that extends from the Paleoproterozoic to the Neoproterozoic. Postdating the Birimian, the initiation of the Meso-Neoproterozoic Madina-Kouta basin (C. Delor et al., 2010) is triggered by a filling of coastal and glacial deposits. The series begins with fluvial deposits (Kafori Formation) fed by the alteration of the Birimian bedrock and continues with the local installation of a carbonate platform (Pelel Formation). Then come the coastal deposits (Dindéfelo Formation). The deposits of glacial tillites around 700 to 630 Ma testify to periods of glaciation (Walidiala Formation) in addition to horizons of post-sedimentary alteration and volcanic activity. This long and rich geological history, which lasted about 2000 Ma, has given rise to a Geoheritage which, in addition to scientific, educational and socio-economic interests, is a real ecological bulwark for highly threatened biological species in Senegal (Youm et al., 2018).

To this end, a geodiversity assessment study was carried out with the objective of enhancing and disseminating geosites. In collaboration with the Cheikh Anta Diop University of Dakar, the University of Chouaïb Doukkali of Morocco and the University of Huelva of Spain, the following achievements have been made on the Dindéfélo Geopark Project: the characterization of geological formations, a census and mapping of geosites (about sixty). A series of tourist and communication panels and posters have been designed to facilitate understanding and support for explanations of the different aspects in line with the needs of guides. And installed in the geology room (lithotheque), the ecomuseum, the Visitor Centre with a local management committee, and at the level of the main tourist circuits. On the other hand, a summary guide on the geology of the reserve. Documentaries for the public were made as well as the construction of roads and access tracks.

The key activity remains the training of tourist guides and teachers and the sensitization of the local population. The training of tourism stakeholders has helped to establish a foundation of knowledge in geology. Two very interesting examples of valorization: the Polyclinic Hospital and the Museum of Earth Sciences of the Cheikh Anta Diop University in Dakar

Delor C. et al. (2010) - Carte géologique à 1/200 000 du Sénégal, feuille Saraya-Kédougou Est. Ministère des Mines, de l'Industrie, de l'Agro-Industrie et des PME, Direction des Mines et de la Géologie, Dakar.

Youm C. et al. (2018) - Neoproterozoic Dindéfélo waterfall geosite (RNCD, Bassari country, Eastern Senegal): biodiversity and geodiversity between conservation and valorization. Journal of Chemical, Biological and Physical Sciences D, 8(3), 197-224.

S9.

Advances in remote sensing for hazard monitoring and geo-resource management through multi-dimensional digital models

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Digital geotourism: unveiling the geological heritage of Laterza (Puglia, Southern Italy)

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Keywords: geotouristic map, Laterza, digital tools.

Geotourism, with its focus on geological knowledge, is emerging as an important tool for the appreciation and conservation of natural heritage. In addition to its cultural and educational importance, geotourism offers a sustainable approach, in line with the goals of the 2030 Agenda, by diversifying tourism patterns. A key development is the use of digital tools, in particular geotouristic maps, to facilitate sustainable tourism initiatives.

The proposal covers the territory of Laterza, a rural town in the Murgia Materana region of southern Italy, characterised by Cretaceous limestone overlain by Quaternary deposits. The landscape has been shaped by the impressive "Gravina di Laterza", an up to 167 m deep canyon stretching for almost 14 kilometres. In order to highlight the geological importance and resources of the area, a geotouristic map has been developed highlighting the geotouristic path outlined, the outcropping sites, the panoramic viewpoints and the cultural landmarks. In addition, the integration of geotouristic data into OpenStreetMap, a collaborative mapping tool, increases accessibility and community engagement.

Digital tools play a crucial role in enhancing the geotourism experience. Geotouristic maps, accessible through mobile devices and online platforms, provide visitors with detailed information about geological sites and cultural attractions. In order to make the geotouristic map proposal more precise, a 3D graphic has been created of a specific area related to the so-called "Via Concerie" of Laterza. Thanks to the development of satellite images and remote sensing techniques, it is possible to create 3D maps within Geographic Information Systems (GIS). The integration of satellite imagery, digital terrain model data, geological information from the Geological Survey and urban details (from OpenStreetMap) into GIS allows the generation of detailed 3D representations of the terrain.

By combining geological narratives with digital mapping technologies, this initiative lays the groundwork for a comprehensive geotouristic proposal, ensuring a nuanced appreciation of Laterza's geological heritage.

Monitoring and identification of environmental crimes: a satellite imagery and machine learning approach

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Keywords: semi-automatic classification plugin, eco-crimes, machine learning.

The analysis of territory using remote data is crucial for monitoring and identifying environmental changes. Environmental crimes, known as eco-crimes, are regrettable in many areas worldwide. To address this issue, we use an automated procedural approach to identify specific eco-crimes through changes in land cover. Using the Semi-Automatic Classification Plugin (SCP) in the QGIS environment, we can conduct a semi-automatic classification of images obtained through remote sensing sensors, allowing automatic data download and pre- and post-processing (Congedo, 2016). The SCP facilitates direct connection to the Copernicus Open Access Hub, the primary data source acquired from the Sentinel mission (ESA). A wide range of spectral indices can be calculated, including NDVI (Normalized Difference Vegetation Index), SMI (Soil Moisture Index), NDWI (Normalized Difference Water Index), NDTI (Normalized Difference Tillage Index), EVI (Enhanced Vegetation Index), ARVI (Atmospherically Resistant Vegetation Index), SAVI (Soil Adjusted Vegetation Index), BSI (Bispectral Index), TCB and TCG (Tasseled Cap Brightness and Greenness). These indices allow a comprehensive assessment of the state of the territory, from vegetation health to soil moisture, from the presence of water to urbanization, thus enabling the identification of significant changes. Subsequently, the extracted spectral signatures are subjected to a change detection analysis to identify variations over time, essential for identifying territorial changes. Through machine learning (ML) algorithms, the processed data are classified to automatically identify features of interest, such as potential illegal activities or significant environmental alterations. At the end of the classification process, the results obtained are subjected to a validation phase to confirm the accuracy of the analyses conducted. In conclusion, this study demonstrates the effectiveness of using satellite images and the SCP plugin in QGIS for monitoring and identifying territorial changes (Tempa & Aryal, 2022). This methodology represents an effective and efficient approach to environmental monitoring and for conducting analyses on the state of the territory and environmental protection.

Congedo L. (2016) - Semi-automatic classification plugin documentation. Release, 4(0.1), 29, https://doi.org/10.13140/RG.2.2.29474.02242/1.

Tempa K. & Aryal K. R. (2022) - Semi-automatic classification for rapid delineation of the geohazard-prone areas using Sentinel-2 satellite imagery. SN Appl. Sci., 4(5), 141, https://doi.org/10.1007/s42452-022-05028-6.

Combining traditional and quantitative multiscale structural analysis to reconstruct the tectono-metamorphic evolution of migmatitic basements: the case of the Valpelline Series, Dent-Blanche Tectonic System, Western Alps

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Keywords: 3D outcrop models, quantitative multiscale structural analysis, high-temperature deformation.

Due to the ongoing development of new technologies, numerous instruments are now available to assist in geological investigations across various scales. These techniques, such as 3D outcrop modeling through aerial photogrammetry and quantitative microstructural analysis, prove valuable in studies of crystalline basement rocks. This contribution merges traditional and quantitative multiscale structural analysis techniques applied to the migmatitic rocks of the Valpelline Series within the Dent-Blanche Tectonic System in the Western Alps. Conventional structural analysis is augmented by extracting structural data from 3D models of representative, smoothly exposed outcrops. Quantitative microstructural and mineral-chemical analyses are integrated to establish links between structural and metamorphic evolution.

This approach enables the identification and correlation of foliations that evolved during three tectono-metamorphic stages. The first stage (D1) involves solid-state deformation, characterized by an early foliation (S1) preserved within metabasite boudins enclosed within migmatite gneiss. The second stage (D2) corresponds to the dominant foliation in migmatite gneiss (S2), concurrent with regional-scale anatexis and the growth of garnet and cordierite. The third stage (D3) is associated with the late folding of S2 and the development of a sillimanite-rich axial plane foliation (S3), which wraps around garnet and cordierite.Finally, this work discusses the advantages and limitations of each innovative methodology while emphasizing the importance of using manually acquired field data as ground control (Caso et al., 2024).

Caso F. et al. (2024) - Combining traditional and quantitative multiscale structural analysis to reconstruct the tectono-metamorphic evolution of migmatitic basements: the case of the Valpelline Series, Dent-Blanche Tectonic System, Western Alps. J. Struct. Geol., 182, 1-21, https://doi.org/10.1016/j.jsg.2024.105099.

Structural characterization of a quarry showing normal faulting and bedding parallel slip: insight from virtual outcrop modeling

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Keywords: SfM-photogrammetry, fault analysis, orthorectification.

In the realm of geological studies, inaccessible, obstructed, and potentially distorted outcrops have long posed challenges to achieving clear interpretations. However, over the past decade, the proliferation of easily deployable multi-sensor Uncrewed Aerial Vehicles (UAVs), commonly known as drones, alongside the rapid advancement of digital photogrammetric processes, has facilitated the creation of three-dimensional representations of geological exposures. These representations, termed virtual outcrop models, provide a means to extract quantitative data from otherwise inaccessible outcrops and generate orthorectified views conducive to meaningful, undistorted, and reproducible interpretations.

In this study, we investigated a quarry exhibiting platform carbonates from the Cretaceous period. These well-layered carbonates are prominently exposed throughout the quarry, lending three-dimensionality to the site. Although the quarry is inactive, its internal space is presently utilized for commercial purposes. The primary geological feature observed within the quarry is a conjugated normal fault system, which served as the primary focus of data acquisition.

Significant geological structures were only discernible after overcoming accessibility barriers through drone-based photo acquisition, followed by the construction of VOMs using Structure-from-Motion Multi-View Stereo (SfM-MVS) photogrammetry workflows, and subsequent data extraction and analysis. The establishment of statistically derived viewpoints facilitated the creation of meaningful orthomosaics, enabling further observation and measurements, such as fault stratigraphic separation diagrams. Notably, this workflow unveiled deformation stages not initially recognized in the field.

Drawing fault and bedding lines on the orthomosaic, which was favorably oriented, enabled the interpretation of the primary fault system, leading to the identification of multiple deformation events and serving as the foundation for generating fault separation diagrams.

Improving geological understanding through the integration of UAV aerial survey and LiDAR scanning: advantages and limitations of a multiscale hybrid approach

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Keywords: multiscale investigation, UAV survey, portable LiDAR.

Integrating Unmanned Aerial Vehicles (UAVs) and Light Detection and Ranging (LiDAR) technology has led to significant advances in geological studies to obtain accurate data about the Earth's surface and subsurface features. This hybrid approach has greatly improved our understanding of geological processes. Here we explore its applications, benefits, and limitations through a selection of study cases. UAVs equipped with cameras or LiDAR sensors capture high-resolution images and elevation data. LiDAR sensors emit laser pulses and measure the time it takes for the light to travel to the ground and back, resulting in detailed elevation models (point clouds). Cameras provide visual information about the landscape. The advantages of this technology are based on: rapid data acquisition, high spatial resolution, and 3D modelling. UAVs cover large areas efficiently, even in rugged terrain and hazardous areas. Geological mapping, landform identification, and hazard assessment benefit from rapid data collection. Detailed images help identify geological features such as rock outcrops, fault lines and sedimentary layers. Geologists analyze these images to decipher the geological history of an area. Combining LiDAR data with imagery enables accurate 3D reconstructions of the terrain. Virtual exploration of rock formations and fault networks becomes possible. On the other hand, there are several limitations to consider: local coverage, weather dependency, and complexity of data processing. UAV surveys are area-specific. Researchers need to plan flight paths carefully. Large area coverage requires additional methods (e.g. satellite imagery). Adverse weather conditions (rain, wind, low cloud cover) affect data quality. Optimal survey times must be chosen based on weather forecasts. Handling large data sets from UAV surveys requires robust algorithms. Extracting meaningful geological information requires thorough processing. Classically, ground-based LiDAR systems, mounted on tripods or vehicles, emit laser pulses horizontally or vertically, capturing detailed point clouds of the terrain. More recently, terrestrial LiDAR scanning can also be performed using portable devices (smartphones, tablets). Advantages are high accuracy, 3D visualization, change detection, and mineral exploration: LiDAR provides accurate elevation data for topographic variation, slope stability assessment and fault mapping. Subtle changes in the landscape are revealed by LiDAR accuracy. Detailed LiDAR models improve geological interpretation. Researchers can virtually explore rock formations, fault geometries and sedimentary layers. Repeated LiDAR scans over time allow monitoring of landscape changes (erosion, landslides, fault movements). Hazard assessment benefits from this temporal perspective. LiDAR helps locate potential mineral deposits by mapping geological structures and alteration patterns. Limitations are: cost, vegetation interference, and instrumental accuracy challenges. Terrestrial LiDAR systems can be expensive to deploy and operate. Researchers must weigh the benefits against the costs. A dense forest interferes with ground measurements and affects LiDAR accuracy. Careful selection of scan locations minimizes interference. Surface roughness, reflectivity and sensor limitations affect data quality. Calibration and quality control are essential.In summary, aerial UAV surveys and terrestrial LiDAR scanning complement each other. Geologists use these tools strategically to overcome limitations and gain comprehensive insights into the Earth's dynamic processes. Whether mapping fault lines, assessing landslide risk or exploring mineral deposits, these technologies continue to advance geological research. As a result of this methodology, the role of the geoscientist and digital cartographer will remain strategic throughout the data publication process and will be able to maintain control of dissemination and communication.

Development of innovative digital methods for assessing the stability of rock masses in the context of railway infrastructure

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Keywords: digital outcrop model, slope stability, tunneling.

In the recent years, the fracture analysis and the geomechanical characterization of rock masses has been significantly improved by the advancements in photogrammetric surveying techniques and the utilization of Structure from Motion (SM) algorithms. This has enabled a more efficient, secure, and accurate approach to extracting a large amount of 3D information from Digital Outcrop Models (DOMs). Particularly, the improvement of sensors and Remotely Piloted Aircraft Systems (RPAS), becoming increasingly manageable, reliable, high-performing, and cost-effective, has greatly facilitated the use of digital photogrammetry in the geomechanical characterization of rock slopes in the field of geological and engineering design. Moreover, the recent increase in hardware and software processing capabilities (e.g., Agisoft Metashape) has reduced the processing time of DOMs and increased the quantity of 3D information that can be extracted, with particular attention to the discontinuity network and its characteristics. The lack of automatic or semi-automatic procedures for the analysis and parameterization of large three-dimensional datasets limits the adequate evaluation of fracturing and stability analysis of rock slopes. Often, analyses such as the Markland Test are employed; however, this approach, while useful, does not fully utilize geometric (such as spacing, fracture intensity, persistence of discontinuities) and spatial information (such as rock mass heterogeneity and the identification of critical areas). Moreover, traditional geomechanical surveys are manually conducted, following outdated methodologies. In this contribute we show a new approach aimed to improve both the robustness and smartness in the identification, targeting, and evaluation of criticalities of fractured rock slopes. The proposed workflow consists of the combination of i) manual extraction of discontinuity data from the DOM combined with ii) a kinematic analysis performed through an automated algorithm (ROKA) that provides an upgraded version of the traditional Markland's test. The results are validated through selected case studies derived from railway linear infrastructures designed or in progress thanks to the collaboration with Italferr S.p.A.

Characterization of Sardinian mine residues using Remote Sensing

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Keywords: mine drainage, earth observations, iron minerals.

Southwestern Sardinia used to be the most important mining region in Italy and among the most relevant at the European scale. Extracted minerals include barium and polymetallic minerals bearing Pb, Ag, Cu, and Zn. Today, all these mines are closed, and their residues are now a potential source of pollution for soil, water, and air due to the weathering of the dumpsites (e.g. Cidu et al., 2011). However, results of recent scientific research have shown that the materials in these deposits can hold significant quantities of base metals and strategic elements, becoming a potential source of critical raw materials (Sedda et al., 2024).

Mapping and monitoring the acidity (pH) and geochemical conditions of legacy mine sites using non-contact sensing systems can be beneficial to understanding the spatial distribution of pollutants and the potential sources of acid mine drainage.

Spectral remote sensing data has proven effective in characterizing mine wastes from a geochemical/mineralogical point of view, allowing for an estimation of environmental pH conditions. Specific iron-bearing minerals, such as jarosite, which is considered a good proxy for acid mine drainage, can be unambiguously mapped via hyperspectral remote sensing data (Flores et al., 2021). Yet, this research domain remains largely understudied, due to the challenges related to spatial resolution in combination with the geometry and topography of the tailing sites. In addition, there is barely any study on the characterization of historical mine sites and tailings in Sardinia using remote sensing technology.

In this context, the present study aims to propose a methodology for characterizing the mineralogical and geochemical composition of mine wastes, by using a combination of proximal and remote sensing techniques over the legacy mines of Montevecchio and Ingurtosu.

During an initial field campaign, different parts of the mine site were sampled considering the texture and color variation of the surface. The sampling sites were also measured spectrally using a handheld spectrometer.

A combination of Sentinel-2 and WorldView-3 data coupled with ground/lab spectroscopy was used to determine the potential acid mine drainage of the test sites. The surface mineralogy was mapped using band ratios and a semi-automatic classification method. The resulting maps were verified by XRD, ICP-OES/MS analysis carried out on the collected samples. The aim was to see whether the technique was suitable for distinguishing different mineral phases in the test areas. This preliminary analysis is meant to pave the way for further research on detecting and mapping acid mine drainage using hyperspectral data acquired by satellite and airborne systems. As there is an increasing interest in mine residues as a potential secondary source of critical minerals, the proposed methods can also provide key information on the re-mining of such critical minerals in the environment.

Cidu R. et al. (2011) - Drainage at Abandoned Mine Sites: Natural Attenuation of Contaminants in Different Seasons. Mine. Water Environ., 30, 113-126, https://doi.org/10.1007/s10230-011-0146-4.

Flores H. et al. (2021) - UAS-Based Hyperspectral Environmental Monitoring of Acid Mine Drainage Affected Waters. Minerals, 11(2), 182, https://doi.org/10.3390/min11020182.

Sedda L. et al. (2024) - Unlocking Strategic and Critical Raw Materials: Assessment of Zinc and REEs Enrichment in Tailings and Zn-Carbonate in a Historical Mining Area (Montevecchio, SW Sardinia). Minerals, 14, 3, https://doi.org/10.3390/min14010003.

InSAR pattern recognition and data analysis in characterizing high-risk seismic areas: a case study from L'Aquila city, Italy

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Keywords: DInSAR, statistical analysis, high-risk seismic areas.

A statistical analysis of time series of A-DInSAR post-seismic data, acquired at the historical centre of L'Aquila city (Italy), in the time range 2010-2021, from the Cosmo-SkyMed and Sentinel-1 missions, has been carried out. This has allowed analysing the relationships between ground deformations and geological, hydrogeological features of the study area, as well as the level of seismic damage to budlings.

The analysis of these data is still ongoing and offers promising research perspectives in the field of subsoil characterization, based on satellite ground deformation data, also useful in seismic hazard characterization and mitigation.

This study is structured into three phases:

– Correlation between Permanent Scatterers (PSs) displacement and earthquake related building damage,
– Correlation between seasonal ground deformation and precipitation fluctuations,
– Correlation between PSs displacement and geological features.

The data analysis revealed a subsidence phenomenon still ongoing, involving the whole study area and showing local heterogeneities. A pattern analysis, involving cluster analysis and inferential statistics, has highlighted that higher ground deformation rate values are associated with higher damage levels to buildings (Sciortino et al., 2024). The correlation analysis between predisposing geological factors and SAR deformation has corroborated the hypothesis that subsidence rates are substantially controlled by the properties and thicknesses of shallower rock layers.

The main results are summarized below.

PSs displacements (i.e., ground deformation) are correlated with earthquake related building damage intensity,

Seasonal average subsidence rate fluctuations and precipitation oscillations exhibit significant statistical correlation,

PSs velocities are mainly controlled by the properties and thicknesses of shallower rock layers.

These evidences pave the way for a potential use of SAR data in mapping and characterizing high-risk seismic areas, at urban scale and at relatively low costs.

Sciortino A. et al. (2024) - Satellite A-DInSAR pattern recognition for seismic vulnerability mapping at city scale: insights from the L'Aquila (Italy) case study. GISci. Remote Sens., 61(1), https://doi.org/10.1080/15481603.2023.2293522.

A 3D model to enhance, study and make an inaccessible quarry "virtually accessible": the example of Cava Porcili (Minervino, southern Italy)

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Keywords: 3d models, Cretaceous quarry, photogrammetry.

The Apulian territory is rich in quarries, which have been used since ancient times to extract and produce materials for modern and traditional construction and architecture. Some of these quarries represent true windows into the geological past of the area, and especially those that have been abandoned deserve a second life. Cava Porcili is a limestone quarry located south of the town of Minervino Murge (southern Italy), situated on the western edge of the Apulian Foreland. The quarry presents a Cretaceous succession, which is rich in peculiar geological features: a thick succession of shallow water limestone, about 90 meters in total, numerous karst cavities, faults, and slumps, which can be very interesting for scientific, educational, and outreach purposes. The quarry is currently inaccessible for geotourism purposes, and given its great educational and scientific potential, an alternative way to admire it using new technologies is proposed here.

Our research aims to unlock the educational and scientific potential of Cava Porcili through the creation of two distinct 3D models, using drone photogrammetry. The first model will be a comprehensive 3D reconstruction of the entire quarry, offering a virtual tour of its geological wonders. The second model will focus on a specific portion of the exposed succession currently under study. These 3D models will not only deepen our understanding of this well-exposed Cretaceous succession but also make this geological treasure accessible to a global audience, enhancing it and making it known worldwide.

Fiastra DSGSD spatio-temporal evolution analysis by means of GPS and DinSAR data

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Keywords: DSGSD, GPS, DInSAR.

Deep Seated Gravitational Slope Deformations (DSGSDs) are rock mass movements that affect entire slopes or valleys. These movements are typically characterized by low deformation rates and are influenced by various factors, including erosional processes, precipitation, post-glacial debuttressing, among others. Seismic activity, in particular, can trigger accelerations or even collapse phases. Consequently, many authors have studied the correlation between ground movements and earthquakes.

The DSGSD being the focus of our study is located on the eastern flank of the Marche Apennines and spans the entire slope from the summit of Mt. Frascare to the valley floor, where the hydroelectric reservoir and the Fiastra dam are situated. This area is characterized by the presence of the formations belonging to the Jurassic and Cretaceous units of the Umbria-Marchigiana stratigraphic succession, which underwent two main tectonic phases: a compressional phase during the Upper Miocene-Lower Pliocene, which later transitioned to an extensional phase during the Upper Pliocene and Quaternary. This seismically active region was struck by the 2016-2017 Central Italy earthquake sequence. This significant event began with the Accumoli earthquake (Mw 6.0) on August 24, 2016. Two months later, two earthquakes (Mw 5.9 and Mw 5.4) preceded the strongest earthquake of the sequence, which occurred 6 km north of Norcia with a magnitude of Mw 6.5 on October 30, 2016. Then, on January 18, 2017, four earthquakes ranging from Mw 5.0 to 5.4 struck 20 km south of Accumoli.

Preliminary studies on the stability of this DSGSD were conducted by Albano et al. (2015), who performed a preliminary stability assessment and proposed the installation of GPS stations and corner reflectors to improve the poor radar coherence of the observed scene. Subsequent research by Polcari et al. in 2017 utilized multiband Differential Interferometry SAR (DInSAR) to analyse displacements induced by the earthquake sequence in Central Italy, while Amato et al. (2018) explored the integration of DInSAR and GPS data as a monitoring system for earthquake-triggered and slow-moving landslides.

The objective of this work is to characterize the displacements linked to the deformation of the Fiastra DSGSD and those related to the ground shaking of the 2016-2017 sequence using remote sensing methods. Unlike the previously mentioned studies, this study was based on a different dataset, covering the period 2015-2019 for both GPS and DInSAR data. The GPS data were processed with RTKlib libraries in both static and kinematic positioning modes. The DInSAR with its wide-ranging analysis capabilities, helps us overcome the limitations of GPS monitoring, which only provides point-specific data. Moreover, these methods produce highly accurate results, which are crucial, especially in the case of landslides characterised by displacement rates of centimetres to millimetres per year.

Albano M. et al. (2015) - COSMO-SkyMed and Radarsat-2 joint analysis and modeling for the evaluation of potential deformations caused by the large mass movements surrounding the Fiastra lake dam. Geosci. Remote Sens. Symposium (IGARSS), 2015.

Amato G. et al. (2018) - Step-like displacements of a deep seated gravitational slope deformation observed during the 2016–2017 seismic events in Central Italy. J. Eng. Geol., 246, 337-348.

Polcari M. et al. (2017) - Using multi-band InSAR data for detecting local deformation phenomena induced by the 2016–2017 Central Italy seismic sequence. Remote Sens. Environ., 201, 234-242.

Monitoring badland features and dynamics through LiDAR and UAV technology

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Keywords: badlands, high-detailed point cloud, survey accuracy.

Badlands are typical landforms on clayey, bare, and sparsely vegetated slopes, characterized by high rates of erosion. In particular, Biancane are Badlands distinguished by small domes protruding several meters above gently sloping micropediments. The drainage patterns within these formations are primarily dictated by erosive pipes and rills on the slopes, while sheet flow predominates on the pediments (Torri et al., 2013) .

Nowadays, modern advancements in geomorphological analysis favour high-detailed Point Cloud (PC) reconstruction derived from Terrestrial Laser Scanner (TLS) and drone-based surveys.

The very high-resolution of PC enables the detection of topographical changes in the range of few cm/y or mm/y (Llena et al., 2020; Marsico et al., 2021). However, each approach exhibits distinct advantages and limitations. TLS-derived PC offer superior resolution for directly exposed slopes (Biancane) but lack coverage of background micropediments and domes. Conversely, drone-based PC provides broader scene coverage but often suffers from lower density and limited penetration under canopy.

This study aims to compare the efficacy of high-resolution PC derived from TLS and drone technologies in comprehensively characterizing Biancane. We evaluated the combined TLS and drone-derived (RGB sensor) PCs against those obtained from drone-borne LiDAR, considering parameters such as density, scene coverage, surface roughness and accuracy. Validation against in-situ data further informed the assessment, acknowledging the inherent limitations of each methodology.

Furthermore, the evaluation of PC density and processing accuracy is crucial for robust survey quality and accurate analysis of erosion/deposition rate. Various sources of error stemming from data acquisition (e.g., strip overlapping, point density, data gaps, etc.), data processing (e.g., geo-referencing, inadequate strip adjustment), and terrain properties (e.g., roughness, surface reflectivity) must be considered (Kamp et al., 2022).

The findings gained from this study contribute to a deeper understanding of topographical change detection and its implications for the evolution of Badlands, providing valuable insights for sustainable land management practices and conservation strategies in fragile environments.

Kamp N. et al. (2022) - Comparability of Multi–Temporal DTMs derived from different LiDAR Platforms: Error Sources and Uncertainties in the Application of Geomorphic Impact Studies. Earth Surf. Proc. Land., 48(6), 1152–1175, https://doi.org/10.1002/esp.5540.

Llena M. et al. (2020) - Geomorphic process signatures reshaping sub-humid Mediterranean badlands: 2. Application to 5-year dataset. Earth Surf. Proc. Land., 45(5), 1292–1310, https://doi.org/10.1002/esp.4822.

Marsico A. et al. (2021) - Erosion rate of the Aliano biancana badlands based on a 3d multi-temporal high-resolution survey and implications for wind-driven rain. Land, 10(8), https://doi.org/10.3390/land10080828.

Torri D. et al. (2013) - The recurring cycles of biancana badlands: Erosion, vegetation and human impact. Catena, 106, 22–30, https://doi.org/10.1016/j.catena.2012.07.001.

Monitoring and quantifying soil erosion rates using LiDAR data and soil erosion models in a Post-Fire area: the Pisticci (Italy) case study

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Keywords: soil erosion, lidar, usped.

One of the main factors in the natural processes of soil degradation is soil erosion, which is caused by the physical forces of wind and water acting on exposed soil surfaces. Post-fire erosion is an important area of study that focuses on understanding and minimizing the increased erosion hazard caused by wildfires. Indeed, it is obvious that modifications in vegetation structure and soil composition, especially following recurrent fires, can have dramatic implications on erosional processes and the overall recovery of ecosystems. This study aims to offer a methodological approach for monitoring and measuring soil erosion and sedimentation rates in post-fire conditions using: i) ultra-high resolution topographic data obtained using multitemporal UAV Lidar data; ii) airborne Lidar data; iii) soil erosion models and iv) landscape evolution models. In July 2023, a wildfire affected a watershed near the town of Pisticci southern Italy. The study area exposes the Early Pleistocene foredeep deposits of the southern Apennine chain, , which includes marine silty clay. The aim of this work is to understand the extent to which the consequences of fire on soil can trigger erosion phenomena. To do this, pre- and post-fire Lidar data were acquired. In particular, the pre-fire data are Lidar data acquired from aircraft in 2013 (acquired by the Basilicata region), while the post-fire data were acquired using a drone lidar in September 2022 and more than a year later in December 2023. Using these Lidar data, DEMs were generated, from which DoDs were made. The results of these differences show how soil erosion is greatly affected by rainfall and land cover. After the wildfire there is an increase in the erosion trend. This trend is also confirmed by the application of erosion (USPED) and landscape evolution (CAESAR Lisflood) models. Overall, this research clearly demonstrates that after monitoring the study area under post-fire conditions, the method using LiDAR data on a cm scale offers a realistic assessment of the amount of soil eroded after fire. These data are confirmed by using erosion and landscape evolution models. These observations are particularly important for assessing impacts in fire-affected areas, the implementation of mitigation strategies and management planning.

SNAP2DQuake: an implemented and automatic tool of ESA SNAP's Python module for DInSAR technique on ground deformation estimation from Sentinel-1 data

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Keywords: DInSAR, earthquakes, SNAP software.

Differential SAR Interferometry (DInSAR) is a largely exploited technique applicable to different case studies involving ground deformation on Earth. A key application is the detection of the effects promoted by large earthquakes, comprising detailed variations in ground deformations at large an local scales. Since one limit of this technique relies on the costs that may be present for the access of some satellitary imagery or software licenses for the data processing, this latter problematic can be solved with the adoption of an alternative processing performed via scripts. In this work, an automatic open-source implemented Python script (Snap2DQuake) based on the "snappy" module by SNAP software 9.0.8 (ESA) for the processing of Sentinel-1 images is presented. The main feature of the script is the reproduction of all the operators contained in SNAP software using the tools of "snappy", in order to avoid some issues that can occurr using the software, and to build a complete, simple and automatic workflow to obtain LOS deformation maps and the derived Horizontal (E-W) and Vertical deformation maps. The automatization of the processing makes Snap2DQuake easy to use and suitable with basic users of programming. The proposed tool has been tested on two case studies referred two different tectonic contexts: the Mw 6.4 Petrinja earthquake (Croatia, December 2020) and the Mw 5.7 to Mw 6.3 seismic sequence occured near Tyrnavós (Greece, March 2021). The output maps of Snap2DQuake, in agreement with field observations and previous work, furnish new insights insights into the deformation pattern linked to earthquakes, demonstrating the reliability of Snap2DQuake as an alternative tool for users working on different applications, even with basic coding skills.

Multiscale geological structural analysis of the late-Eocene to Early-Miocene mylonites from the southern Calabrian Peloritani Orogen (Aspromonte Massif-Southern Italy): new insights for the western Mediterranean geodynamics

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Keywords: multiscale geological data analysis, vorticity analysis, Mediterranean geodynamics.

In recent years, most of the thematic cartography can now be truly catalogued numerically through well-defined sharing protocols (e.g., geosciml.org/), and are ready to be used, in turn, for further multiple uses. This is particularly relevant in the multiscale and multi-source analytical approach used in geological investigations, spanning data acquired by satellite image processing, UAV surveys, field investigations, direct (e.g. drilling), and undirect (e.g. geophysical) surveys, increasingly integrated by more or less complex laboratory investigations (e.g., optical microscopy, EDS and/or WDS analysis and so on).

In this contribution, we present multiscale geological investigations starting from the digital restitution of the UAV survey campaign up to the microscale quantitative data analyses of opportunely oriented tourmaline-bearing pegmatitic mylonites for vorticity analysis purposes, passing through portable LiDAR and Micro-CT fabric analysis.

Specifically, the case study outcrops are located in the eastern sector of the Aspromonte Massif, where most of the basement rocks were involved in the activity of late-Eocene to Early-Miocene Montalto Shear Zone (MSZ). MSZ activity is dated from at least 36 Ma by Heymes et al. (2010) and produced mylonites cropping out over an area of about 200 km2, locally reaching an apparent thickness of 900 m.

The present study contributes to better defining the different paleo-domains of the Calabrian Peloritani Orogen (CPO), where the Aspromonte Massif, together with the Peloritani Mountains in Sicily, can be interpreted as the southernmost termination of the southern CPO (sCPO), a piece of the original continental southern European Variscan margin, which differs substantially from both the Serre and the Sila Massifs basement rocks. This sCPO sector is composed of a first order nappe-like structure, subvisible from bottom to top into three main tectonic complexes: (i) the Lower complex (Cirrincione et al., 2015), exclusively surfacing in the most external part of the Peloritani Mountains nappe-edifice; (ii) the Upper complex, exposed on both sides of the Messina Strait in the Peloritani Mountains and Aspromonte Massif, respectively; (iii) the Stilo Unit (Fazio et al., 2015), occupying the most internal and highest part of the tectonically-stacked system, and exclusively occurring on the Aspromonte side. The entire nappe-edifice is characterized by an exclusive SE-ward nappe emplacement, consistent with a constant Africa-verging tectonic structure, at least since the Eocene.

The research study area is distinguished by the presence of highly informative outcrops of the brittle tectonic contacts between the Stilo Unit klippe and the underlying Upper Complex units. Additionally, there are amazing evidences of the deep-seated tectonic processes that have driven the juxtaposition of the two lowermost tectonic units of the Upper Complex, namely the Madonna di Polsi Unit (MPU) and the Aspromonte Unit (AU), which are actually marked by the MSZ mylonites (Pezzino et al., 2008).

An outcrop of tourmaline-bearing pegmatitic mylonites has been investigated in detail by an integrated multiscale structural approach. This was useful to better constrain quantitatively the kinematics and strain-rate of this most recent deep-seated mylonitic horizon of the CPO structural evolution, favoring new insights for the western Mediterranean geodynamic reconstruction.

Cirrincione R. et al. (2015) - The Calabria-Peloritani Orogen, a composite terrane in Central Mediterranean; its overall architecture and geodynamic significance for a pre-Alpine scenario around the Tethyan basin. Period Mineral, 84, 701–749, https://doi.org/10.2451/2015PM0446.

The overturned nappe-like structure of the Peloritani Mountains Upper Complex in the light of the new multiscale structural investigations (Peloritani Mountains - Sicily): new insights for the western Mediterranean geodynamics

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Keywords: multiscale geological data analysis, vorticity analysis, Mediterranean geodynamics.

New and more detailed multiscale structural investigations confirmed the overturned framework of the Peloritani Mountains nappe-like structure.

The Peloritani Mountains, together with the Aspromonte Massif, in southern Calabria, constitutes the southernmost termination of the Calabrian Paloritani Orogen (CPO), that can be subdivided from bottom to top into a first order three piled up tectonic complexes: (i) the Lower complex (Cirrincione et al., 2012), exclusively outcropping in the most external part of the Peloritani Mountains nappe-edifice; (ii) the Upper complex, outcropping on both sides of the Messina Strait in the Peloritani Mountains and Aspromonte Massif, respectively; (iii) the Stilo Unit, occupying the most internal and highest part of the tectonically-stacked system, and exclusively outcropping on the Aspromonte side.

The Upper Complex, in turn, is characterized by an overturned second order nappe-like structure formed during the Apennine stage of the Alpine orogenic cycle (Pezzino et al., 2008; Cirrincione et al., 2012). This asymmetrical Africa-verging fold system involved part of the original Variscan basement units, and its Mesozoic sedimentary sequences forming an Eocene to Oligocene paleo-accretionary wedge (Cirrincione et al., 2012). According to Pezzino et al. (2008), this exclusively Alpine metamorphic unit was successively extruded along the suture of the collisional zone along a late–Eocene to early-Miocene retrograde shear-zone linked with the youngest mylonitic process that have driven the former CPO formation (i.e., the Montalto Shear Zone, Pezzino et al., 2008; Cirrincione et al., 2012; 2015). The present contribution confirmed, with new and more detailed multiscale structural data, as the Variscan basement units of the Upper Complex are preserved in the core of a constant Africa-verging regional recumbent fold system, where the overturned limb, mostly outcropping on the Peloritani side, comprises a reversed tectono-stratigraphic nappe characterized, at the base, by the anchimetamorphic metasedimentary Ali sequence (AS), overlain by the low- to medium-grade Variscan metamorphic Mandanici Unit (MU), with lithotypes ranging from phyllites (at the base) to garnet-staurolite micaschists (at the top). The MU is overprinted by the same low- to very low grade prograde to retrograde Alpine metamorphic cycle affecting the Alì sequence (Cirrincione & Pezzino, 1991).

Cirrincione R. & Pezzino A. (1991) - Caratteri strutturali dell'evento alpino nella serie mesozoica di Ali' e nella Unità metamorfica di Mandanici (Peloritani orientali). Mem. Soc. Geol. It., 47, 263-272.

Cirrincione R. et al. (2012) - Fault-related rocks: deciphering the structural–metamorphic evolution of an accretionary wedge in a collisional belt, NE Sicily. Int. Geol. Rev., 54, 940–956, https://doi.org/10.1080/00206814.2011.623022.

Cirrincione R. et al. (2015) - The Calabria-Peloritani Orogen, a composite terrane in Central Mediterranean; its overall architecture and geodynamic significance for a pre-Alpine scenario around the Tethyan basin. Period. Mineral., 84, 701–749, https://doi.org/10.2451/2015PM0446.

Pezzino A. et al. (2008) - Alpine Metamorphism in the Aspromonte Massif: Implications for a New Framework for the Southern Sector of the Calabria-Peloritani Orogen, Italy. Int. Geol. Rev., 50, 423–441, https://doi.org/10.2747/0020-6814.50.5.423.

Insights on the geological characterization of Solfatara using data from PRISMA mission

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Keywords: PRISMA mission, hyperspectral data, Solfatara.

The Campi Flegrei (CF) area (Southern Italy) is a typical example of a large collapse caldera in which post-caldera volcanic activity is polygenetic (Pedone et al., 2017 and references therein) characterized by fumarolic emissions, "bradismic crisis" and uplift phases still ongoing.

We may propose that the CF area has a "dual" value which makes it a highly interesting place for scientific research. On the one hand, from a volcanic and natural hazard assessment point of view, CF is one of the most dangerous volcanoes on Earth in terms of its proximity to a densely populated urban area (the Neapolitan district is home to about three million people living between CF, Vesuvius and Ischia). On the other, from a Planetary Science point of view, the Solfatara crater (and Pisciarelli site) high-temperature geothermal environment is comparable to terrestrial analogue of Early Mars, Early Earth, as well as Early rocky bodies inside the Solar System.

Fumarolic characterization was carried out at Solfatara by using in-situ analysis (e.g., Aiuppa et al., 2013) or proximal by using Tunable Diode Laser Spectroscopy (Pedone et al., 2014). The adoption of novel technologies to estimate fumarolic CO_2 fluxes has revealed that the fumarolic contribution to the whole CO_2 flux of the area is substantial, representing ~50% of the soil CO_2 output (Aiuppa et al., 2013; Pedone et al., 2014). In a study by Pedone et al. (2017), fumarolic CO_2 emissions at Campi Flegrei and their dispersion in the lowest atmospheric boundary layer were investigated, innovatively utilizing a Lagrangian Stochastic dispersion model combined with the Eulerian model (DISGAS) to diagnose the dispersion of diluted gas plumes over large and complex topographic domains.

Due to the scientific value this site represents, in the view of a comprehensive characterization, we show the preliminary results of the exploitation of PRISMA (Caporusso et al., 2020) data for the spectral characterization of the acidic products of the Solfatara crater and for the fumarolic gases detection.

Aiuppa A. et al. (2013) - First observation of the fumarolic gas output from a restless caldera: implications for the current (2005-2013) Campi Flegrei unrest. Geochem. Geophys. Geosystems, https://doi.org/10.1002/ggge.20261.

Caporusso G. et al. (2020) - The Hyperspectral Prisma Mission in Operations. IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, 3282-3285, https://doi.org/10.1109/IGARSS39084.2020.9323301.

Pedone M. et al. (2014) - Volcanic CO_2 flux measurement at campi flegrei by tunable diode laser absorption spectroscopy. Bull. Volcanol., https://doi.org/10.1007/s00445-014-0812-z.

Pedone M. et al. (2017) - Improved quantification of CO_2 emission at Campi Flegrei by combined Lagrangian Stochastic and Eulerian dispersion modelling. Atmos. Environ., https://doi.org/10.1016/j.atmosenv.2017.09.033.

Integrating probabilistic and hydrodynamic models for enhanced Flood Hazard Assessment and Mapping in the Basento River Basin (southern Italy)

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Keywords: flood, hydrodynamic models, rivers.

River flooding affects more people worldwide than any other natural hazard, increasing the importance of the capability to predict and prevent the related harm. There are several methods used to estimate flood hazard whose performance depends on the catchment features, dimension, timespan, resolution and uncertainty level. In this contribution, a catchment-scale application of the probabilistic model proposed in La Salandra et al., 2022 is combined with hydrodynamic models, in order to assess flood hazard and flood mapping on a test case of the Basento river (Basilicata, southern Italy). Hydraulic parameters and peak discharge rates were estimated in five different cross-sections of the main river channel, spanning different morphologies from braided to meandering channels. A sensitivity analysis was carried on to investigate the difference in flood probability by means of high-resolution drone-derived multitemporal Digital Terrain Models (DTMs), highlighting the areas where morphological changes can occur more frequently. FLO-2D and HEC-RAS hydrodynamic models were used for flood simulations for each river cross-section area, by using the same digital terrain models and the same inflow input calculated with the Probabilistic model. Results demonstrate the control of morphology on the flood hazard among the different cross-sections (from 0.05% to 6.65% related to a 10-years reference period). The comparison of the simulations outcomes with the Probabilistic model results shows a good agreement regarding the flow depth and flow velocity outputs. The performance of FLO-2D and HEC-RAS models is better in the downstream and upstream catchment area, respectively. The combination of these models represents a useful tool for improving flood mapping and flood hazard assessment.

La Salandra M. et al. (2022) - Probabilistic hydro-geomorphological hazard assessment based on UAV-derived high-resolution topographic data: The case of Basento river (Southern Italy). Sci. Total Environ., 842, 156736, https://doi.org/10.1016/j.scitotenv.2022.156736.

Digital field mapping of granitoid outcrops: a study case of late Variscan granitoids from Michelino Beach, Capo Vaticano Promontory (southern Calabria)

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Keywords: remote sensing, UAV, 3D VOM.

Different remote sensing technologies, including drone-based photogrammetry and LIDAR (light detection and ranging), allow creating 3D digital representations of outcrop surfaces that can be used in mapping geology. We applied this integrated approach to Michelino Beach in Parghelia (38°41’07”N, 15°55’15”E), one of the rare places in southern Calabria with a well-exposed sector of the lower-intermediate levels of the Serre Batholith, a c. 13-km thick composite sheeted-like late Variscan granitoid complex. Indeed, in this area, biotite tonalites (BT) come into contact with overlying K-feldspar megacrystic two-mica granodiorites and granites (PMBG) by means of sharp intrusive contact. In more detail, at the roof of the tonalitic unit, emplacement of the overlying porphyritic granodioritic magma involved incorporation of small rounded to angular blocks of tonalite, but also displacement of the mushy tonalite, with its local disaggregation in rounded blocks up to 1.5 meter in size. Such latter evidence indicates a rigid state of the tonalites at the time of granodiorite emplacement, even though rare occurrence of hybrid rocks in the contact zone testifies for possible mixing processes also between the granodioritic magma and the mushy tonalite. Moreover, Michelino Beach is an ideal location to investigate the emplacement dynamics of granitic magma with significant implications on the construction of magmatic complexes. Petro-structural mapping, assisted by LIDAR-equipped iPad, of the orientation of K-feldspar megacrysts in MBPG identified an ESE-WNW and E-W direction as preferential magma flow directions associated to a dominant NNE-SSW shortening axis. This work would like to contribute to the advance of digital field mapping methodologies, not only facilitating a better understanding of the spatial distribution and structural relationships within magmatic units but also opening up new possibilities for quantitative analysis and modelling of geological processes.

Macro- to micro-scale investigation of the relationships between granitoid magma emplacement and tectonics at Capo Vaticano Promontory (southern Calabria, Italy)

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Keywords: field relationships, batholith architecture, deformation microstructures.

This study offers new macro- to micro-scale insights into batholith architecture and the link between shear zone and granitoid magmatism at Capo Vaticano Promontory, a dislocated segment of the late Variscan Serre Batholith in southern Italy. Through comprehensive field surveys and detailed petrographic analyses, we present the first geological map of the area at a scale of 1:140.000, illustrating the intricate relationships and the structural characteristics of the exposed magmatic units. Our findings reveal two main sectors: a northern sector representing a coherent cross-section of the Serre Batholith, ranging from strongly foliated amphibole-biotite tonalites and quartz diorites at lower depths to less foliated intermediate-seated porphyritic two-mica granodiorites and granites at shallower levels. In contrast, the southern sector exhibits a more irregular distribution of the magmatic units. Widespread supra- to subsolidus deformation microstructures, coupled with the presence of kinematic indicators and a well-defined fabric, suggest that the emplacement of early tonalites/quartz diorites was controlled by shear zones. Subsequent emplacement of the less deformed porphyritic granitoids likely occurred during phases of reduced shear zone activity. Field foliations for the deep-intermediate seated granitoids exposed in the northern Capo Vaticano Promontory sector, after removing the effects of the Miocene to recent rotation, are in accordance with the NW-SE shortening axis recorded for the same granitoid units in the Serre Massif. Recorded dominant shortening, along with field and microscopic indications of sub-simple shear, reveal a transpressional regime for the emplacement of the deep-intermediate seated granitoids from Capo Vaticano Promontory.

The role of advanced surveying technologies for geomechanical analysis of artificial caves: the case study of Gravina in Puglia (Puglia region, Southern Italy)

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Keywords: artificial caves, geomatic modeling, geomechanical analysis.

Accurate modeling of natural and artificial caves is crucial for understanding the genesis and evolution of these underground environments, which is necessary for hazard assessment and urban planning of built-up areas and critical infrastructures. This research leverages advanced geomatic technologies, including terrestrial laser scanning (TLS), SLAM-based mobile mapping systems (MMS), and digital photogrammetry with 360-degree cameras, to create detailed three-dimensional models of artificial caves, which can be complex and hard-to-access environments (Giordan et al., 2021). The integration of these high-resolution technologies enables the detailed mapping and analysis of these caves, enhancing the understanding of their spatial distribution and structural integrity.

Dealing with the artificial caves of Gravina in Puglia (Puglia region, Southern Italy), characterized by significant architectural, historical, and cultural value (Parisi et al., 2020), this study focuses on two main objectives: (i) improving the understanding of the planimetric development of the artificial caves with reference to the built-up environment; (ii) integrating geological and geomechanical data to support structural monitoring, sinkhole hazard assessment, and the identification of areas at high risk of structural degradation (Fazio et al., 2017).

The performance of various geomatic techniques, including TLS based on VIS (Visual Inertial System), SLAM, and spherical photogrammetry, for three-dimensional model reconstruction and geomechanical stability assessment has been evaluated. The comparative analysis aims to determine the efficacy of each method to enhance the accuracy of geotechnical evaluation and risk assessment (Idrees & Pradhan, 2016). This comprehensive approach helps to address the immediate challenges posed by the underground environments, as well as it contributes to the broader field of geotechnical engineering by providing essential data for future urban development and conservation strategies.

In conclusion, this research will provide insights related to the optimal use of these advanced surveying technologies for modeling complex underground caves, thus offering a methodological framework that can be applied to similar geological settings. This will ultimately aid in the hazard assessment associated with underground caves, as well as in leading to the development of more resilient urban settlements.

Fazio N.L. et al. (2017) - A three-dimensional back-analysis of the collapse of an underground cavity in soft rocks. Eng. Geol., 228, 301-311, https://doi.org/10.1016/j.enggeo.2017.08.014.

Giordan D. et al. (2021) - Survey Solutions for 3D Acquisition and Representation of Artificial and Natural Caves. Appl. Sci., 11, 648. https://doi.org/10.3390/app11146482.

Idrees M. & Pradhan B. (2016) - A decade of modern cave surveying with terrestrial laser scanning: A review of sensors, method and application development. Int.l J. Speleol., 45(1), 71-88, https://doi.org/10.5038/1827-806X.45.1.1923.

Parisi A. et al. (2020) - Le cavità antropiche di Gravina in Puglia (Bari, Puglia): aspetti storici e geotecnici. Opera Ipogea, 1/2, 263-272.

Measuring geological surfaces in virtual outcrop models

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Keywords: virtual outcrop models, best-fit plane, trace digitization.

Over the past two decades, major advancements in close-range remote sensing techniques that facilitate the 3D digitization of geological structures have resulted in the rapid proliferation of virtual outcrop models (VOMs) within the geosciences. The emergence and refinement of accessible and highly portable sensory platforms, such as terrestrial lidar, digital cameras, smartphones, tablets, and uncrewed aerial vehicles, have played a pivotal role in catalyzing this digital revolution. The analysis of geological discontinuities represents a key component of many VOM studies. Specifically, establishing the orientation distribution of discontinuities, such as fractures, faults, or bedding planes, represents the preliminary analysis in many applications. In this context, there is a growing need to establish standards for the digital measurement of geological discontinuities exposed in VOMs. Such standards should be tailored towards the complexities of natural outcrops, where geological discontinuities often intersect the outcrop topography and are expressed as 3D traces. Digitizing geological discontinuities expressed as trace data is typically conducted manually via polyline interpolation along the exposed trace, with discontinuity orientation estimated through planar model fitting through the polyline's component nodes. Presently, establishing quality control for such measurements lacks standardization due to the absence of robust benchmarks, with the validity of the resultant orientation data heavily relying on the interpreter's expertise.

With the aim of bridging this gap, we present the results of the manual digitization and orientation estimation of bedding planes expressed as traces across seven natural outcrops. We use two digitization strategies: one employing a previewed best-fit plane during digitization and another without. These methods represent active model-guided and unguided digitization approaches, respectively, with their comparison aimed at building benchmarks and best practices. Specifically, we analyze parameters derived from the digitized traces and their corresponding best-fit planes. We compare these parameters with the deviation of the best-fit plane from the true orientation of the bedding surface. Such a comparison highlights the impact of node collinearity on best-fit plane precision and accuracy, with a robust benchmark for this parameter provided. This quantitative comparative analysis is complemented by recommended best practices for 3D trace digitization, such as a high value of coplanarity, maintaining a quasi-constant node-to-node distance relative to the model's resolution, and ensuring a minimum number of nodes to guarantee the robustness of the fitted planar model.

The role of ASI in the development of novel user-driven EO-based products for geo-hazards applications: the "Multi-mission and Multi-frequency SAR" and "I4DP_SCIENCE" Programs

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Keywords: Earth observation, synthetic aperture radar, geo-hazards.

Nowadays, geo-hazard scientific research and practice in Italy substantially rely on Earth Observation (EO). This was achieved owing to a growing ecosystem of research bodies and universities that developed world-leading competence in forefront EO technologies, among which Synthetic Aperture Radar (SAR) and SAR Interferometry (InSAR) represent an unquestionable excellence.

To consolidate this strength, the Italian Space Agency (ASI) promotes new SAR missions, SAR/InSAR-based scientific research, and demonstration of novel downstream applications. The most recent national R&D program was the *"*Multi-mission and multi-frequency SAR*"* program (Tapete et al., 2022; 2023), during which innovative algorithms to process SAR data were tested (e.g., for natural hazards applications).

To move from pure R&D to exploitation in pre-operational contexts and provision of useful input into final users' workflows, in 2022 ASI launched the *"*Innovation for Downstream Preparation*"* (I4DP) program, promoting the development of downstream through the use of spatial data, acquired and provided by national and European space systems (e.g., PRISMA, COSMO-SkyMed, SAOCOM, etc.). In particular, the I4DP_SCIENCE channel focuses on "Scientific Downstream" and is mainly addressed to the Scientific User Community (i.e., Italian Universities, Public Research Bodies, etc.). I4DP_SCIENCE consists of joint projects with ASI, devoted to the demonstration and dissemination of the usefulness of novel methods and algorithms in supporting applications of user's interest, regarding topics of national relevance (e.g., National Copernicus User Forum), and/or outlined in international agendas (e.g., UN Sustainable Development Goals, SDGs). To date, two thematic calls were released: *"*Sustainable Cities" and "Agriculture and Sustainable Use of Water Resources".

Out of the projects selected in the first call, GEORES specifically addresses the theme of metropolitan cities and urban sustainability. The project is led by the University of Bari (UNIBA) and the Institute for Electromagnetic Sensing of the Environment (IREA) of the National Research Council of Italy (CNR), together with ASI. Aim of GEORES is the development of a geospatial application to improve environmental sustainability and resilience to climate changes in urban areas, by setting up a multi-risk WebGIS platform, consisting of four main modules: Sediment Connectivity, Land Displacement, Urban Floods, and Urban Wildfires. Each module makes use of EO data, calculation models, and algorithms, integrated together to identify high-risk "hot-spots" in the urban and peri-urban territory, in order to point out regions interested by land degradation due to hydrogeological instability, sediment flow, or vegetation fires. Main targets of GEORES are the Metropolitan City of Bari and the urban settlements in Gargano Promontory, Apulia Region, southern Italy.

Tapete D. et al. (2022) - ASI's "Multi-Mission and Multi-Frequency SAR" Program for Algorithms Development and SAR Data Integration Towards Scientific Downstream Applications. In: 2022 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 4498-4501, https://doi.org/10.1109/IGARSS46834.2022.9884937.

Tapete D. et al. (2023) - ASI's "Multi-Mission and Multi-Frequency SAR" Program for Algorithms Development and SAR Data Integration: Achievements and Future Perspectives. In: 2023 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 1412-1415, https://doi.org/10.1109/IGARSS52108.2023.10282854.

Leveraging machine learning for ground motion prediction: advancements in seismic hazard assessment

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Keywords: natural hazard, ground motion prediction, machine learning implementation.

Ground motion intensity measures are crucial for seismic hazard assessment and design, traditionally derived from Ground-Motion-Prediction-Equations (GMPEs). However, recent decades have witnessed a paradigm shift towards the integration of artificial intelligence, particularly Machine Learning (ML), that aims to address nonlinear phenomena in seismology.

This study is based on a rich dataset compiled from seismic events in central Italy, including the earthquakes in L'Aquila (2009) and the Amatrice-Visso-Norcia sequence (2016-2018). Approximately 34000 waveforms constitute this robust dataset, meticulously curated by previous researchers, thereby establishing a foundation for accurate prediction models.

We employ supervised ML algorithms to calibrate prediction models, contrasting their performance with the widely used Italian Ground Motion Prediction Equation (GMPE, ITA18). Notably, XGBoost emerges as the optimal algorithm, offering a blend of error minimization, interpretability, and computational efficiency.

Evaluation metrics encompass various Intensity Measures (IMs), including Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and Acceleration Response Spectra (SA) across different time periods. The ML model developed herein demonstrates superior accuracy, surpassing traditional GMPEs. These results signify a significant stride in seismic hazard assessment, with implications transcending local contexts to global applicability, contingent on the availability of seismic data.

Cascading landslide risk assessment by means of an integrated approach

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Keywords: landslide risk assesment, FEM modeling, remote sensing tecnique.

Cascading landslides represent a dynamic and hazardous geological phenomenon, characterized by a sequential chain reaction of slope failures triggered by various factors such as heavy rainfall, seismic activity, wildfires, or anthropogenic activities (i.e. excavation or deforestation). This phenomenon generally starts when an initial landslide destabilizes the surrounding terrain, leading to subsequent landslides that may intensify the damage caused by the initial event or create a predisposed environment for subsequent slope failures, (Hungr et al., 2014) often resulting in significant environmental and societal impact.The Morino-Rendinara cascading landslide is one of the most significant Italian appenine examples of cascading landslides in terms of landslide mechanism, impact. The municipality of Morino is situated in the Ernici mountains along the border of Abruzzo and Lazio in Italy. Local geology consists of Mesozoic formations displaced by normal faults, overlain by Messinian arenaceous-pelitic formations and Quaternary deposits. Significant-flow springs are present at the landslide head and fed by highly fractured carbonaceous aquifer cropping out immediately upslope. Morino Renidnara landslide is formed by a rock fall/avalanche landslide in the upper sector of slope, a deep-seated rotational slide in the middle sector of the slope and a debris flow that dammed Liri River as consequence of the last recorded reactivation in March 2021. This study employs a multidisciplinary approach, combining different advanced technologies, to comprehensively understand the complexities of the Morino-Rendinara landslide. Field activities, UAV image acquisition, Differential Interferometry SAR (DInSAR) using SENTINEL-1 images processed by the SUSIDENCE software, and pixel offset analysis based on the procedure applied on high-resolution Google Earth images (Guerriero et al., 2020) offer insights into the geological and hydrogeological conditions contributing to slope instability through an analysis of elaborated rainfall data and time series derived from interferometric analysis. The study aims to reconstruct a subsurface model and basal failure surface through specific Finite Element Method (FEM) slope stability analyses, with a particular emphasis on the water's contribution to slope stability. Through the integration of FEM slope stability analyses and remote sensing techniques, it is possible to assess the risk associated with this complex phenomenon and understand its impact on the environment. The integration of these techniques enables a deep comprehension of the landslide, providing valuable information on velocity, components, displacement, foundament to assess the risk.

Guerriero L. et al. (2020) - Digital Image Correlation of Google Earth Images for Earth's Surface Displacement Estimation. Remote Sens., 12(21), 3518, https://doi.org/10.3390/rs12213518.

Hungr O. et al. (2014) - The Varnes classification of landslide types, an update. Landslides, 11(2), 167-194.

S10.

The role of multidisciplinary approach in the geochemical study of natural systems

CONVENERS & CHAIRPERSONS

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Assessing the origin of N-bearing species in the surface waters from the Arno River Basin (Tuscany, central Italy): insights from nitrogen and oxygen isotopes in dissolved nitrate and nitrite

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Keywords: nitrogen isotopes, water quality, environmental management.

Agricultural and industrial activities are regarded as the main responsible for the discharge of pollutants in natural environments, and river waters are extremely sensitive to anthropogenic contamination. Over the years, the influence of man-related activities, together with the effects of climate change, has led to an impoverishment of water quality. N-bearing species (i.e., NO^{3-}, NO^{2-}, and NH^{4+}) are considered to be among the main pollutants in surface waters and shallow aquifers at global scale, these compounds being released by multiple sources (industrial discharges, domestic and agro-zootechnical wastes, nursery and agricultural activities). Nitrogenated species are strictly regulated since the consumption of water containing high levels of nitrogenated species can cause severe health problems, i.e., cancer, birth defects, methemoglobinemia, and other adverse effects. Therefore, assessing the sources of N-bearing species is a pivotal step to improve water management.

The Arno River Basin (ARB) has been suffered more than a century of industrial and demographic development and it is currently affected by a significant anthropogenic pressure due to the presence of relatively large cities (e.g., Florence, Prato, Pisa) and widespread industrial and agricultural activities. In this work, 26 water samples (13 from the Arno River and 13 from the main tributaries) were analyzed to assess the water pollution status. Moreover, the $\delta^{15}N$ and $\delta^{18}O$ values in both nitrate (NO^{3-}) and nitrite (NO^{2-}) were determined to understand the origin and fate of nitrogenated species. The Arno River composition evolves from Ca-HCO_3 to Na-Cl(SO_4) from the source to the mouth with an increasing deterioration in terms of quality of the surface waters. The significant increment of the Na^+ and Cl^- contents downstream of Florence has to be attributed to anthropogenic contributions (i.e., untreated, or partly treated, wastewaters from industrial activities) and, eventually, to seawater instrusion. Critical concentrations in nitrate and nitrite (up to 63 and 9 mg/L, respectively) were detected in the Middle and Lower Valdarno sub-basins. The Ombrone and Usciana tributaries are the main contributors of anthropogenic pollutants into the Arno River, whilst the Elsa tributary supplies the main course with significant contents of geogenic sulfate. The Sieve, Pesa, Egola and Era tributaries act as diluters of the Arno River waters, partially decreasing the Na^+ and Cl^- impact. The combined application of $\delta^{15}N^-$ and $\delta^{18}O$-NO_3 allowed to identify sewage and domestic wastes as primary sources for dissolved NO3- in the ARB running waters. Moreover, the isotopic data of $\delta^{15}N$ and $\delta^{18}O$ in NO_2 clearly suggest that the nitrification process (oxidation of NH^{4+} to $NO^{3-}$with NO^{2-} as an intermediate product) affects the waters flowing in the ARB, thus playing an important role in terms of abundances and respective proportion of the nitrogenated species.

Geothermal energy as an integration of existing district heating and cooling grids: evaluation of the thermal performance of the system and of thermal disturbance on the ground from a real case study in NW Italy

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Keywords: geothermal energy, numerical simulations, district heating.

The geopolitical situation since February 2022, has led governments to find solutions to reduce energy imports, and fight against climate change impacts. New approaches for the decarbonisation of the heating and cooling sector, which is still responsible for almost half of the final energy consumption in Europe and significantly depends on energy imports, are strongly required. Therefore, European government has to put in place short and long-term measures aimed at shielding consumers from the direct impact of the rising energy prices across Europe, and to counteract the continuous economic volatility (Sgaravatti et al., 2023). In this framework, low carbon sources such as geothermal energy can substantially decrease energy consumptions and costs, especially if included into decarbonized heating and cooling grids (Goetzl et al., 2022) The recent multiple crises have led to increased interest in using geothermal energy in district heating and cooling grids to substitute fossil fuels, especially gas boilers and air conditioners for the heating and cooling demands, respectively. However, due to shortcomings in the market development efforts in the past years, services needed for the rollout of heating and cooling networks in Europe are limited and require significant ramp-up periods (Costa et al., 2017).

To this regard, this work deals with an integration of shallow geothermal energy for a small existing district heating in small city in NW Italy (at about 70 Km SE from the city of Turin). Specific field tests in a real case study such as hydrogeological, geophysical, and thermo-physical surveys of the underground soils were conducted. Moreover, the realization of a field ground response test (GRT) together with a continuous thermal monitoring at different depths, allowed to better evaluate the thermo-physical parameters of the underground soils inside a real pilot borehole. Starting from the real data obtained from these specific field surveys, a further sensitive analysis through the use of the FeFlow software which uses a finite element code, allowed simulating the thermal behaviour of the ground and the thermal performances of the whole system, during the plant operation in the short and long term. Thermal performances were also simulated using different geothermal pipe configurations: this revealed useful to better understand the thermal power extraction from each borehole as well as to know how much the thermal plume can expand around it over time. All these data allowed for a very useful information in better designing a shallow geothermal plant, as an integration for a district heating and cooling system as that planned in the investigated area.

Costa A. et al. (2017) - Development of Future EU District Heating and Cooling Network Solutions, Sharing Experiences and Fostering Collaborations. Proc., 1, 1105, https://doi.org/10.3390/proceedings1071105.

Goetzl G. et al. (2022) - Pathways to better integrate geothermal energy at its full technological scale in European heating and cooling networks. Eur. Geol., 54, https://doi.org/10.5281/zenodo.7882918.

Sgaravatti G. et al. (2023) - National fiscal policy responses to the energy crisis", Bruegel Datasets, https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices. Last access on 28/03/2024.

Fluid evolution in the deep reservoir of the Larderello geothermal system: insights from microthermometry and LA-ICP-MS analyses of quartz-hosted fluid inclusions

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Keywords: fluid inclusions, LA-ICP-MS, Larderello geothermal system.

The study of fluid inclusions (FIs) is a valuable tool to investigate fluids that permeated geothermal reservoirs, now or in the past. One of the advantages of FIs is that they general exhibit "closed system" post-entrapment behaviour. Although this is often the case, fluid inclusions can reequilibrate (via diffusion, deformation or reaction with the host mineral), or undergo changes in volume or shape (i.e., necking down processes). Petrographic observations are thus key to identify pristine inclusions that are representative of the original trapped fluid.

We undertook a comprehensive FIs study on samples recovered from a deep well of the Larderello geothermal system (Italy), where no FI analysis of trace element chemistry on modern fluids has been conducted. This well, named Sesta6bis, from the north-western part of the system, reaches a depth of 3921 m b.s.l., with temperatures of about 300°C measured in the well during production tests (Barelli et al., 2000). We targeted three core samples, obtained from 2733-2737 m, 3085 m, and 3803 m depths in order to study quartz-hosted FIs. Our ultimate goal is to reconstruct the hydrothermal fluid history in this vapor-dominated geothermal system.

Following petrographic classification of FIs assemblages, we performed micro-thermometric analyses on assemblages from all three core samples. The shallower samples contain multiphase inclusions in combination with primary two-phase liquid-rich (L-rich) and vapor-rich (V-rich) inclusions. The latter two inclusion types are also present in the deeper samples, highlighting an ongoing boiling process at the time of entrapment. Homogenization temperatures for the primary FI assemblages range between 340 and 370°C. In contrast, secondary L-rich FIs observed in the deeper samples are characterized by a lower homogenization temperature, in the range of 310-325°C. These lower temperature are in good agreement with the present-day fluid temperature recorded at the wellhead during production tests, suggesting the secondary inclusions represent trapping of the current geothermal reservoir fluids.

In addition to microthermometric determinations, we conducted laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analyses on the above described FIs. In advance of LA-ICP-MS analyses, quartz grains were imaged by scanning electron microscopy (SEM) based cathodoluminescence imaging, with the aim to identify potential growth zones in quartz and later recrystallization of fractures. This CL-mapping was used to more definitively target both primary and secondary FIs. The trace element composition of these well-characterized FIs assemblages can be assumed as representative of the recent and current hydrothermal fluids circulating in the deep Larderello geothermal reservoir. We report preliminary results of these LA-ICP-MS analysis and provide insights on the evolution of the fluids that circulated in the portion of the Larderello geothermal system.

Barelli A. et al. (2000) - Recent deep exploration results at the margins of the Larderello-Travale geothermal system. Proc., 965-970.

Comparison of the isotope based early warning model application to two different municipal solid wastes landfills in Central Italy

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Keywords: groundwater pollution, stable isotopes, environmental hydrogeology.

Water is regarded as one of the most important natural resources. Indeed, water resources and water quality are important and indispensable for human survival, the ecological environment and sustainable economic and regional development. Nowadays, one of the serious environmental threats is groundwater contamination due to leachate from municipal solid waste landfills with a significant organic component.

In recent years, the use of stable isotopes as environmental tracers to identify groundwater contamination phenomena has found application in environmental hydrogeology as they can be used to determine the sources, pathways and timescales of environmental processes. Deuterium (^{2}H) and oxygen (^{18}O) isotopes have been successfully applied to assess contamination phenomena when groundwater interacts with leachate. In these cases, the groundwater presents isotopic compositions relating to ^{2}H and ^{18}O, highlighting an enrichment of $\delta^{2}H$, probably caused by methanogenesis phenomena in which bacteria preferentially use the "lighter" isotope of hydrogen (^{1}H). In this way, the remaining hydrogen is enriched in ^{2}H, the "heaviest" isotope, without producing a proportional increase in ^{18}O. Deuterium excess (d-excess) influences the isotopic content of deuterium and oxygen 18 and can be used to identify processes that occur under non-equilibrium conditions. Therefore, an early warning model based on the d isotope is used, dependent on evaluating changes in deuterium excess in groundwater samples. This model involves the determination of an F index as a percentage change in d-excess, which allows the definition of a system of three alert levels to evaluate and control groundwater contamination by leachate. F index values higher than 1.1 highlight possible contamination phenomena of the aquifers due to leachate.

In this study, we compare two different municipal solid waste landfills in central Italy. In particular, we applied this isotopic model both in a site where contamination of groundwater by leachate occurred and a variation in the isotopic content was therefore recorded, and in a site where there was no contamination and consequently no variations in isotopic contents were recorded. This demonstrates the effectiveness of the application of deuterium as a tracer of the leachate presence in groundwater near municipal solid waste landfills. Furthermore, it highlights how innovative monitoring tools that achieve high sampling frequencies with low-cost procedures or analyses represent a significant improvement likened to traditional approaches.

Geochemical characterization and biotechnology potential of marine sediments from a small maritime area around Elba-Argentario Basin (Tyrrhenian Sea, Italy)

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Keywords: marine sediments, metal distribution, microbiology.

Bottom sediments representing an average stratigraphic depth of 20 cm across northern-central Tyrrhenian Sea, approximately between the Arno river mouth and the Argentario Promontory are this work focus in the framework of the CNR project named SeaGMA. Preliminary analytical effort included aqua-regia digestion of selected samples followed by ICP-MS determinations while X-Ray fluorescence spectrometry in combination with gravimetric analysis for the evaluation of total composition and volatile content was for all samples. Data analysis helped recognising three major areas:

- a wide population of fine grained samples characterized by relatively high concentrations of As, Cr, Cu, Zn and other elements that can source from volcanic rocks.
- a second population with a likely enhanced content in carbonates and contributions from the ophiolitic rocks outcropping inland.
- the smallest population includes mostly sandy sediments with elevated CaO and Sr contents in the westernmost sectors near main islands.

These geochemical signals (e.g., volcanic vs terrigenous) helped to select relevant sites for microbiological exploration toward discovering new microorganisms and natural processes functioning as environmental bioremediation tools. In a multidisciplinary effort, we isolated 60 strains among 22 genera from five selected sampling sites based on their capacity to resist harsh conditions. Biotechnology potential from marine sediments is elevated according to tested strains tolerance to selected stressors such as pH (pH Tolerance assay) and industrial waste leachates (Maximum tolerance concentration assay).

We promptly found bacteria suitable for CCS or capable of other interesting processes, likely because of local anthropic stressors. The causal association between geochemical anomalies and extremophiles would unlock biotechnology potential at producing new substances or recovering raw materials.

S behavior, sulfate and SO_2 emissions during a basaltic eruption in Central America: the case-study of the December 29th, 2013 eruption of the San Miguel volcano, El Salvador

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Keywords: Ca-sulfate, SO2, San Miguel volcano (El Salvador).

The San Miguel or Chaparrastique volcano (E of El Salvador) is a medium size (1.500 m of vertical development) basaltic-andesite basaltic stratovolcano representative of a large number of similar active arc volcanoes outcropping along a 1400 km long transect at the frontal pacific coast from the Mexico-Guatemala border sector till central-western Panamá. This volcanic front is related to the subduction of the Cocos plate under the Caribean one, a moderately thick continental crust. These basic volcanoes represent the recurrent volcanism at the region, being the silicic large lake calderas related to much lesser frequent and much larger eruptions. In this context, a great number of surveillance efforts in the regions are devoted to the forecasting of the volcanic activity of these medium-sized basaltic stratovolcanoes, including SO2 surveys. However, the SO_2 emissions prior to the eruption of December 29th 2013 eruption of the San Miguel volcano were not predictive, while emissions after the explosive event provided deveral cycles much higher contents along the successive month.

The December 29th, 2013 eruption was associated to an important emission of ash along a vector around 90 km long, thus traversing most of the El Salvador republic. A set of 13 pristine samples distributed along this vector were sampled in the 36 successive hours before raining. These samples were physically and chemically characterized, including granulometry, SEM+EDS morphoscopy and microchemical composition, XRF whole rock chemistry, Rietvelt refined XRD mineral and glass composition, ATD-TG profile of degassing, etc. An aliquot of these samples was also leached with ultrapure water and the leachates characterized (conductivity, pH, chemical composition by ICP-MS).

The ash and leachate studies provide a number of evidence that allows for the explanation of the non-forecasting behavior of preeruptive SO_2 emission. First of all, calcium sulfate (mostly compatible with anhydrite) is widespread, and looks not just like a sublimate generated in the eruptive column, but also as a magmatic primary phase in ash, a fact that have been also described in a number of subduction volcanoes everywhere. The morphoscopy of ash grains provides a good image of how proceed the liquid fragmentation in the course of this short-lived eruptive event. All of these features strongly suggest that SO_2 behavior might be related at least pro-parte to magmatic sulfate phenocrysts breakdown in a context of an open conduct. On other hand, leachate provides excellent evidence of a chemical zonation of trace elements along the 90 k, vector of diffusion of the ash plume, a fact easily correlatable to the geochemically well-known mobility of some elements and the gradual cooling of the plume along the path traveled. This fact might be very common, but as well as we know it is usually not reported neither used in the geochemical models of dispersion related to environmental effects of volcanic ash dispersion.

Decadal geochemical monitoring of CO_2 and SO_2 outgassing activity of Vulcano Island, Aeolian Archipelago, Italy

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Keywords: geochemical monitoring, soil CO_2 degassing, SO_2 plume output.

The Active cone of La Fossa caldera is a close conduit volcano affected by solphataric activity, manifested in the hot fluids released from fumaroles and the associated thermal anomalies in groundwater and exposed ground.

The evaluation of the volcanic activity changes was inferred by the near real-time monitoring of soil CO_2 fluxes diffused at the La Fossa Cone and the peripheral areas of Palizzi and Levante Bay and by the discontinuous monitoring of CO_2 fluxes diffused by soil in areas around the CO_2 continuous monitoring stations, La Fossa Cone, Palizzi and Levante Bay (Inguaggiato et al., 2022a).

In particular, three main changes in degassing activity were recorded in 2009, 2021, and 2022 and allowed us to evaluate in near real-time the level and duration of the exhaling crisis affecting the Island of Vulcano, by measuring the changes in mass and energy carried by the fluid release (Inguaggiato et al., 2022b).

The strong and deep input of volatiles released, in the last decades, from the underlying magma batch strongly modified the chemical composition of the shallow plumbing system, leading the system to an increase in the level of CO_2 over time.

Moreover, near continuous plume SO_2 fluxes, measurements have been carried out by a network system of SO2 measurements at Vulcano Island, Italy. Two Scan-DOAS stations belonging to the NOVAC Project are located respectively at NE and SW of volcanic cone.

The fluxes of SO_2 plume acquired by the UV-scanning DOAS network showed, in the study period (2021 – 2022), monthly average values between 20 and 121 t d-1. Starting from June 2021 onwards, the SO_2 output showed a positive trend with an abrupt increase reaching the highest monthly value in September 2021 (monthly average value= 121 t d-1) and the highest daily measurement 16 November 2021 (daily average = 248 t d-1).

The atmospheric dispersion model (AERMOD), designed for simulate the dispersion of air pollutant from stationary anthropogenic and natural emission source, have been utilized to produce the dispersion SO_2 maps and evaluate the air SO_2 concentrations in the neighboring areas of the Vulcano island. These maps have been constructed using environmental parameters such as wind speed and direction measured by the local network installed in different points of the island and at different altitudes. These SO2 iso-concentration maps compared with the limit values shown in the human health tables have made it possible to identify the most harmful areas (Vita et al., 2023).

Inguaggiato et al. (2022a) - The extensive parameters as a tool to monitoring the volcanic activity: The case study of Vulcano Island (Italy). Remote Sens., 14(5), 1283.

Inguaggiato S. et al. (2022b) - The volcanic activity changes occurred in the 2021–2022 at Vulcano island (Italy), inferred by the abrupt variations of soil CO_2 output. Sci. Rep., 12(1), 21166.

Vita F. et al. (2023) - Environmental and volcanic implications of volatile output in the atmosphere of vulcano island detected using SO_2 plume (2021–23). Remote Sens., 15(12), 3086.

Unravel the groundwater dynamics in a landfill with water isotopes: the peculiar case of Corinaldo Municipality landfill

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Keywords: water isotopes, landfills, groundwater.

Water plays a crucial role in landfill biogeochemistry, influencing waste degradation, leachate composition, and environmental impacts. At the same time, the movement of groundwater below and in the vicinity of landfills interacts with surrounding slopes and man-made structures built to contain the waste, such as earth dams and embankments. Such interaction can be relevant in presence of low permeability soils and when large excavations and filling are carried out, two conditions that are typical for landfills area. In this context isotopic analysis of water molecules provides valuable insights into the sources, movement, and transformation flow paths within landfill unraveling the hydrological dynamics, their implications for slope stability, and therefore facilitating targeted remediation efforts and monitoring strategies to safeguard water quality and geotechnical works. Actually, several studies demonstrated that variations in isotopic signatures can indicate changes in the source of water feeding into landfills, such as precipitation, surface water, or groundwater, which may have implications for dam safety.

This study investigates the relationship between landfill water isotopes and the potential for dam instabilities. Indeed, in the year 2016, the large downstream embankment of the Corinaldo landfill (Marche Region, central Italy) experienced a geotechnical failure, precipitating the implementation of extensive stabilization and monitoring measures. These initiatives were aimed at arresting further embankment displacement guaranteeing monitoring groundwater dynamics and characteristics within the study site.

Integrating isotopic analysis with traditional geotechnical and hydrological investigations, such as infiltrometer tests, and artificial tracer tests within the piezometers, we obtained the vertical hydraulic conductivity of the vadose zone (≈10-5 -10-6 m/s) and the effective groundwater velocity of the saturated zone (≈ 10-7 – 10-9 m/s), assessing the presence of a possible paleochannel responsible for preferential groundwater drainage and movement within the site, which crosses the dam foundation and which was linked to the geotechnical failure. Moreover, using tritium on leachate and groundwater we explored the possible dispersion of leachate into the water table through the identified paleochannel. The tritium values found in groundwater are low respect to those of the local meteoric waters, while the stable isotope values are consistent with local infiltration of rainwater, excluding hydraulic contact between the landfill and the groundwater body. This interdisciplinary study underscores the importance of considering isotopic signatures in assessing the potential impacts of groundwater movement below landfills on associated geotechnical works stability, besides emphasizes the role exerted by heterogeneous lenses or layers in low permeability lithologies where landfills are usually located.

Isotope composition of dissolved sulfates reveals solutes origin and groundwater flows: insights from aquifer systems in Tuscany

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Keywords: sulfate isotopes, groundwater.

Groundwater is a vital resource, providing fresh water for drinking use, agriculture, industry, and ecosystems across the globe. However, overexploitation and pollution make groundwater vulnerable, requiring careful management and protection to ensure its availability for future human society. Stable isotopes are widely used in many disciplines of earth and environmental sciences as tracers of several natural and anthropogenic processes. Their use allows us to unravel the origin of water and solutes and to recognize groundwater flows and circulation patterns, especially in environments where the geologic and geomorphologic evolution has played an important role (e.g., tectonics, metamorphism and mineralization, karst processes). The stable isotope composition of dissolved sulfates is widely used to recognize different sources, both natural and anthropogenic, and trace the sulfur cycle (e.g., Urresti-Estala et al., 2015). $\delta^{34}S$ and $\delta^{18}O$ of sulfate are controlled by 1) the isotopic signature of SO_4 sources, 2) isotope exchange reactions, and 3) isotope fractionation during biogeochemical processes. Here we present the results of an isotopic screening of dissolved sulfates carried out in the period 2018-2022 on groundwater of some important aquifers in Tuscany. 28 water samples were collected from springs (13), wells (4), surface waters (3), and acid mine drainage (1) in three main areas from north to south: the Apuan Alps, the Monti Pisani and Monti d'Oltreserchio, the Colline Metallifere. Stable isotopes ($\delta^{18}O$-H_2O, $\delta^{2}H$-H_2O, $\delta^{18}O$-SO_4, $\delta^{34}S$-SO_4) were measured on collected samples, in addition to chemical (major and trace elements) analysis. Pyrite and Fe-Al-K secondary sulphates were also collected from mineralization in the Apuan Alps and analyzed for sulfur isotopes. The isotope ratios of oxygen and sulfur of dissolved sulphates reveal multiple sources of sulfates. Two distinct water groups may be recognized. The first one includes water samples with lower $\delta^{18}O$-SO_4 and $\delta^{34}S$-SO_4 values spanning from 0.3‰ and -9.6‰ to 2.9‰ and -2.2‰, respectively. These samples were from springs, stream, and mine drainage in a catchment of the southern Apuan Alps heavily impacted by past mining activities (Doveri et al., 2021). Accordingly, they fall in the field defined by the isotopic ranges of pyrite and secondary sulphates found in the mines upstream, indicating that groundwater sulfate is mostly controlled by sulfide oxidation. The second group of water includes samples with higher $\delta18O$-SO_4 and $\delta34S$-SO_4 values ranging from 8.4‰ and 10.6‰ to 11.7‰ and 15.8‰, respectively. These values indicate a sulfate origin from the dissolution of gypsum/anhydrite, suggesting groundwater is deep enough to interact with the Triassic evaporitic formations (e.g., Boschetti et al., 2011) at the regional scale. However, a few samples fall along a mixing line between two water groups, suggesting possible mixing between sulfide and evaporitic components.

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Hydrothermal hydrocarbons generation and migration into the basement rocks of Southern Tuscany

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Keywords: hydrothermal hydrocarbons, hydrothermal fluids, biodegradation.

The occurrence of hydrocarbons (HC) in geothermal settings as a consequence of the interaction of organic-rich rocks with elevated temperature and/or hydrothermal fluids, is often overlooked or underestimated in the geological record despite ther importance in the uptake or reduction of metals during interaction with hydrothermal fluids to form ore deposits (Parnell, 1988).

Some of the most important ore mineralization in Italy is hosted in Southern Tuscany where the presence of hydrocarbons (mainly bitumen) associated with mineralization has been noted since the 70ies (Arisi-Rota & Vighi, 1971), but whose origin has been never fully explained.

In the metamorphic rocks of Monti Romani in Southern Tuscany, carbonaceous material in the form of graphitic carbon, amorphous carbon and liquid hydrocarbons have been studied togheter with paleo-fluids temperatures. Raman spectroscopic analyses show a contrast in structural ordering between carbon in the host rocks and carbon films and nodules at the contact with high temperature mineralized veins. Microscopy and gas chromatography additionally indicate liquid hydrocarbons, with a thermal maturity at the peak of the oil window and biodegradation in the depth interval between about 100 and 1500 m. Fluid inclusions analyses suggest temperatures moslty higher than 200°C in the veins hosting hydrocarbons and low-ordered carbonaceous material.

The association of hydrocarbons with high temperature fluids together with gas chromatographic and spectroscopic data indicate a probable hydrothermal origin of the oils, from the late Miocenic sediments that fill the Tafone Graben. A model is proposed in which hydrocarbons were generated along the fault that borders the Tafone Graben and then migrated toward the basements rocks at the footwall.

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Variations in elemental sulfur viscosity and volcanic hazard assessment implications

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Keywords: sulfur viscosity, hydrothermal systems, volcanic hazard.

Several volcanic eruptions unheralded by precursory signals occurred in historical times causing casualties (e.g. Lewis, 2021). Deciphering the causes behind these unpredicted eruptions are important to improve volcanic hazard assessment.

Evidences of layers of elemental sulfur accumulated by magmatic degassing, have been discovered below water at volcanoes hosting crater-lakes. In these settings, the variations in sulfur viscosity, as pure element, were considered responsible to cause both lake water temperatures' cycling, and temporary sealing of the vent system, causing eruptions (Christenson et al., 2010). Pure sulfur viscosity is highly temperature dependent, because of its complex polymerization behavior: a four-orders-of-magnitude increase in viscosity occurs at ~160°C, up to a maximum of 93.2 Pa·s between 186 and 188ºC (Bacon & Fanelli, 1942). Besides viscosity, also step-changes in density, compressibility, and electrical conduction, occur in pure sulfur at temperatures ~160ºC. However, sulfur is also extremely sensitive to the presence of impurities, as noticed since the 1940s. In the presence of hydrogen sulfide, organic material, hydrocarbons, ammonia, or halogens significant different viscosity-temperature relationships occurs with respect to the pure S case. This behavior is critical in volcanic settings, where these components are common, and sulfur is not pure. Several volcanoes have shown transitions between periods of dome growth and periods with crater lakes, and sulfur melts have been reported at volcanoes with no records of historical eruptions, and no crater lakes; sulfur presence has been recently reported at submarine calderas. These evidences suggest that elemental sulfur accumulation within hydrothermal systems is indeed a common process, not restricted to crater lakes (Scolamacchia, 2024). Both emission types, and amounts, of gas species released at the surface, critical for volcano monitoring, would be altered, following chemical reactions within impure S, invalidating signals to issue alerts. Chemical reactions within impure sulfur, and viscosity variations can explain contrasting signals reported at volcanoes, and restless calderas, worldwide (Scolamacchia 2024). Implications for volcanic-risk-mitigation strategies are envisaged.

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Decoding the processes that lead to the extraordinary enrichment of lithium in the Salar de Atacama (northern Chile): new insights from Li, B and Sr isotopes in surface and groundwater

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Keywords: lithium, stable isotopes, Salar de Atacama.

Northern Chile, northwest Argentina, and southwest Bolivia represent a world-class lithium deposit. However, this extraordinary enrichment remains controversial, and different processes have been invoked over the years, including active volcanism, leaching of soluble salts from volcanic rocks, and leaching of lithium-rich clays. The Salar de Atacama (SDA) represents one of the wealthiest Li reservoirs in northern Chile and has been widely studied in recent years. Most studies have focused on the southern and southeastern parts, where the highest lithium concentrations have been reported. However, a comprehensive model of water recharge in SDA still needs to be more precise. In this study, by combining isotopic ($\delta^{7}Li$, $\delta^{11}B$, and $^{87}Sr/^{86}Sr$) and chemical composition of a set of water samples from salt lakes, geothermal manifestations, groundwater, and diluted surface waters (rivers and streams with low salinity), we explore the hydrogeochemical processes that control SDA solute distribution. Our data confirm that ignimbrite weathering constitutes one of the most critical processes of solutes origin in the region, where deep water-rock interactions operate at high temperatures, enhancing the leaching of Li and other solutes. We determined that the groundwater flow entering the SDA has undergone pre-enrichment processes (e.g., leakage of salt pans from the Altiplano and dissolution of evaporites, among others) associated with salt contributions from the Western Cordillera. Our results provide a step towards a comprehensive understanding of the processes governing brine formation and lithium enrichment in a hyperarid environment, contributing to sustainable lithium exploration and exploitation in these environments.

The effect of anthropogenic pressure on the coastal groundwater resources: the case of Toro Bayo aquifer, Southern Chile

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Keywords: hydrogeology, stable isotopes, saline intrusion.

Over recent decades, population growth, urbanization, and climate change have intensified water demand. Under current scenarios, surface water storage declines along with widespread depletion of water quality, increasing human activity dependence on groundwater. In particular, coastal aquifers represent strategic groundwater reservoirs, providing a secure water source for more than one billion people living in coastal regions. Coastal areas are generally more densely populated than the interior and have been found to exhibit higher rates of population growth and urbanization. For this reason, coastal aquifers require a great management effort since they present a high degree of vulnerability due to overexploitation, which can lead to irreversible damage such as saline intrusion. In Chile, a country with a coastline of 6,435 km, most of the largest cities are located in coastal areas (for example, Viña del Mar, Concepción, and Valdivia, among others). More than two million Chileans live in coastal areas, and agricultural use, industrial activities, and urban use overstretch water reserves. The study area is located on the south-central coast of Chile, in the district of Toro Bayo, in the estuary of the Valdivia River, 5 km southwest of Valdivia. This sector has been subject to a significant population increase in recent years, and the lack of a municipal water network has determined the consequent increase in groundwater extraction by private wells. In addition, industrial and agricultural activities are present in the area, which supply the entire water demand with groundwater.

By analyzing the chemical and isotopic composition ($^{87}Sr/^{86}Sr$, $d^{11}B$, and $d^{7}Li$) of groundwater, as well as hydrogeological and physicochemical data (water level, transmissivity, T, and conductivity), this study has successfully determined the vulnerability of the Toro Bayo aquifer to saline intrusion, as a direct result of overexploitation. The implications of these findings extend beyond the local context, representing a significant advancement in the sustainable management of water resources globally.

Synergic application of stable isotopes (N-O, B, C) to recognize nitrates sources and processes in the shallow phreatic aquifer of the Metauro River Basin (Central Italy)

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Keywords: stable isotopes, hydrogeochemistry, nitrate contamination.

The shallow coastal aquifer of the lower Metauro River valley has been experiencing a long-lasting story of nitrate contamination since the 1970s when the increase in the use of agricultural fertilizers contributed to very high levels of pollution (NO_3 up to >300 mg/L). The waters of the Metauro area represent a fundamental resource exploited daily for drinking, agricultural, and industrial uses. This anthropic pressure exposes the water resources to depletion and quality degradation risks, making the area of high social and scientific interest. Previous studies on the shallow coastal aquifer focused on the chemical characteristics of this water resource, preliminarily highlighting the importance of anthropogenic and natural inputs in modifying the pristine composition of the waters, strongly increasing NO_3 and, though at a lower extent, chloride, sodium, and sulphates.

In this work, the different sources of nitrates and processes occurring in the shallow phreatic aquifer were defined by applying a multi-isotopic approach involving $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$, $\delta^{11}B$, and $\delta^{13}C$-TDIC on sixteen samples collected twice during April and October 2023. The $\delta^{13}C$-TDIC values were relatively homogeneous throughout the surveys, varying between -14.2 and -7.1‰ vs. V-PDB, with the higher values related to the surface water samples and likely recording a higher degree of interaction with carbonates in the river basin with respect to groundwater. Isotopic results on NO_3 indicate different biogeochemical processes and sources. Values of $\delta^{15}N\text{-}NO_3$ were indeed between +2.3 and +23.2‰ vs. AIR, while those of $\delta^{18}O\text{-}NO_3$ ranged from -3.9 up to +20.2‰ vs. V-SMOW. In both cases, no markedly high differences were recorded among the two surveys. Most samples fall in the overlapping fields of organic pollution (sewage and manure) and soil nitrogen. However, the latter can be discarded as a primary nitrate source, being NO_3 always >30 mg/L. On the contrary, the five samples showing the lowest NO_3 concentrations (<10 mg/L) have heavier isotopic content of both N and O (i.e., >10‰ in both cases), suggesting the possible occurrence of denitrification processes. By coupling the $\delta^{15}N$ values with those of $\delta^{11}B$, the latter ranging from +2.9 up to +34.7‰ vs. NIST-SRM 951, the primary sources of nitrates were better constrained, suggesting that they are mostly related to sewage and septic tanks and, secondly, to swine manure inputs.

Eventually, to have an ultimate and more comprehensive view of the nitrate pollution issue in the area and give the local environmental agency robust and reliable information on where to intervene with remediation actions, the proportional contributions of the different NO3 pollution sources will be evaluated by applying the Bayesian stable isotope mixing model MixSIAR.

S11.

BACK TO THE FUTURE. History of geological studies and mapping as a key for sustainable development

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Two forerunners of Northern Apennines tectonics: a tribute to Roberto Signorini and Carlo Ippolito Migliorini

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Keywords: Northern Apennines, Roberto Signorini, Carlo Ippolito Migliorini.

Roberto Signorini (1901-1980) was born in Florence into a family of artists. His uncle was the famous painter Telemaco, exponent of the "Macchiaioli" current. Since the establishment of the AGIP national oil company in 1926, Signorini was employed as a geologist and entrusted with various assignments throughout the country. He studied in Belgium, graduating from the Mining Engineering School of Liege in 1929 and a year later in Engineering at the University of Rome. In 1936, he was appointed Chief of the Geological Section of AGIP, position held until 1946. He made great efforts during the World War II to keep alive the Italian Geological Society, serving as Secretary (Alvarez, 2009). After the war, having obtained professorship in 1942, he worked as adjunct professor of Physical Geography from 1947 and of Engineering Geology from the subsequent year. In 1968, he moved to Siena, as lecturer of Engineering Geology, in the newly established degree course in Geology, held until his retirement in 1971. Despite his great experience and eclectic attitude, Roberto was never permanently hired in an academic position (Moretti, 1980).

Signorini had a productive relationship with another Tuscan petroleum geologist: Carlo Ippolito Migliorini (1891-1953), born in Bibbiena, in the Casentino area (Trevisan, 1953). After the bachelor in Florence, Migliorini studied in England, his mother's homeland, at the Camborne School of Metalliferous Mining. His early passion for geology led him to join the Italian Geological Society already at the age of fifteen. Hired by AGIP in 1934, Migliorini led missions in Somalia between 1936 and 1939. He was in charge of the company's Exploration Section until 1943, when the employment relationship ended. Overcoming the difficulties of the post-war period, he took advantage of his experience as a consultant of national and foreign oil companies in Italy and abroad (Africa, Middle East).

The applied research for hydrocarbon in the Po Plain and Peninsular Italy led progressively the two colleagues to develop, with integrated approach, an innovative vision of the stratigraphy, structure and tectonic evolution of the Northern Apennines (Merla, 1984). It happened long time before alloctonistic theories were applied to the Apennine orogeny, and the global tectonics theory had not yet been developed. As usual in the history of scientific thought, their paradigms have been overcome in the following decades, and the memory of their work progressively faded over time. This paper aims at remembering Migliorini and Signorini, paying due credit to these forerunners of modern sedimentology and Apennine tectonics for their innovative contribution to the progress of the Italian geology in the middle 20th century.

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Tommaso Tittoni, a geologist to the Prime Ministership

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Keywords: history of geosciences, Ivanoe Bonomi, Tommaso Tittoni.

In the early stages of the Kingdom of Italy, geology was highly considered in the national culture; the economic development of the newborn State depended in fact mostly on the research of natural resources and on great engineering works, based on updated geological maps. At that time, geological knowledge was the prerogative both of mining engineers and naturalists, although with some conflicts between them. Consequently, eminent scientists and technicians filled relevant public positions between late 19th and early 20th century, because of their competence and authoritativeness. Among them, four Earth scientists or engineering geologists achieved (or barely touched) even the role of Prime Minister of the Kingdom of Italy. First, we must cite Luigi Federico Menabrea (1809-1896), hydraulic engineer, General of the Savoy Army and politician, Prime Minister between 1867 and 1869. The SGI founder Quintino Sella (1827-1884), Member of Parliament and thrice Minister of Finance, in 1881 was entrusted by the King with the formation of a new government, unfortunately without success. A third relevant personality was Ivanoe Bonomi (1873-1951), graduated in 1896 in Natural Sciences at the University of Parma, with a thesis in palaeontology, concerning the ichtiofauna of Mondaino, near Rimini (Baraldi, 2014); after a second graduation in law (1900), he early quitted the scientific activity and became lawyer, journalist and politician (thrice Prime Minister, but also Member of Parliament, Senator, Home Secretary, Minister of War and of Public Works, member of the Constituent Assembly, first President of the Senate of the Republic). This contribution focuses though on Tommaso Tittoni (1855-1931), which was Prime Minister in 1905 for only 13 days, until now the record of shortest period in charge (Tassani, 2019). Tittoni has been jurist, diplomat and politician (Member of Parliament, Senator and President of the Senate from 1919 to 1929, President of the Provincial Council of Rome). Beside his several political writings, he produced also a few geological papers and maps of the volcanic areas surrounding Rome. After his graduation in law, Tommaso became also student of Giuseppe Ponzi, the founder of the Roman geological school, at the Sapienza University; later he studied also in Oxford and Liege (Novarese, 1931). His father Vincenzo Tittoni, politician and member of the *Destra Storica*, introduced him to Sella, which became his mentor in geology. Therefore, Tittoni was among the founders of the Italian Geological Society in 1881, being appointed first Treasurer. Nowadays, the growing awareness about our changing Planet urgently requires a global revision of the relationship between humanity and Earth. In such a framework, the history of influence of geological culture on Italian society and politics could provide useful insights to find strategies for a sustainable future.

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The problem of the age of "greenstones" in the Western Alps: the perspective of Carlo Bruno (1831-1916)

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Keywords: Carlo Bruno, Western Alps, history of geology.

In the history of the geological studies of the Western Alps, one the most debated topic in the 19th century was the chrono-stratigraphy of the vast mass of predominant carbonate micaschist (calcschist) associated to distinctive "greenstones" (including serpentinite and metabasite), quartzite and limestone. This group of rocks was identified by Bartolomeo Gastaldi (1818-1879) as the "Zona delle Pietre Verdi", believed to be of Paleozoic age. It was mapped in the "Carta Geologica delle Alpi Piemontesi" based on field studies conducted between 1860 and 1879 by Gastaldi himself, Martino Baretti, Heinrich Gerlach, Giovanni Michelotti, Carlo Bruno and Luigi Bruno. A Mesozoic age for this zone was definitely imposed later by the studies of Secondo Franchi (1898).

In this contribution, we present previously unpublished material from the ISPRA Library, showcasing ideas about the lithostratigraphy of the Maritime and Ligurian Alps developed at the end of the 1870's by Carlo Bruno (1831-1916), priest and natural history teacher and one of the collaborators of Gastaldi. In these sectors of the Western Alps, in particular, he was able to date the dolomitic limestones to the Triassic based on abundant fossils he had found. In his last writing, Gastaldi gave credit to Bruno, acknowledging that his previous chronostratigraphic interpretation was mistaken (Gastaldi, 1878). In addition, Bruno had observed the superposition of "greenstone" masses to Triassic dolomitic limestones in some localities and then he also asserted a Triassic age for the "greenstones". At the beginning of 1880, Bruno conveyed his significant conclusions in two letters to Felice Giordano, then Chief Inspector of the Regio Corpo delle Miniere and employed in the planning of the studies of the Italian Western Alps for the geological cartography project of Italy. In these letters, Bruno also expressed the intention to prepare a paper on the subject to be submitted to the Accademia dei Lincei, and requested Giordano to send "a commission of geologists" to verify his claims with him in the field. The letters are accompanied by a hand-drawn watercolour plate containing two geological sections across the Maritime and Ligurian Alps, which show the relationships among the different rocks, and in particular the supposed stratigraphic superposition of "greenstones" to the Triassic carbonates.

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Children's Eco-Museum (I.C. Via Santo Savarino, Rome): history and memory of the Genius loci of the "Agro romano"

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Keywords: ecomuseum, Agro romano, geosites.

In Greco-Roman mythology, the Genius Loci was a minor deity, sometimes quite mischievous, who did not reside on Mount Olympus but dwelled in places, among houses, woods, springs, and in the spirit of people. It was a metaphorical representation of the collective memory linked to the world in which a community physically and spiritually resided. The Spinaceto-Tor de' Cenci neighborhood, located in the southwest quadrant of Rome, was created within the framework of Law 167/62. During that period of economic boom, the progressive abandonment of the countryside had led to a sudden and massive migration to cities, creating an urgent housing need. The neighborhood, the largest project of public and residential housing ever built in the world, was born with the intention of creating a New Town, following the model of those in Northern Europe where the preservation of the Roman countryside landscape and sense of place was a priority. The Roman countryside had an anonymous but indispensable history for the evolution of the city for the production of foodstuffs (agriculture and animal husbandry) and building materials. The landscape is marked by farmhouses, hydraulic works for land reclamation, quarries of leucitic lava (used for the production of cobblestones), pozzolana, sand, and gravel. Among the inhabitants, the memory of its "Arcadian past" is still preserved, harmonizing within a distinctly multi-ethnic population. A territory museum is being created within the school to collect, study, and archive testimonies and experiences in order to enhance the material, natural, and immaterial heritage of the Tor de' Cenci Spinaceto area. The territory, viewed through the lens of Earth Sciences, becomes a place of adventure and experience starting from the history of the first geological explorers. The numerous outcrops, mainly related to the Tor de' Cenci Unit but also to the Ponte Galeria Formation, the Pozzolane Rosse, and the Lave di Vallerano, are remnants of past mining activities discontinued in the 1950s, which remain, as monuments of industrial architecture, among the buildings or paths of the parks. A section of the museum is dedicated to the history of geology and to the authors who, over time, have studied this territory. Fifty years have passed since the neighborhood was built, and in this span of time, the community has acquired its own identity, which is recognized in the territory, steeped in a shared history. The territory itself then acquires the dimension of a place of shared memory, a backdrop for the events experienced by the inhabitants. The transformation of a place of memory, shared by the experiences of many people, into a monument, that is, into a symbol with which to identify, requires an educational process of transforming memory into history, through a process of critical and orderly reconstruction of past events and occurrences, both human and natural, starting from geology. The museum activity, carried out within the Ottorino Respighi Complex, is part of the "Open Schools" project funded by the Municipality of Rome, which offers students activities to be carried out within the school outside of school hours.

Historical data revision of the 1688 Sannio-Matese earthquake: dataset of environmental effects for constraining the seismogenic source

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Keywords: 1688 earthquake, historical data revision, ESI-07 scale.

The Sannio earthquake of 5 June 1688, with a magnitude of Mw=7 and epicentral intensity I=XI, had a devastating impact on Southern Italy, causing significant damage to the economy and the natural environment. The earthquake induced both primary, superficial faulting, and secondary effects, including gravitational phenomena, ground fractures, liquefaction and extensive hydrological alterations linked to the flow of springs and rivers. Despite being a well-known earthquake, the seismogenic source and the environmental effects induced by it are still subjects of scientific debate. Currently there is little knowledge about the environmental effects induced by this earthquake and a vision accounting for all the available data is still missing. In this context, we aim at collecting all available data and build a complete geodatabase, including information on the spatial location the above mentioned phenomena, with the best possible accuracy.

We present preliminary results deriving from the study of historical data revision. Data on the environmental effects of earthquakes (EEE) are collected from various sources, such as scientific articles, historical information, original archival sources and geological reports, will be integrated with subsequent field investigations. The EEE are then catalogued according to the guidelines of the ESI-07 scale. The final objective is to create a homogeneous and accurate dataset containing all the EEE induced by the 1688 Sannio-Matese earthquake. Moreover, this dataset will be used along with geological and geophysical data for constraining the 1688 Sannio-Matese seismogenic source through a multidisciplinary approach. Our preliminary results highlight the importance of collecting and analyzing data on environmental effects of earthquakes to better understand local seismic hazard of the Sannio-Matese area and the potential impact of earthquakes on natural environment.

The "Signora" of limnology. Rina Monti: geological experience, ecosystem protection and the impact of human activity

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Keywords: limnology, environmental impact, ecology.

After receiving her degree in Natural Sciences in 1892, Rina Monti (1871-1937) carefully took care of her education and, in the academic year 1892-93, she decided to assist the mineralogist Francesco Sansoni in his research activity at the University of Studies of Pavia. It was a short but crucial period for Monti's professional growth as it allowed her to come into direct contact with geology for the first time; on the other hand, Sansoni himself, to increase the young woman's knowledge, decided to pair her up with the engineer and geologist Arturo Cozzaglio who was conducting field studies in Val Camonica at that time. After months of work, Monti produced and published some articles (Monti, 1894) which were published in the Journal of Mineralogy, Crystallography and Petrography directed by Sansoni. Rina's contributions, completed by those of Cozzaglio (Cozzaglio, 1894), represented the culmination of a study path aimed at learning geology techniques and tools, which proved to be of great importance and effectiveness for her mature studies. Participation in 1906 at the Congress of Italian Naturalists in Milan, promoted by the Italian Society of Natural Sciences, and her marriage to Augusto Stella, an important Italian geologist, sealed the living and ever-constant bond between Rina and Earth science. For Rina, however, the geological description represented the first step to truly understand the history and present of the lakes and the complex and very delicate ecosystems that they protected. Rediscovering the origins of these places pushed the researcher to ask herself what the modifications had been that had altered their natural harmony. Her studies are more relevant than ever because they focus on the conservation, protection and promotion of the environment. For this reason they are capable of making us reflect on fundamental issues of our era (Monti, 1929a, b).

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Microhistory of the civilization of mines: from the golden fleece to the critical raw material act

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Keywords: mining industry, sustainability, history of technology.

In 2024, the EU unveils the Critical Raw Material Act, a legislation embedding the mining sector within the framework of the "Green Deal" strategy. This act aims to address the issue of global warming by promoting policies supporting a new economy based on sustainability, energy transition, and the establishment of a new relationship between humans and nature.

The history of civilization is marked by epochs that begin and end with events which over time generate radical cultural revolutions economically, socially, culturally, technologically, and consequently environmentally. The first major techno-economic revolution was the agricultural one. In a few millennia, the spread of technical knowledge extended across the then-known world, creating an initial "global market". However, nature is certainly stronger than technology.

The second major revolution occurs in the mid-1700s, symbolically marked by the steam engine, powered by coal and produced in iron. Humanity begins massively altering nature. In the 19th century, industry spreads throughout Europe and the Americas, ushering in the age of gas, oil, and the internal combustion engine. This period is characterized by steel, new metals such as aluminum, and reinforced concrete. However, the environmental impact of industry is high, with a total lack of environmental awareness.

The 20th century heralds the atomic age, with humanity convinced that technology could lead to its demise. The age of plastic develops, and environmental issues become increasingly relevant in the consciousness and regulations of Western states.

In the 1970s, the explosion of the electronic revolution occurs, dominated by information technology. The global market spreads, and humanity begins to realize its destructive impact on the environment and climate. This marks the beginning of the third industrial revolution, leading to the energy transition from coal to cleaner energy sources. Nature becomes a moral category, and articulated environmental regulations develop. Western countries begin to gradually phase out the most impactful industries. The global market triumphs, rendering some sectors, including mining, non-competitive.

Today, we are experiencing the fourth industrial revolution, the era of intelligent machines managed by cyber-physical systems via Cloud computing. Science has demonstrated that human activity alters the climate. The new electronic industry demands rare materials, such as rare earths, essential for the electronics industry. Changes in the global geopolitical context and the closure of the global market challenge European strategic production.

However, we are on the brink of a new industrial revolution outlined by the EU's Green Deal. It proposes a more ethical vision of industry and the economy, integrating factors such as sustainability. Crucial is the environmental issue and policies for mitigating global warming and ensuring the supply of materials without which the energy transition will be difficult to achieve. The future involves new methods of waste recovery, the use of renewable energies, and the integration of sensors to reduce energy consumption. This revolution will only be possible through the use of rare and strategic materials outlined in the Critical Raw Material Act.

The relevance of the 1973 mining map of Italy: its revamping in the GeoSciencesIR project

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Keywords: mining map, georesources.

In 1973, the Geological Survey of Italy published the Mining Map (scale of 1:1,000,000), followed in 1975 by a rich analytic description (Castaldo & Stampanoni, 1975). The release was promoted by the Director Jacobacci who, approaching the 100th anniversary of the Royal Geological Survey, prompted the Mining Corps to complete the knowledge of the Italian mining heritage. In fact, since the early years of the Geological Survey's activity, there was a need to produce a technical-administrative tool that, through coordinated cartographic research and documentation, would frame the knowledge about the national mining heritage. Therefore, Jacobacci, in the endeavour to fulfil the initial institutional mandate, renewed efforts by recruiting top experts on mining issues from the Geological Survey, the academia, the industry and the mining districts. Since, until then, knowledge of the mining heritage was only derived from information and memories of the past or from a multitude of random, unplanned discoveries, the introduction, emphasised the importance of collecting homogenous information.

The mining map showed the distribution of mineral deposits and of active and inactive mines, at the time of its drafting. The map's legend and the associated text proposed an exhaustive state-of-the-art of the national mineral deposits, laying a valid premise for further development of more detailed mining knowledge. The graphic content displayed the properties of deposits ("corpi minerari") relative to genetic, depositional and composition parameters of the resources. This work advanced synthetic standards for depositional and mining terminologies, providing also an in-depth literature analysis. To this aim, the 1973 Mining Map was planned and structured analytically as a geodatabase consisting of 350 georeferenced points, locating areas of interest of mineral bodies (Servizio Geologico d'Italia, 1973). The deposits were characterized through scientific research and mining activity data, analytically describing the following characteristics: name of mineral body, nature of mineral/s, morphology of deposits, type and age of host rocks, genetic process, relevance and estimated dimension of deposit and mining activity status.

The valuable content and the method with which the 1973 Mining Map was created is still appreciated. It constituted the cornerstone for the RIMIN project (1986-1998) aimed at laying the scientific basis for private operational research, in order to expand the potential of existing mines and to discover new deposits. Then, mining research products, through different national and European projects, were collected by the GeMMA database. Finally, in the framework of the GeoSciencesIR project, it was deemed convenient to digitise the map and the text data, to revamp this knowledge and to integrate it with last 50 years of data. In fact, the deposit-based interpretation and synthesis of analytical mining data can still offer a complete and updated insight of mineral resources in Italy.

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On the burning earth: the fascination of Vesuvius and the origins of modern geology

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Keywords: Vesuvius, Gimbernat, Babbage.

Between the end of the 18th century and the first decades of the 19th century, at a time when the foundations of modern geology were being laid, Vesuvius and the entire volcanic area around Naples became a compulsory destination for the observations of local and foreign scholars. The uniqueness of the Neapolitan landscape and the majesty of the irascible volcano became a classic in geological literature, and two very different scholars, Carlos de Gimbernat (1768-1834) and Charles Babbage (1791-1871), could not help but write about it (Gimbernat, 1819; Babbage, 1847, 1864). Fascinated by Vesuvius, they both travelled the same routes, risking burning themselves in the 'frightful furnace', but their paths would never cross.

Carlos de Gimbernat is an original and fascinating figure of a scholar, well known and included in the scientific community of the early nineteenth century. His life is almost the plot of an adventure novel that sees him travelling around a Europe tormented by wars and revolutions. A cosmopolitan scientist with multiple interests, his arrival in Naples in 1818 coincided with a spectacular and long eruption of Vesuvius: an event with a strong symbolic value that would condition his future. His stay would be devoted to geological and volcanological excursions and observations, which he would combine with libertarian ideals a highly symbolic blend of new scientific and political ideas.

A farsighted mind, mathematician, physicist, scientific reformer, Charles Babbage was also a tireless traveller. Bewitched by Vesuvius and the geological riches of the Campi Flegrei, he arrived in Naples in 1828 and was enraptured by the mountain that 'ejected red-hot fragments of lava'. Visiting the Serapeo, he lingered over the singular circular marks and mysterious holes left by shellfish on the marble of the 'most remarkable building on the face of the earth', clear proof that the Temple of Serapis was not always at the same level with respect to the sea. With the help of his calculating machine, the Difference Engine, he proposed an interpretation of the observed phenomena that would be accepted by the most talented geologists of the time

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The De Filippi expedition (1913-1914) and the geological exploration of the Aksai Chin (western Tibet)

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Keywords: Karakoram, Italian Expedition, Cretaceous stratigraphy.

Between the years 1913 to 1914 the De Filippi Expedition, led by the Italian explorer and mountaineer Filippo De Filippi (1869–1938), traversed the Himalayan Range from Kashmir to Baltistan and Xinjiang. Exploring mostly unknown territories, traveling more than 2000 kilometers, and equipped with advanced instruments for geodetic and meteorological measurements, the expedition members surveyed, mapped and collected a large number of rocks and fossils samples. Members of the expedition included physicists, meteorologists, alpine guides, military men from Italy and the British Empire, along with several local carriers. Prominent figures were the geologist Giotto Dainelli and the geographer Olinto Marinelli who surveyed the topography and geology of the area. In June 1914, leaving from the base camp south of the Karakoram Pass, they led the exploration of the remote Aksai Chin region, characterized by mountains and highlands located at more than 5000 m asl, while the rest of the group was employed elsewhere (Fabbi et al., 2024). They realized geological maps and collected hundreds of well-preserved fossils, mostly referred to the Cretaceous, which was documented for the first time in the whole Trans-Himalayan Range by the De Filippi expedition (Sha et al., 2020). After almost two years, the expedition returned to Italy via a long route through Central Asia and Russia, however, publication of the findings was delayed due to the outbreak of the First World War.

Due to the enduring geopolitical tensions between India and China over territorial borders since the late 1950s, the Aksai Chin region has remained a nearly inaccessible area. Thus, the paleontological material collected by Dainelli and Marinelli and their syntheses of the geology and stratigraphy of the area represent unique documents for reconstructing the stratigraphy and geology of this sector of Western Tibet (Gaetani 2011; Sha et al., 2020). The De Filippi collection is housed in the Natural History Museum of the University of Florence and constitutes still today a valuable resource regarding the history of the scientific exploration and understanding of the geology of the region, providing a unique window into a very remote and fascinating part of the World.

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Military geology and historical archives: from De Ambrosis' monographs to Bulow-Krantz-Sonne's Wehrgeologie, the role of geology in the Second World War

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Keywords: history of geoscience, military, geology.

In recent decades, the study of the impact of the battlefield terrains on military strategy and tactics has greatly expanded. The strong climate conditions during the winter 1943-1944 and the influence of huge rain and snowfall was first described by Cori (1994) giving a first attempt to define the environmental conditions during the Sangro River battle, 28th-30th November 1943.

The Central Appennines Meso-Cenozoic carbonate stratigraphic sequences, sorrounded by mainly clayey-sandy hilly foothills played an important role for military strategy (Narebski, 2011). The German Todt Organization planned the defense lines months before the starting of the battles and located them in the narrowest points (isthmuses) of the Central Apennine, i.e. the Gustav line running from Garigliano river mouth in Lazio country to Ortona on the Adriatic coastline, and the Gothic Line, from La Spezia (Tyrrhenian Sea) to Pesaro (Adriatic Sea). The German strategy to choose the mountainous carbonate massifs for their defense lines, using the available lithoid material, managed to slow down the progress of the allies, forced to operate on landslides and easily erodible hilly area (slopes> 30 °, alternation of gorges and ditches), aided by the harsh climate and hydrography, with rivers that served as natural trenches. The German defensive lines were the emblem of how a deep knowledge of natural element can be a multiplier of forces for an army (Chasseaud & Doyle, 2005).

The serendipiteous findings of the General Delfino De Ambrosis monographies regarding the military geography of Italy, printed for the official cadets training in the Italian School of War, had open new questions on the previous knowledge of the German-Italian Army in preparation of the line positions, as the countries were allied till the September 8th. Prior the Italian Campaign, during the Fascism Period, De Ambrosis surveied the whole Italian landscape, from North to South and the Libic Italian, too, giving the first complete decription of geology, georesources, climate and idrology of Italy at the time for war purposes (De Ambrosis, 1924).

The Wehrgeologie Handbook published by Bulow-Krantz-Sonne in 1938 is also here presented to better understand the importance of the geology in the warfare strategy planning, and how the application of principles and knowledge of Geology is a truly force multiplier for an Army.

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One against all: fifty years after the geological scheme of Calabria by Leo Ogniben (1973)

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Keywords: Leone Ogniben, Calabria.

The academic world of geology in the 1960s and 1970s in Italy has been undoubtedly affected by radical changes: a true revolution, on the wave of the advent of plate tectonics (Praturlon, 2012). This transformation completely redefined the mechanisms and behaviors governing both intra- and extra-departmental relationships, as well as the rules of engagement and power dynamics. At the same time, there was a shift towards a new way of conducting research, based, consistently on the international trend, on quantitative rather than qualitative methods.

Many factors contributed to this revolution: legislative reforms (in particular the law on national geological mapping of 1960, due to the politician Fiorentino Sullo); reforms of University and of the National Research Council (CNR); funding of "big science" projects (above all, the "Progetto Finalizzato Geodinamica"). The new scenario forced academic research to break out of its shell and to collaborate with other institutions and energy industry. These changes were also fostered by the emergence of a new generation of scholars, ready to break free from the constraints imposed by established conventions and sustained by their mentors.

In this period of intellectual and scientific ferment, Leone Ogniben was a controversial figure who followed a completely different path with respect to most academics. Before becoming professor at the University of Catania, he spent a nearly 20 years post-graduate career in the industrial sector, acquiring a different mindset with respect to the majority of his colleagues (Roda, 1991). On one hand, this background had led him to be a modern, independent, and unconventional academic, anchored in a strong quantitative scientific approach, but, on the other hand, it had also made him a rigid man, closed in his convictions and little inclined towards dialogue and intellectual exchange. Furthermore, despite the severity with which he proclaimed his idea of conducting good research, Ogniben ended up betraying these paradigms in order to demonstrate and apply his geological schemes.

Leone Ogniben is known for his studies concerning Eastern Sicily, the Calabrian-Lucanian Border, and especially his monography on the Calabria-Peloritani Arc (Ogniben, 1973), which sparked a harsh response from a sizable group of researchers (Amodio Morelli et al., 1976). This famous discord should not be interpreted solely as a skirmish or animosity between geologists with different views and temperaments, but rather as paradigmatic of that period of great change mentioned earlier, with young researchers who struggled to stay within the rigid academic logics with which Ogniben identified.

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Geosciences and engineering of Lungro rock salt: unveiling Italy's longest-lived underground mining site in Calabria

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Keywords: rock salt, mining history, solution mining.

The Lungro area is renowned for the presence of the longest-lived Italian underground rock salt mine, exploited almost continuously from ancient times until 1978. The history of mining activity is documented since the Middle Ages, although evidence suggests that salt production by near-surface excavation dates to the Greek and Roman civilization or even to prehistoric times. During the Middle Ages, mining methods were aimed to the maximum profit, and the mine, rather than being rationally developed, was deepened along the vertical, following the winding path of higher quality salt layers. This approach led to problems such as of rock instability, inadequate ventilation and water infiltration arose (Galli, 1828), that characterized this mine up to its recent abandonment.

Following the Napoleonic invasion of the Kingdom of Naples (1806-1815), the modernizing spirit of the new rulers was aimed to reorganize the feudal administration and diminish most of the rights and privileges of the old nobility. As part of this process, mines were nationalized, and the mineral resources of Calabria attracted the interest of the French government. In 1811 the naturalist and geologist Giuseppe Melograni published a comprehensive report on the site, rich in geological considerations, technical descriptions, geometrical surveys, and practical recommendations for a modern and rational mining operations (Melograni, 1822). Concurrently, Pietro Pulli, Inspector General of the Kingdom, was commissioned to provide information on the economic and social conditions existing in Lungro (Pulli, 1813). By the mid-19th century, the mine, with its four production levels, a ventilation shaft and a complex tunneling network, was an important industrial enterprise, with over 400 miners, alongside a technical and administrative staff, a number comparable only to the steam spinning mills of Villa San Giovanni (Reggio di Calabria). In 1879, Torquato Taramelli visited Lungro and the surrounding area during a field trip to Calabria, and provided invaluable stratigraphic and paleontological observations, both still very unknown at the time (Taramelli, 1880). His report contains also a precious first-hand description of the bad working conditions he experienced inside the mine.

Although partially renovated at the end of the 19th century, both in its internal structure and in work organization, the mine decline began in the early 1900s. This decline accelerated as the Italian government estimated that sea salt produced in Sicily was cheaper than rock salt from Lungro. Consequently, a "slow death" approach was used, gradually decreasing exploitation of the deposit until all workers retired, without layoffs but also without new hires. Miners access to the underground was never solved: still in the 1970's, two of the eight working hours of the daily shift were lost to descend into and ascend from the mine, as there were over 2000 steps to walk. Poor mining methods persisted throughout the 20th century, culminating in its final abandonment in 1978.

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Reflection vs. refraction seismic: Tiziano Rocco and the development of applied geophysics in Italy

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Keywords: seismic reflection, history of geosciences, exploration geology.

Tiziano Rocco (Motta di Livenza, 12/2/1908 – Milan, 02/07/1984) was a mining engineer involved since his early career in a key and new activity for oil companies around the world in the 1930s: applied geophysics. Hired in 1929 by the Italian state-owned company AGIP (founded in 1926) under the guidance of Guido Bonarelli and Arnaldo Belluigi, then manager of the geophysical section, after a short period of training he led gravimetric, magnetic and electrical survey teams in Italy, during the 1934 campaign in eastern Sicily. Rocco eagerly studied the scientific literature and soon learned that a new geophysical method for oil exploration, seismic reflection, had been successfully tested in the USA since the early 1930s (Guidi, 1998).

In 1937, after some trials with German equipment and the in-house construction of rudimentary seismic units, AGIP asked Francesco Vercelli (Trieste Institute of Geophysics) to visit Berlin to verify the state of the art of the German allies, and look for a more convenient alternative than that of the American Western Geophysical, already contacted by Rocco. Vercelli and Rocco visited Berlin, and they verified the lack of satisfactory technical standards, which instead they found in the USA in another joint visit (1938). Upon their return, the Board of AGIP approved Western's offer (although with great political worries), and in 1939 two seismic groups arrived in Italy. The first survey was carried out on 10 June 1940, the very day Italy entered WW2, in the Po Valley basin (Pozzi, 2009). Good results arrived quickly: in late 1940, the structures of Ripalta, Caviaga, Cortemaggiore and Piadena had already been outlined. Rocco located the first exploratory wells, which led to the first success in 1944, the discovery of Caviaga gas field. Rocco foresaw the potential of geophysics, and in particular of reflection seismic, at least a decade in advance in Europe, in times of poor collaboration between Companies, Universities and Research Institutes, when scientific and technological advances were shared with difficulty.

Rocco left AGIP in 1943, due to the turbulent events of the armistice and the German occupation of Italy; from 1945 he worked with SPI (Società Petrolifera Italiana) and from 1948 with Western Geophysical. He returned to AGIP in 1951, as Director of exploration. In the 1950s and '60s he significantly contributed on the company's successes in Italy and foreign countries (Iran, Egypt, Nigeria, Tunisia and Libya), as well as for the detailed definition of the geological structures of the Po Valley basin (Rocco, 1942, 1949). He retired in 1968, and in the same year he was elected President of the Italian Geological Society (SGI) for the two-year period 1968-69. Rocco had been SGI member since 1940, and held the position of Vice President under the chairmanship of Roberto Malaroda (1966-67). With his appointment, SGI intended to open up to the applicative aspects of geosciences and intensify the relationships with the industrial sector, and particularly with AGIP.

Guidi F. (1998) - Un pioniere dalle intuizioni vincenti, Notiziario Interno AGIP, 129, 30-34.

Pozzi D. (2009) - Dai gatti selvaggi al cane a sei zampe: tecnologia, conoscenza e organizzazione nell'AGIP e nell'ENI di Enrico Mattei, Marsilio, Venezia, 547 pp.

Rocco T. (1942) - Progressi della sismica a riflessione nell'esplorazione petrolifera dell'A.G.I.P. nella pianura padana, Rivista Italiana del Petrolio, marzo, 13-19.

Rocco T. (1949) - Possibilità del metodo sismico nella ricerca degli idrocarburi, in: Atti del VI Congresso sul metano, Padova, 245-263.

Antonio Stoppani: a pioneer of petroleum geology and his activity in the Italian oil production industry

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Keywords: petroleum geology, history of geology.

This work deepens into the significant advancements made in petroleum geology, geosciences, and technology within Italy during the mid-19th to early 20th centuries. These advancements laid the groundwork for the emergence of the national petroleum industry. Specifically, it scrutinizes the pivotal role played by Antonio Stoppani, who catalyzed the inception of modern petroleum geology studies in Italy. Following E.L. Drake's landmark discovery in Pennsylvania in 1859, a flurry of activity in petroleum production, refining, and export burgeoned in North America—a phenomenon named the "oil rush," which stands as one of the earliest instances of commercial globalization (Novelli & Sella, 2009). Within a brief span, a multitude of companies engaged in oil and gas exploration emerged in Italy, drawing upon the nation's rich historical and scientific heritage, as well as centuries-old artisanal practices of harvesting and trading olio di sasso (rock oil) (Stoppani, 1864).

Initially concentrated in the Emilia region (including the provinces of Piacenza, Parma, and Modena) (Macini et al., 2018), this activity soon expanded into Abruzzi (particularly the Pescara Valley, between Tocco da Casauria and Lettomanoppello), Lazio (former region of Terra di Lavoro, between Ripi and San Giovanni Incarico) and Sicily.

Since 1864, Antonio Stoppani embarked on the development of various aspects encompassed by contemporary "petroleum geosciences." Notably, in a seminal article, he comprehensively addressed the distribution, characteristics, and origins of oil and gas from a global perspective, surpassing the confines of Italian geography. This approach, unprecedented for its time, underscored Stoppani's profound familiarity with recent American scholarship, particularly that of T.S. Hunt, whose work elucidated the theory of anticlines.

In 1866, Stoppani further augmented his contributions by publishing a map delineating the petroleum-rich zones of the Emilia Region (Stoppani, 1866). This endeavor coincided with the initiation of an ambitious cartographic project aimed at crafting a geological map of Italy.

Stoppani's endeavors extended beyond scholarly discourse; he meticulously analyzed the scientific underpinnings of oil exploration in Italy, pinpointing the most promising locales, formulating hypotheses regarding hydrocarbon origins, and delineating the technical and economic constraints inherent in domestic oil management. His commitment was exemplified by extensive visits, studies, and advisory roles at virtually all Italian petroleum production sites.

Ultimately, Stoppani assumed the presidency of the "Società Italiana delle Miniere Petrolifere di Terra di Lavoro," overseeing oil extraction operations at S. Giovanni Incarico, situated in present-day in Frosinone province. However, in 1881, disillusioned perhaps by the profit-driven motives of his partners, who prioritized immediate gains over the broader scientific, technological, and societal benefits of sustained endeavors, Stoppani disengaged from all involvement in the petroleum production industry.

Macini et al. (2018) - Historical Study on Geosciences and Engineering in the Oil Fields of Emilia Romagna Region in the Socio-Economic Context of the Post-Unitarian Italy (1861-1914). In: Jonathan Craig, Francesco Gerali, Fiona MacAulay et al. (eds), History of the European Oil and Gas Industry, Geological Society of London, Special Publications 465, London, pp. 305-332.

Novelli L. & Sella M. (2009) - Il petrolio, una storia antica, Silvana Editoriale, Cinisello Balsamo.

Stoppani A. (1864) - Saggio di una storia naturale dei petrolii, Il Politecnico, 23, fasc. 100-101, 5-94.

Stoppani A. (1866) - I petrolii in Italia, Il Politecnico, IV-I, Milano, F. Zanetti.

The conquest of the submerged landscape: a neglected history

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Keywords: marine geology, submarine geomorphology, oceans.

Underwater topography is modelled by physical, chemical and biological processes operating at depth on rocks and bottom sediments. The study of underwater topography began in the mid-19th century and before then bathymetric data were practically absent. Kant, in 1802, in 'Physical Geography', reported of a captain who, on a voyage to the North Pole, failed to find the bottom at 4680 feet, the greatest depth ever measured. Kant, however, suggested that the greatest depths of the sea must be in proportion to the highest mountains. Lieutenant Maury in 1854 published the first map of the seabed of the Atlantic Ocean in which the mid-Atlantic ridge was completely unknown. In 1912, the map of the aforementioned Ocean by the German oceanographer Gerhard Schott showed the aforementioned ridge for the first time. So until the 20th century, almost nothing was known about the ocean floor. It was only in the 1960s, thanks to geophysical campaigns and the great work on the interpretation of bathymetric data by Barren et al., which were published in 1977 (Beran et al., 1977), that a map with the main landforms of the ocean floor was produced. Even today, the ocean depths are inaccessible, poorly known and largely yet to be surveyed and measured.

Berann H.C., Heezen B.C. & Tharp M. (1977) - Manuscript Painting of Heezen-Tharp World Ocean Floor map. (Retrieved from the Library of Congress 30/06/18), https://www.loc.gov/item/2010586277/.
Kant I. (1802) - Physische Geographie. Partly edited by Rink T., Königsberg, Göbbels e Unzer.
Maury M.F. (1854) - The Physical Geography of the Sea. Thomas Nelson and Sons, Paternoster Row, London, pp. 310.
Schott G. (1912) – Geographie des Atlantischen Ozeans. Hamburg, C. Boysen.

The *Der Aetna* and the studies on Etna by Sartorius von Waltershausen (1809-1876)

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Keywords: history of cartography, geological map, history of volcanology.

A detailed reading of the second volume of Der Aetna clearly shows that the comprehensive work of Sartorius and his collaborators constitutes the most important scientific work in the field of geological and mineralogical studies carried out on Etna. The work began with the drafting of the topographic and geological map of the volcano published in 1838, and concluded with the posthumous publication of Der Aetna, revised and completed by Lasaulx in 1880. Noteworthy, Der Aetna treats the topics with a detail and completeness never addressed before in a single work, as well it includes of the only map at scale 1:15.000 existing to date of the Valle del Bove. At the same time, it has been the least read work ever, mainly due to the complexity of German language and, above all, it has been cited as mere bibliographic reference. These reasons led to diminish the impressiveness and importance of Der Aetna, which has frequently been compared to the outdated monograph on the volcanology of Etna by Carlo Gemmellaro of 1858 and to the short work by Charles Lyell published in the Philosophical Transactions of the Royal Society of London in 1858. In this context of oblivion, most of the findings and conclusions of Sartorius and Lasaulx have been reproposed during the 20th century as new hypotheses on the evolution and structure of Etna, ignoring that they had already been formulated.

Today, more than 140 years later the publication of the second volume of Der Aetna, the map of the Valle del Bove, and the previous geological cartography of the Atlas des Aetna, constitute a unique collection of geological and volcanological data of a historical nature for Etna, most of which have been erased by the volcano's eruptive activity. Among all the volcanological works carried out on Etna during the 19th century, Der Aetna and the associated cartography are the only ones still used in the 21st century by researchers, who extract the volcanological parameters of historical eruptions, which are fundamental for the implementation of volcanic hazard studies.

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Lyell C. (1858) - On the Structure of Lavas Which Have Consolidated on Steep Slopes; With Remarks on the Mode of Origin of Mount Etna, and on the Theory of "Craters of Elevation". Philosophical Transactions of the Royal Society of London, 148, 703-786.

Sartorius von Waltershausen W. (1845-1861) - Atlas des Aetna, Berlin, Schropp (vol. 1), Gottingen, Vandenhoeck (voll. 2-4), Weimar, Geographisches Institut (voll. 5-8).

Sartorius von Waltershausen W. & von Lasaulx A. (1880) - Der Aetna, Leipzig, Engelmann.

The geological map of the western side of the high Agri Valley

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Keywords: hydrogeological complexes, Agri Valley, southern Apennines.

Geological maps provide a fundamental support for engineering/land use decisions and for locating natural resources. In particular, they greatly help in assessing groundwater distribution and in the definition of the main hydrogeological complexes. In this context a new geological map of the western side of the Agri Valley area (axial sector of the southern Apennines), has been carried out to better define the complex carbonate hydrostructure of the Monti della Maddalena (Grimaldi & Summa, 2005). The intense deformation recorded in the study area, combined with a complex tectono-stratigraphic setting, produces a significant compartimentalization of the aquifers, that requires detailed geological mapping to be reliably described. Available geological maps in the study area (505 "Moliterno" and 521 "Lauria" sheets 1:50000, ISPRA) do not provide the necessary level of detail to correctly define the complex hydrostructure and need to be updated with the newly investigated stratigraphic and tectonic units.

We have carried out a geological mapping at 1:25.000 scale, using a new scheme of the tectonic units, and applying a finer stratigraphic subdivision, which includes members or beds. As a result, we provide a formation to member-detailed geological map of the western side of the high Agri Valley with sufficient resolution for defining the tectonic structures that influence the circulation groundwaters in the study area. The area displays a stack of tectonic units consisting of Mesozoic to Cenozoic rocks represented from top to bottom by: i) the ocean-derived Liguride Units; ii) the carbonates of the Apennine Platform; iii) the pelagic successions of the Lagonegro Basin. The tectonic units, piled up during Miocene to Pliocene contractional tectonics, are offset by low- to medium-angle normal faults and by different sets of high-angle transtensional to normal faults, developed during the Late Pliocene to the Pleistocene. Some of these faults controlled the formation of the NW-trending Agri valley basin, filled by Middle Pleistocene lacustrine and alluvial deposits.

The main results are:

1. a third Lagonegro tectonic unit besides the Lagonegro I and II ones. The new unit is located in between the Lagonegro and the Apennine Platform units at bottom and at top, respectively. It shares many stratigraphic features with the Lagonegro II Unit so that it is believed to results from the tectonic doubling of this latter unit;
2. the definitive dismission of the Moliterno Formation, formerly interpreted as the base of the Apennine Platform (Sheet 505 "Moliterno"-ISPRA). The formation has been either reconducted to the Monte Facito Formation or to thin slices of the Apennine Platform;
3. the tectonic nature of the basal contact of the Albidona Formation, which has been framed within the Liguride Units.

These results allowed to better define tectonic multilayer of the southern Apennines, greatly improving the knowledge of the groundwater circulation in the area.

Grimaldi S. & Summa G. (2005) - Caratteri idrogeologici ed idrogeochimici del settore meridionale dei Monti della Maddalena (Appennino Merdionale). Giornale di Geologia Applicata (2), 348-356, https://doi.org/10.1474/GGA.2005–02.0–51.0077.

The woman who painted the ocean floor: celebrating Marie Tharp's legacy

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Keywords: women in geology, marine geology, Mid-Atlantic Ridge.

Marie Tharp was a pivotal figure in the advancement of Earth Sciences, particularly in marine geology and ocean floor cartography. Her groundbreaking work played a significant role in reforming the concept of continental drift and laying the groundwork for the plate tectonics revolution of the early 1960s (Barton, 2002; Romano & Chiocci, 2020). Initially met with skepticism, the theory of continental drift proposed by Alfred Wegener in 1912 faced opposition from the scientific community, including prominent paleontologists and geophysicists, who denied the mechanism proposed by Wegener for the movement of rigid sial continental crust above sima basaltic oceanic crust. Tharp's contributions became crucial in bridging this gap in understanding. Prior to her work, knowledge of the ocean floor, covering over 70% of the Earth's surface, was very limited. Tharp's meticulous analysis of bathymetric data, the discovery of the Mid-Atlantic Ridge and somital axial valley, challenged existing scientific paradigms. Despite initial resistance, her findings, alongside those of her colleague Bruce Heezen, provided essential data supporting the theory of seafloor expansion that may account for the drifting of crustal fragments on Earth surface favoring the floor to the modern plate tectonics paradigm. Tharp's interdisciplinary expertise in geology and mathematics was instrumental in transforming raw bathymetric data into comprehensive maps and profiles, utilizing early computer technology to aid in data analysis. The graphical representation of ocean floor data pioneered by Tharp and Heezen revolutionized scientific communication, facilitating the visualization of complex geological structures and fostering the development of new hypotheses. Their publication of the first complete world map of ocean floors in 1977 provided a comprehensive overview of the Earth's geodynamic processes, highlighting the interconnectedness of ocean ridges, transform faults, fracture zones, seamounts, and trenches. Despite facing gender-based discrimination early in her career, Tharp's pioneering work ultimately earned recognition for its significant contributions to the advancement of science. Her story echoes those of other overlooked figures in scientific history, underscoring the importance of acknowledging and valuing the diverse contributions of women in shaping our understanding of the natural world.

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Romano M. & Chiocci F.L. (2020) - Celebrating Marie Tharp. Science, 370(6523), 1415-1416.

Early interpretations of the Eocene Bolca Fossil-Lagerstätte (Italy): three centuries of debates for the emerging Earth Sciences

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Keywords: history of paleontology, Bolca Fossil-Lagerstätte, Eocene.

The well-known Eocene Bolca Fossil-Lagerstätte is a prominent and influential fossil site of the Cenozoic Era, renowned for its exceptional completeness, diversity, and preservation of vertebrate, invertebrate, and plant fossils (Carnevale, 2020). Centuries of excavation at primary sites like the Pesciara, Monte Postale, Purga di Bolca, and Monte Vegroni have yielded over 500 described species, facilitating nuanced interpretations of the lower Eocene western Tethys tropical marine ecosystems. These specimens are revered as iconic representations of Italian paleontology and have graced collections across Europe and North America for centuries. Bolca's fossils have not only contributed to scientific discourse but also shaped the early trajectories of paleontology and geology. This contribution offers a historical overview of Italian scientists' initial contributions to Bolca's fossil sites from the sixteenth to the eighteenth centuries, amidst fervent debates within the emerging field of Earth Sciences (Romano & Carnevale, 2023). Despite varying hypotheses about the origins of Bolca's fossil fish deposits, Italian scholars pioneered concepts rooted in empirical field data. Key controversies, including the organic versus inorganic origin of fossils, underscore the contributions of Italian scholars like Fracastoro, Scilla, Colonna, and Vallisneri. Debates regarding the presence of marine fossils in in areas now emerged up to the highest mountains sparked controversies between diluvialists and antediluvialists, reflecting broader scientific discourse in Earth Sciences. These seminal debates, entrenched in the early works on Bolca's deposits and fossils, underscore Bolca's enduring significance in geological history, examined chronologically from the sixteenth century onward.

Carnevale G. (2020) - I fossili di Bolca, icone della Paleontologia italiana. Geologicamente, 2, 38-47.

Romano M. & Carnevale G. (2023) - The early studies on the Eocene Bolca Fossil-Lagerstätte (Italy): An historical overview. Boll. Soc. Paleontol. Ital, 62, 105-142.

The legendary Central Asiatic Expedition: celebrating 100 years of Oviraptor

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Keywords: dinosaurs, Oviraptor, Cretaceous.

In this contribution, we commemorate the bicentenary of the first scientific description of the theropod *Oviraptor* by American paleontologist Henry Fairfield Osborn. We delve into the history of its discovery in Mongolia and the initial interpretations surrounding this iconic dinosaur. *Oviraptor philoceratops*, a small bird-like dinosaur from the late Cretaceous period, was first discovered in 1923 by George Olsen of the American Museum of Natural History (AMNH) during a Central Asiatic Expedition led by Roy Chapman Andrews. The discovery, made atop a dinosaur egg nest in the Gobi Desert, initially led Osborn to speculate that *Oviraptor* was an egg thief, an interpretation that provided the name for the new genus (Osborn, 1924). Osborn formally named the species *Oviraptor philoceratops*, suggesting a preference for ceratopsian eggs. Despite Osborn's initial hypothesis, subsequent discoveries of nesting oviraptorids demonstrated their role as nurturing parents rather than egg thieves. Our contribution sheds light on the historical context of *Oviraptor*'s discovery and the evolution of scientific interpretations over the past two centuries. By commemorating this milestone, we honor the legacy of the legendary Central Asiatic Expedition and the ongoing advancements in our understanding of dinosaur behavior and evolution.

Osborn H.F. (1924) - Three new Theropoda, Protoceratops zone, central Mongolia. American Museum Novitates, 144, 1-12.

Staring into the abyss: the unfathomable true age of the Earth or how to reshape the way we perceive Time

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Keywords: deep time, epistemology.

The human mind is not used to the cognitive exercise of comprehending the vastness of the concept of deep time. Yet geoscientists have been able to measure it: something that transcends and far exceeds the human scale. From the rejection of anti-scientific biblical limitations, to the term *arche-fossil* coined in 2008 by Meillassoux (2014) to express the staggering realisation that science can now report events that predate human consciousness, even the advent of life itself, the idea of geologic time was given this new name, "deep time", by McPhee (1981; Gee, 1999) – hinting at how all of human history is just scratching the surface of Earth history.

In order to discern the mind-widening scope of deep time, the aim of this contribution is to engage in an epistemological reflection on the representations of the concept, as well as the implications of this evolution as time goes by. It begins with an analysis of how and to what extent James Hutton's findings at Siccar Point (Berwickshire, Scotland) (in: Gould, 1983) impacted the notion of the world's origins, and it looks at ways to make sense of the intimidating, astonishing thought of deep time in the present.

Besides offering musings upon the difference between geological time and everyday time, we suggest travelling back and forth in time well beyond the temporal constraints imposed by human nature, in an effort to demonstrate how geological time admits no narrative until some other means emerge to favour a different view that recognizes the true magnitude of Deep Time.

Gee H. (1999) - In Search of Deep Time: Beyond the Fossil Record to a New History of Life. Comstock Books, Cornell University Press, 267 pp.

Gould S.J. (1983) - Hen's Teeth and Horse's Toes: Further Reflections in Natural History. W. W. Norton & Company, 416 pp.

McPhee J. (1981) - Basin and Range. New York, Farrar, Straus, Giroux, 215 pp.

Meillassoux Q. (2014) - Time Without Becoming. Lecture by Quentin Meillassoux at Middlesex University, London, UK, 8 May 2008. Longo A. (Ed.), Milan: Mimindelicesis International, 52 pp.

Maria Matilda Ogilvie Gordon: the "Lady of Dolomite", a pioneer of geological surveying and more…

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Keywords: gender bias, pioneer female geologist.

Maria Matilda Ogilvie Gordon, or May as she was known, was born in 1864 in Scotland. Her passion for geology began with a holiday in the Scottish Highlands. May graduated in 1890 as a Bachelor of Science specializing in geology, botany, and zoology, but when she wanted to attend University in Berlin, she was denied entry because was a woman. Despite this, May attended the University of Munich, even though was not officially enrolled: to listen to lectures she had to sit in a separate room with the doors half open. In the summer of 1891, following a stay in various locations in the Dolomites, May was so fascinated and attracted by them that decided to stay at Corvara, in Alta Badia, to study those mountains. At that time those places were inhospitable, there were no roads or inns; she had to leave before dawn and returned in the evening exhausted, with a backpack full of samples and fossils, but her passion and stubbornness got the better of her tiredness. Of course, a woman alone attracted attention at that time, but the mountain guides respected her, and taught her to climb. May produced detailed geological maps and identified and studied over 300 species of corals, sponges, and crustaceans, without any guide or control of a supervisor. She was the first woman in the United Kingdom to receive the DSc degree of Science in 1893 from the University of London and the first woman to obtain the PhD in 1900 from the University of Munich (Wachtler & Burek, 2007). May was also the first woman to publish scientific articles concerning the structural geology of the Italian territory and published many other articles and books, including some geological guides also aimed at a non-expert audience (Argentieri, 2020). Despite this, only very late some merits were recognized, such as the prestigious Lyell medal of the Geological Society of London received in 1932, and more than 60 years after her death, her name was given to a new genus of Triassic fern found in the Dolomites. May also became an activist of the Liberal Party and leader of various associations created for the cause of women's emancipation and was the first woman to preside over a district court of Justice, and much more. For all this she was awarded the honor of "Dame Commander of the Most Excellent order of the British empire" conferred by King George V in 1935 (Burek, 2005). It was not easy to reconcile her scientific interests with family duties (she was married and had 4 children) and commitment to social life, and above all it was difficult to fight the prejudices according to which being interested in Science was an exclusively male prerogative.

To introduce Italian girls to this geoscience pioneer and encourage them to undertake scientific studies, overcoming the unfortunately still widespread stereotype that Sciences are "men's stuff", a short video was produced (by: Perrini, Billotta, De Giorgio, Sportelli), and shown on numerous occasions dedicated to University orientation for high secondary school classes.

Argentieri A. (2020) - La Dama delle Dolomiti. Maria Matilda Ogilvie Gordon (1864-1939). Geologia e emancipazione femminile in Europa fra il XIX e il XX secolo. Geologicamente, 2, 75-76, https://www.geologicamente.it/267/geologicamente-numero-2.html.

Burek C.V. (2005) - Who were they? The lives of geologists. 5. Dame Maria Matilda Ogilvie Gordon – A Britisher – and a woman at that (1864-1939). Teaching Earth Science, 30(4), 42-44, http://hdl.handle.net/10034/10723.

Wachtler M. & Burek C.V. (2007) - Maria Matilda Ogilvie Gordon (1864 - 1939): a Scottish researcher in the Alps. In: Burek C.V., Higgs B. (Eds), The Role of Women in the History of Geology. Geological Society of London, Special Publication, 281, 305-317, https://doi:10.1144/SP281.20.

Seismic maps between historical approach and scientific research. A contribution from the history of science to risk reduction

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Keywords: seismic maps, history of science, territory and risk management.

The presentation will highlight one of the crucial moments for the evolution of scientific knowledge on seismic phenomena and their dissemination: the drafting of a seismic map of the national territory between the end of the 19th and the beginning of the 20th century, in conjunction with the creation of the Italian geological map. As the scientific and public debate demonstrates to date, the construction and adoption of seismic maps can be configured as tools for a more or less functional and ethical approach for land management planning, as well as for the prevention and mitigation of risks. The history of emergency management by the various Italian governments has recently been reconstructed (Botta, 2013, 2020), and the different stages of the cultural development of earthquakes in Italy (Guidoboni & Pourier 2019).

However, the history of seismic maps has not yet been addressed through a long-term perspective, useful for detecting significant passages in the protection of the territory and the mitigation of natural risks in Italian scientific and cultural history. Since the 1970s, Italian scientific research has analyzed, under the impetus of industrial needs, a considerable amount of data aimed at creating seismic maps and databases which have been decisive for the evolution of the in-depth knowledge of seismic structures of our country and, at the same time, have provided decision-makers and public opinion with important tools for knowledge of the territory and risk management (CFTI15MED and DBMI15).

The first part of the talk will be dedicated to the reconstruction of the scientific context that allowed the development of the first Italian seismic map, with particular reference to the innovative interdisciplinary methodology developed by M.S. De Rossi, T. Taramelli, and M. Baratta. The convergence of several disciplinary instances (geological, geographical, historical, physical, archaeological, and paleontological) was decisive for the appearance of a work, and at the same time of a scientific research tool, useful for the seismic knowledge of the national territory and for the implementation of risk mitigation policies to reduce vulnerability. Subsequently, the contribution of historical seismology will be analyzed which, recovering the experience of the early twentieth century, has been able to develop, also thanks to the evolution of computer applications, seismic maps that are increasingly advanced and accessible to public opinion and politics. Finally, the current public debate on adopting the national seismic map, especially on the methodological side, highlights the double character of seismic maps: scientific and cultural. The neglect of this last point contributes to the increase in the vulnerability of our territory, therefore an appropriate dissemination of seismic maps to public opinion becomes strategic for improving the management of the territory and the associated risks.

Botta S. (2013) - Politica e calamità: il governo dell'emergenza naturale e sanitaria nell'Italia liberale (1861-1915), Soveria Mannelli Rubbettino.

Botta S. (2020) - Macerie d'Italia: storia politica di una nazione in lotta contro la natura, Firenze Le Monnier.

Guidoboni et al. (2018) - CFTIMed, Catalogo dei Forti Terremoti in Italia (461 a.C. -1997) e nell'area Mediterranea (760 a.C.-1500). Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.6092/ingv.it-

Guidoboni E. & Pourier J.-P. (2019) - Storia culturale del terremoto dal mondo antico a oggi, Soveria Mannelli Rubbettino.

The ancient mine of Poggio Mozzeto in the Bai Valley (Roccastrada, Grosseto)

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Keywords: Copper mine, Southern Tuscany, Middle Age.

The copper-silver deposit of Poggio Mozzeto is located in the valley of the river Bai about 3 km from Roccastrada. The area, consisting mainly of Triassic formations, is in the western margin of the Monticiano-Roccastrada Paleozoic ridge. At Poggio Mozzeto in the Middle Ages (Sienese documents of the 14th -15th centuries), and perhaps even earlier in the Classical Age, was active a substantial extraction of copper, silver and lead minerals, witnessed still today by numerous tunnels, trenches and little shafts. On these mining remains there are testimonies of 18th century scholars (Pecci, Bartoloni) and 19th century (Simonin, Caillaux). During some mineral prospecting conducted in the last century were reported sporadic findings of concentrations of iron hydroxides ("*brucioni"* consisting of goethite, limonite and sporadic hematite) containing traces of copper minerals: chalcocite, azurite, malachite. Currently, due to erosion and dense vegetation cover, it is very difficult to detect traces of mineralization. All existing geological studies on the deposit and the characteristics of mineralisation are examined and discussed in this paper.

Bartaloni D., (1875) - Memorie istoriche riguardanti la terra di Roccastrada coll'aggiunta d'altre notizie spettanti alle famiglie del paese raccolte nel 1769 dal dottor Domenico Bartaloni professore pubblico nell'Università di Siena – pp. 59, Editore Cappelli, Siena

Caillaux A. (1858-1859) - Études sur les mines de la Toscane. – Bulletin de la Société de l'Industrie Minérale, Tome IV, pp. 153-200 - Dunod Éditeur, Paris

Simonin M.L. (1858) - De L'exploitation des mines et de la métallurgie en Toscane pendant l'Antiquité et le Moyen Age. – Annales des Mines, Série V, 14, pp. 557-615 – Dalmon et Dunod Editeurs, Paris

S12.

Field and digital geological mapping: the numerous facets of CARG project from crystalline basement to sedimentary deposits

CONVENERS & CHAIRPERSONS

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Attilio Sulli (Università di Palermo)

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Timing and lithofacies of the intermountain basins quaternary infilling from 1:50.000 geological maps (Piedimonte Matese, Isernia and Castel di Sangro sheets)

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Keywords: Quaternary geology, chronostratigraphy, intermountain basins.

Piedimonte M., Isernia and C. di Sangro 1:50.000 geological sheets host several intermountain basins and alluvial plains. They are filled by very thick quaternary sedimentary successions made of fluvial, alluvial fan, slope, fluvial-marshy and palustrine-lacustrine lithofacies assemblages. Field and boreholes geology, supported by tephro-stratigraphical and geochronological (14C, Ar/Ar, U/Th and OSL-TL), highlights that the infilling successions were constrained between Lower Pleistocene and Holocene. A great part of the infilling was deposited during Middle Pleistocene, probably due to the strong activity of extensional faults bordering and intersecting tectono-sedimentary basins. Faultings and long-term climatic changes caused the terracing and/or entrenching of the quaternary geological units, allowing us to distinguish and group them in synthems and subsynthems.

Piedimonte M. sheet. In the Volturno and Calore R. alluvial plains, more generations of alluvial fans, slope, travertine and fluvial deposits were recognized. Five boreholes were carried out in order to estimate the thickness and lithofacies assemblage of the not outcropping deposits. Based on geochronological data and morpho-stratigraphical constraints, they were grouped in 3 synthems: 1) Lower Pleistocene p.p.-Middle Pleistocene synthem presenting intercalated Roccamonfina tephra layers (c. 600 ka, Rio Rava, B and WTT); 2) Late Pleistocene synthem containing CI (39 ka) and NYT (15 ka) tephra layers. Also U/Th datings on travertine deposits and OSL-TL datings on fluvial sandy layers support this grouping; 3) Late Pleistocene and Holocene synthem thank to the presence of archaeological remains and 14C datings.

Isernia and C. di Sangro sheets. In the Isernia and Venafro basins, quaternary deposits were grouped in 3 synthems. 1) Lower Pleistocene-Middle Pleistocene p.p. synthem (> 600 ka) thank to morpho-stratigraphical constraints and paleomagnetic data; 2) Middle Pleistocene synthem thank to Ar/Ar datings on intercalated tephra layers, U/Th datings on travertine deposits and OSL datings on fluvial sandy layers; 3) Late Pleistocene-Holocene synthem. In the Isernia le Piane basin, a deep borehole (80 m) reaching carbonatic bedrock was carried out. The whole investigated quaternary succession, from the bottom to the top, shows lithofacies of: a) lacustrine-palustrine environments of Lower Pleistocene age based on paleomagnetic data; b) fluvial marshy, fluvial and travertine deposits of Middle Pleistocene age based on Ar/Ar datings from intercalated tephra layers (between ca. 540 and 460 ka); c) fluvial-marshy deposits of Late Pleistocene-Holocene age. Also in the Sessano basin, quaternary infilling shows fluvial marshy deposits constrained between Middle Pleistocene and Holocene age based on Ar/Ar datings on intercalated tephra layers, as well as in the Rocchetta and C. S. Vincenzo area travertine deposits were constrained to Middle-Late Pleistocene based on U/Th datings.

The Jurassic-Miocene Apenninic limestones in southern Matese: biostratigraphy and sedimentary evolution from geological mapping of the Sheet 418 Piedimonte Matese

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Keywords: lithostratigraphy, shallow-marine carbonates, biotic events.

This work depicts the present status of a revisiting and updating based on the biostratigraphy and facies analysis of carbonate platform successions, Jurassic-Miocene in age and cropping out in the southern sector of the Matese Massif, southern Apennines of Italy. This sector of the Apenninic chain, that is going to be included in the Sheet 418 "Piedimonte Matese", CARG project, is characterized by the substantially persistence in these areas of carbonate platform and ramp settings during the Mesozoic until to the Miocene (Parente et al., 2022).

New and old peculiar evidences are here presented by geological mapping, coupled with the measurement and correlation of the Monaco di Gioia-La Pizzuta-Mt. Acero-Monticello (for the older units) and Pietraroia-Regiapiana (for the younger ones) stratigraphic sections. Calcareous algae and benthic foraminifera biostratigraphy, integrated with a sedimentological and facies analysis, allows reconstructing the main bioevents as well as the sedimentary evolution of the Matese area.

The first noteworthy event in the *calcari con requienie e gasteropodi* Fm. (CRQ) of the Monte Acero section (570m thick, Kimmeridgian *p.p.*-Aptian *p.p.*) is the presence, few meters after the LO of *Campbelliella striata*, of *Pseudoclypeina*? *crnogorica* Radoičić, large dasycladalean alga considered an additional tool for dating the Berrasian in the field.

Following, at Monaco di Gioia-La Pizzuta, *Selliporella johnsonii* (Praturlon, 1964) nov.comb. appears at the end of the Weissert event (late Valanginian) and disappears at the Valanginian-Hauterivian boundary (Barattolo et al., 2021); the LO of *Salpingoporella annulata* marks the Hauterivian-Barremian transition; the LO of *Clypeina solkani*, *Clypeina parasolka* and *Campanellula capuensis* coincide with the early-late Barremian (Amodio et al., 2020).

Last but not least, three Plattenkalk horizons, at "La Peschera" Cusano Mutri, M.te Cigno and at "Le Cavere" Pietraroja, bearing fishes, amphibians, reptiles, invertebrates and plants (gymnosperms angiosperms) characterize the lithofacies of *calcari ad ittioliti* (CRQa). These dolomitic and marly limestones, which at Pietraroja contain the notorious small dinosaur *Scipionyx samniticus*, accumulated in a restricted lagoon (Pietraroja) as also in more distal environments and were included between the *Salpingoporella dinarica* and *Sabaudia minuta* (*Akcaya minuta)* biozones (upper Aptian-lower Albian).

Starting from the late Aptian, a synsedimentary tectonics induced emersion the platform as testified by the bauxite deposits embodying the Albian *p.p.*-Turonian *p.p.* During the Coniacian to Campanian, rudist dominated bioclastic associations developed but in open ramp settings. After the Palaeogene hiatus, only interrupted by the Eocene discontinuous shallow-water limestones discovered at the Monticello section, the sedimentation was resumed in the Early Miocene and ended in the late Serravallian-Tortonian when chain building started.

Amodio S. et al. (2020) - Carbonate ecosystem and environmental evolution during the Valanginian–Barremian: discussion on possible controlling factors in the Apennine Carbonate Platform record (Italy). Cret. Res., 108, 104351, https://doi.org/10.1016/j.cretres.2019.104351.

Barattolo et al. (2021) - *Selliporella johnsonii* (Praturlon) nov. comb. and *Selliporella neocomiensis* (Radoičić) (green algae, Dasycladales), taxonomic reconsideration and chronostratigraphic calibration. Cret. Res., 125, 104848, https://doi.org/10.1016/j.cretres.2021.104848.

Parente M. et al. (2022) - Stratigraphy and facies of the Apennine Carbonate Platform (southern Italy): the record of Mesozoic OAEs and Miocene transgression. Geol. Field Trips & Maps, 14(2.3), 1-74, https://doi.org/10.3301/GFT.2022.06.

Geological map of the Mesozoic and Cenozoic carbonate units cropping out in the southern Gargano Promontory: new stratigraphic constraints for the tectonic evolution of the area

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Keywords: Apulian foreland, Manfredonia, CARG.

The Gargano Promontory has received in the last decades a renewed attention by the scientific community due to the peculiar geological features of this sector of the Apulian foreland, which is considered seismically active. Furthermore, the outcropping Mesozoic carbonate units represent potential field analogues for the petroleum reservoirs discovered in the southern Adriatic Sea. Although the high number of scientific papers published on the aforementioned topics has given a notable contribution to the geological knowledge of the Gargano Promontory, the southern sector still remains quite underexplored due to the lesser availability of well-exposed outcrops. The geological survey of 397 Sheet "Manfredonia", as part of the CARG project, have contributed to filling this gap by proposing new stratigraphic and structural constraints for the interpretation of the tectonic evolution of the Gargano Promontory. The aim of this study is to illustrate the main structural elements that have deformed the Mesozoic-Cenozoic carbonate units in this sector of the Apulian foreland. Detailed lithostratigraphic analysis played a pivotal role in the geological survey because, under certain conditions (such as limited exposure and well-exposed outcrops), it has been the only usable tool to identify the occurrence of tectonic features otherwise unrecognisable. The following lithostratigraphic units have been recognised: Calcare di Bari Fm. (Callovian *p.p.*- Cenomanian *p.p.*), Calcare di Altamura Fm. (Coniacian *p.p.*-Santonian *p.p.*); Calcarenite di Gravina Fm. (Middle-Late Pliocene). In addition, the informal units of Masseria Belvedere fm. (late Serravallian), Masseria Spagnoli fm. (late Tortonian); Masseria Pezza Nuova fm (Messinian ?) and Valle di Vituro fm. (late Messinian?). Most of the tectonic structures mapped in the studied area as the Mattinata and Rignano faults along with their wrench related structures, NW-SE oriented faults and folds systems formed after distinct tectonic phases showing a common deformation style. In the southern Gargano three tectonic phases have been recognised due to the stratigraphic constraints provided by the Neogene units: a) the Masseria Spagnoli fm. onlaps both the Masseria Belvedere fm. and the Mesozoic substrate along the southern limb of a major anticline developed on the footwall of the Rignano Fault. This relationship suggests that the early phase of formation of this structure occurred during early/middle Turonian times; b) a later tectonic tilting (about 20°) recorded by the Masseria Spagnoli fm. reveals a reactivation of this structure after late Tortonian times; c) the Calcarenite di Gravina Fm. crops out at the footwall of the reverse Monte Granata fault and close to Manfredonia town, where it is partly deformed by the strike slipe Ortolino fault. This enabling to date the activity of these structures after Pliocene times.

Offshore geological map in south-eastern Sicily: the "Siracusa - 646" (CARG project)

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Keywords: Siracusa, marine geology, geological mapping.

The south-eastern Sicilian coast has always been object of several studies to reconstruct the geological framework especially in terms of tectonic evolution and geohazards, due to its position between two important structures in the central Mediterranean region, the Hyblean Plateau and the Hyblean-Malta Escarpment. New data collected in the frame of the geological mapping of the sheet 646 "Siracusa" (CARG Project) implemented the knowledge of the continental shelf area, located from the Augusta Bay to the Maddalena Peninsula (offshore Siracusa), between the eastern Sicilian coast and the Malta Escarpment.

The new dataset, acquired during two different oceanographic campaigns in autumn 2023 and spring 2024, allowed the re-interpretation of the pre-existing data of this sector. We collected both multibeam data in the inner part of the continental shelf and a Side Scan Sonar mosaic, calibrated by 40 sediment samples from the seabed. The dataset was completed with existing CHIRP sub-bottom profiles and new Sparker seismic reflection profiles.

In the continental shelf we distinguished and mapped six depositional systems, from the inner shelf, characterized by several erosive channels up to 400 m wide, and the outer shelf, where there is a depositional basin with sediments up to 35 m thick, organized in 5 seismostratigraphic units pertaining to the Late Quaternary Depositional Sequence (LQDS), which has no relevant thickness in the inner shelf area.

In the upper continental slope zone, a complex system of canyons and gullies has been mapped. The absence of lowstand wedges suggests an ongoing erosional activity responsible for the retreat of the shelf break. Furthermore, two main sets of normal faults were distinguished with NNW-SSE and ENE-WSW trend respectively. The first system conforms with that detected on land and pertain to the Malta Escarpment regional fault system. This is responsible for the "fault-blocks structures" that characterize the whole area. Both systems produced different displacements of the pre-quaternary sequences thus defining the accommodation space for the LQDS. These results have ensured a step forward in the geological knowledge of this area of the Mediterranean and contribute to the assessment of the marine geohazards in a potentially exposed region.

Surface and subsurface geology of Gravina in Puglia, Southern Italy

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Keywords: Apennine foreland-foredeep, surface geology, thickness map.

Gravina in Puglia, located at the southern margin of the Murge relief, is an ideal site to explore the stratigraphic and structural relationships between Southern Apennine foredeep and foreland geological units. The town, flaked to the west by a NS-oriented canyon, is prone to several geological hazards including rock falls, seismic amplification and sinkholes related to widespread cavities in the shallow subsurface. Despite this geological complexity, local geologists are called to face these challenges without an adequate official geological map. As the available geological map (sheet 188 of the Geological Map of Italy to scale 1:100.000) dates back to the 1966, a new geological map, at a higher resolution, is required for land management.

We present here two maps depicting surface and subsurface geology of the urban area of Gravina in Puglia. Surface geology is characterized by the following lithostratigraphic units. The Cretaceous Calcare di Altamura formation (ALT, in nearby sheets of the Geological Map of Italy to scale 1:50.000), is part of the Apulian foreland carbonate platform and is dominated by micritic limestones with occasional rudist-bearing horizons. This formation is exposed in the Gravina canyon and in the northern part of the town. The Plio-Pleistocene Calcarenite di Gravina formation (GRA), largely exposed in the urban area, includes two lithofacies: the first with prevalent lithoclasts from the ALT formation, the second dominated by nearshore bioclasts. The boundary between ALT and GRA is marked by an angular unconformity with truncation of ALT strata and locally by a conglomerate horizon. GRA is overlain by a Pleistocene sedimentary succession, with overall coarsening and shallowing-upward trend, exposed on the hills surrounding the town. This succession represents the upper Bradanic-Foredeep infill and is composed of silty clays, laterally correlative to the Argille Subappennine Formations (ASP), grading upwards into fossiliferous sands and calcarenites. The latter are locally overlain with erosive contact by etherolithic gravels and conglomerates. Gravina in Puglia historically developed onto the GRA formation, and subsequently expanded over ALT limestones and on the ASP muds.

The thickness of GRA, represented in the subsurface-geology map, increases southward from zero to approximately 50 m, controlled by a series of NW-SE trending normal faults and paleo-cliffs, with possible structural control. Locally thickness of GRA may increase northward of few meters in the hanging-wall of NE-dipping faults. The subsurface-geology map represents an important predictive tool because the boundaries between ALT and GRA, and GRA and ASP, characterized by markedly different mechanical properties, may represent important seismic reflectors which may cause local amplification of the seismic signal. Moreover, the knowledge of the depth of the ALT-GRA and GRA-ASP boundaries is crucial for the design of shallow-subsurface infrastructures.

Paleotectonics imprint on the southern edge of the M. Morrone structure (Central Apennines)

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Keywords: field mapping, paleotectonics, breccias.

Field mapping carried out for the new 1:50,000 scale 370 Guardiagrele sheet (CARG Project) showed along the southern edge of the M. Morrone thrust-related-anticline several large S-SW dipping tectonic normal faults with evidence of their pre-compressive activity. In particular:

- the faults are curvilinear and strike from NW-SE to about E-W, moving to the east and approaching the M. Morrone thrust front;
- where the faults can be detected, they always have a low immersion angle (maximum 40°), becoming a 'normal angle' when the footwall layers are brought back to the horizontal position;
- the extensional structures, despite their conspicuous downthrown (several hundred meters), do not displace the M. Morrone thrust front in a significant way; also, they do not form planes at the hangingwall;
- on the hangingwall of the normal faults, several generations of breccias and conglomerates are exposed, also highly tilted. Some of them are similar to the Rigopiano conglomerates (even with the occurrence of terrigenous clasts), found on the ridge of M. Morrone and classically attributed by literature to a wedge-top deposits due to the polygenic origin of their clasts, while other breccias are made up exclusively of clasts of local succession;
- in addition to the breccias, near the site of Colle Ardinghi, on the hangingwall of the large normal fault of the Fosso Vella, Upper Miocene deposits, both limestones and clayey, are exposed directly transgressive on Lower Cretaceous limestones, along what was probably a tectonically tilted and uplifted block, then down-sunk;
- on the hangingwall of the Il Rio fault, olistoliths of several hundred square metres, made of local carbonate succession, are exposed, apparently 'floating' onto the Upper Miocene flysch; they can be interpreted as large underwater rockslides occurred during Late Miocene interval.

New geological map at a 1:10.000 scale and tectono-stratigraphic review of the NW Campania-Basilicata boundary (Southern Apennines, Southern Italy)

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Keywords: Southern Apennines, geological field mapping, litho-biostratigraphy.

A geological survey at a 1:10.000 scale and litho-biostratigraphic investigations have been recently undertaken in the Southern Apennines among the villages of Bella, Castelgrande, Muro Lucano, San Fele and Laviano (NW Campania-Basilicata boundary), within the framework of the CARG Project, sheet n.469 Muro Lucano. The data gathered during the survey allowed a careful revision of the exposed lithostratigraphic units and an improved definition of the tectonic structures. The results are summarised in a new geological map of the area at a 1:10.000 scale, where the following tectono-stratigraphic units are distinguished:

the Lagonegro Basin Unit, characterised by the Rhaetian-Jurassic Scisti Silicei of the S. Fele facies (Scandone, 1967), mostly made up of jaspers, with a sequence of 1 m-thick silicified calcirudite beds in the lower portion, and the Berriasian-Aptian *p.p.* Flysch Galestrino (Patacca & Scandone, 2007), made up of an alternation of marlstones and laminated calcarenites to calcilutites;

the Apennine Carbonate Platform Unit, consisting, from bottom to top, of: i) dolomitised limestones (Upper Triassic?); ii) well-bedded limestones with *Palaeodasycladus mediterraneus* and *Orbitopsella praecursor* (Hettangian?-Toarcian *p.p.*); iii) poorly-bedded oolithic limestones (Middle Jurassic?); iv) up-to-very-thick fine-grained limestone beds with thin green marly intercalations (Upper Jurassic?); v) limestones with acteonellids and requienids, stromatolitic laminae, green marly clasts and black clasts (Lower Cretaceous-Cenomanian *p.p.*); vi) biolithoclastic limestones with radiolitids and caprinids, and black pebbles (uppermost Cenomanian to Turonian);

Langhian-Serravallian thrust top/foredeep deposits of the Castelvetere Formation (Pescatore et al., 1969), lying unconformably on top of the Apennine Platform and consisting of two intervals. The lower, sandy-conglomeratic interval, includes a huge olistostrome consisting of Argille-Variegate-Group terrains containing 10 m-sized olistoliths deriving from the Apennine Platform. The upper marly interval includes centimetric siliciclastic siltstone-to-fine-grained-sandstone beds, metres-thick medium-to-coarse-grained sandstone beds, large slabs of Sicilide-affinity and thousands-of-cubic-metres olistoliths of the Apennine Platform;

sediments of the Pliocene Intra-apenninic Basins (e.g., Servizio Geologico d'Italia, 2013) consisting of pelitic-sandy to gravelly-sandy lithofacies with ichnofossils and bivalves.

Contractional structures, mostly affecting the Castelvetere Formation, consist of wide and rarely overturned folds, in some cases connected to fault propagation, with about E-trending hinge lines. Cenozoic East-directed contractional and transpressional faults and Miocene-Quaternary extensional fault sets with E-W, NW-NE and NE-SW orientations affect both the Castelvetere Formation and the Apennine Platform.

New insights into the Southern Apennines evolution are provided by this study.

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Scandone P. (1967) - Studi di geologia lucana: la serie calcareo-silico-marnosa e i suoi rapporti con l'Appennino Calcareo. Boll. Soc. Natur. Napoli, 76, 301-469.

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Stratigraphic and structural relationships between the Matese Mts and the Montagnola di Frosolone: new field data from the Geological Sheets 404 "Isernia" and 418 "Piedimonte Matese" (CARG Project)

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Keywords: carbonate platform, field mapping.

In the area of the Matese Mts falling within the CARG Project Geological Sheets 418 "Piedimonte Matese" and 404 "Isernia", the Meso-Cenozoic relationships between carbonate platform, slope and basin are well exposed. These relationships can be recognized in two different tectonic units, namely the Matese (MaU) and the Montagnola di Frosolone (MFU) units, which were issues of discussion by different Authors (e.g., Patacca & Scandone, 2007) for their structural relations. The results of the field mapping of these sheets, based on stratigraphic data and structural analysis, highlight the geometric relationships between the different sectors of the Matese Mts and the Montagnola di Frosolone. The Piedimonte Matese Sheet is characterized by a Triassic to Middle Miocene shallow-water carbonate platform succession, interrupted by a "mid" Cretaceous stratigraphic gaps marked by thick bauxitic levels, and by a wider Paleogene gap represented by a discontinuity surface between the Miocene and Cretaceous platform carbonates. The Isernia Sheet is characterized by an upper slope (MaU) and a lower slope-basin (MFU) successions. Slope successions consist of bio-lithoclastic grainstones and rudstones (Calvello Fm., VLO; Campanian-Maastrichtian) resting unconformably on carbonate platform deposits. Moving from east to west, the width of this stratigraphic gap increases to manifest as an angular unconformity between VLO and Triassic platform dolostones (Dolomia superiore Fm.). Moving northwards, the slope-to-basin transition is mostly exposed at Patalecchia Mt. Here, dolomitized calcirudites and calcarenites with chert intercalations (Pesche Fm.; ?Middle Jurassic-Lower Cretaceous) pass upwards to thin-bedded cherty calcarenites, micrites, green shales (Coste Chiavarine and Foresta Fms.; Lower-Upper Cretaceous) and to mass flow and turbidite-rich deposits of VLO. The occurrence of VLO in the Cretaceous slope-basin succession of the Montagnola di Frosolone (Pescatore, 1965; Bertinelli et al., 2005) represents the lithostratigraphic (and paleogeographic) linking element between the upper slope succession of MaU and the lower slope-to-basin succession of MFU. The linkage zone, situated in the Longano area, is strongly deformed by the development of an E-W asymmetric macro-fold structure with a northward vergence. This structure extends along the entire Longano valley for approximately 10 km and is thrusted within its central portion. The new stratigraphic and structural data allow us to well document the tectono-stratigraphic evolution of the Mesozoic carbonate platform margin and its structuration during the Cenozoic. The Isernia Geological Sheet features a legend presenting a dual lithostratigraphic framework for Meso-Cenozoic carbonate platform-to-basin formations: "Campania-Molise" and "Latium-Abruzzi" promoting continuity between adjacent sheets. The boundary between these nomenclatures is the Volturno River valley, filled with Quaternary sediments.

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Patacca E. & Scandone P. (2007) - Central-Southern Apennines (Italy) Simplified Geological-Structural Map, S.EL.CA, Firenze. Scale 1:500.000. In: Mazzotti A., Patacca E., Scandone P. (Eds), Results of the CROP project, sub-Project CROP 04 Southern Apennines (Italy). Boll. Soc. Geol. It. (It. Journ. of Geosci.), Spec. Issue 7, 75-119.

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The highest regressive coastal deposits of the Bradanic Trough (Basilicata, Southern Italy): old vs new stratigraphic schemes in the official geological cartography

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Keywords: regressive deposits, Bradanic Trough, Apennines foredeep.

The study area is located in the central part of the Bradanic Trough, along the chain-foredeep boundary of the Southern Apennines orogenic system and is characterized by the occurrence of lower Quaternary deposits that represent the outcropping part of the topmost in-fill succession of the basin. These deposits form a regressive succession made up of silty clays (Argille subappennine Fm) followed by coarse-grained deposits. The latter in the official geological maps of Italy (1:100.000 scale) are represented by two lithostratigraphic units described and cartografically represented as tabular ones: the Sabbie di Monte Marano Fm below and the Conglomerato di Irsina Fm above. In the New Geological Map of Italy (1:50.000 scale) this scheme was abandoned, and above the Argille subappennine Fm a sandy and conglomeratic unit occurs (regressive coastal deposits by Pieri et al., 1994; 1996). The new scheme is supported by several studies performed along the Bradanic Trough, which also allowed us to obtain the evolutive history of the basin.

In particular, in Genzano di Lucania and Banzi areas the coarse-grained deposits form a lithostratigraphic unit, up to 100 m thick, continental to marine in origin, made up mainly of conglomerates in the WNW sector (Banzi area) and mainly of sands with tongue of conglomeratic layers, in the E-SE sector (Genzano di Lucania area) (Cilumbriello et al., 2008). These successions present an aggradational stacking pattern of conformably lying bodies, induced by the interference between a low-order relative sea-level rise (basin subsidence) and high-frequency sea-level changes during the evolution of a basin margin depositional system. In an adjacent area (Irsina) the same succession (a bit younger in age), known as Monte San Marco formation, shows a progradational and downward-shifting stacking pattern (Sabato et al., 2004). This stratigraphic architecture was induced by the interference between a low-order relative sea-level lowering (regional uplift) and high-frequency sea-level changes.

These stratigraphic features record a geodynamic change in the evolution of the Bradanic Trough during the Early Pleistocene when a still active foreland-basin began to experience an "anomalous" uplift after a long period of "normal" subsidence.

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Pieri P. et al. (1994) - Evoluzione tettonico-sedimentaria della Fossa bradanica a sud dell'Ofanto nel Pleistocene. Quaderni Bibl. Prov. Matera, 15, 35-54. Edizioni Osanna, Venosa (PZ).

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Sabato L. et al. (2004) - Problemi di cartografia geologica relativa ai depositi quaternari del F° 471 "Irsina". Il Conglomerato di Irsina: mito o realtà? Il Quaternario, 17 (2/1), 391-404.

Towards a lithostratigraphic correlation of Mesozoic-Cenozoic carbonate platform-to-basin successions of central and southern Apennines: insights from the CARG Project

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Keywords: Meso-Cenozoic carbonate platform-basin, Lazio-Abruzzo vs. Campania-Molise successions, lithostratigraphic correlation.

Significant stratigraphic problems may arise when applying lithostratigraphy within the Mesozoic and Cenozoic carbonate platform-basin successions of the south-central Apennines. Inconsistencies in unit definitions and nomenclature among the " Lazio-Abruzzo succession" (LAS) and "Campania-Molise succession" (CMS) could obscure the identification of regional stratigraphic trends. Nevertheless, these successions share major similarities regarding (i) general stratigraphy, (ii) depositional environments, (iii) age, (iv) paleogeographic domain (i.e., the Apennine Carbonate Platform, albeit with local paleotectonic complexities), (v) record of paleoecological events, and biostratigraphic scheme, as well as (vi) tectono-stratigraphic evolution.

The refinancing of the national geological mapping project (CARG Project) at a 1:50,000 scale, which resulted to the ongoing production of several geological sheets in the central (Lazio-Abruzzo) and southern (Campania-Molise) Apennines, has brought to light this long-standing problem, as already highlighted during the previous phase of work on the CARG Geological Sheets in the early 2000s (Di Stefano et al., 2011). Mismatch in lithostratigraphic application thus necessitated coordination led by the Geological Survey of Italy (ISPRA) to prevent discrepancies between adjacent geological sheets.

To enhance clarity and address definitional ambiguities, the geologic, litho-, and biostratigraphic aspects of the Mesozoic-Cenozoic carbonate units described on the already published geological sheets of the CARG Project for the central and southern Apennines were critically examined to produce a super-regional standardization. Differences in nomenclature arise from an historical tradition linked regionally to specific names, reflecting different approaches and criteria rather than lithostratigraphic differences. Revisions to existing frameworks were made and chrono-lithostratigraphic schemes were developed to facilitate correlations across different depositional settings. The aim is to introduce in the ongoing CARG Project, a double legend for Meso-Cenozoic shallow water-to-basin successions, referring deposits of the same age and with comparable litho-biostratigraphic characteristics respectively to the LAS and CMS. The boundary between areas where CMS or LAS nomenclature is applied is primarily morpho-structural and artificial, identified along the Roccamonfina graben to the west and in the upper Volturno River valley to the east and northeast. Four ongoing geological sheets bordering the regions of Lazio, Abruzzo, Molise, and Campania—specifically 392 Castel di Sangro, 404 Isernia, 416 Sessa Aurunca, and 417 Teano—have been identified where the implementation of a double legend is deemed necessary. Such lithostratigraphic approach strategically ensures cartographic consistency between geological sheets exhibiting either Lazio-Abruzzo or Campania-Molise lithostratigraphic affinities.

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Recognition of a pre-LGM, km-wide collapsed DGSD in Bregaglia Valley (Italian Central Alps): a case study in the frame of the CARG Project sheet n. 038 "Chiavenna"

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Keywords: DGSDs, geomorphological evolution, Central Alps.

Deep-seated Gravitational Slope Deformations (DGSDs) affect large portions of high-relief mountain slopes and the shape of alpine valleys (Crosta et al., 2013), influencing their Neogene and Quaternary evolution. New geological mapping of the lower Bregaglia Valley (Lombardy Region, Italy), in the frame of the CARG Project 1:50.000 scale Geological map of Italy, sheet Nb. 038 "Chiavenna", not only confirms the presence of several DGSDs affecting its southern flank (Tibaldi & Pasquarè, 2008), but also reveals the presence of a landslide body related to DGSD collapse in the area where bedrock has been reported so far. The lower Bregaglia Valley is located between the Tambò Nappe, Chiavenna Unit and Gruf Complex. The southern slope is made of mafic and ultramafic rocks of the Chiavenna Unit, in contact with the Gruf migmatites and paragneisses of the Tambò Nappe. The northern slope is made of Tambò paragneiss. Complex lithological relationships on the south slope have been justified by previous Authors through a combination of folds, faults and tectonic contacts (e.g., Schmutz, 1976). The Marmitte dei Giganti Park (East of Chiavenna, near the confluence of the Liro and Mera rivers) is a ca. 100 m high relief, next to the valley thalweg, well known for its glacial and fluvioglacial forms of excavation. This relief has been mapped so far as a bedrock body (e.g., Schmutz, 1976). South of it, the slope shows widespread gravitative trenches, scarps and counterslopes. The relief is composed of ultramafites and amphibolites that, to the west, do not correlate with the surrounding geology: the nearest amphibolite outcrop is about 1 km south and 500 m higher on the mountain slope. Moreover, evidence from a nearby drill hole SW suggests an inversion of the lithology order, with the Tambò paragneisses being beneath the main body of the park. The relief is crosscut by a network of fractures allowing a constant temperature air circulation, historically exploited for food conservation, that needs large fractured-porous volumes in the rocks to be maintained. This evidence led us to interpret the Marmitte dei Giganti Park relief as a DGDS collapse, namely as a km-wide landslide, made up of hectometer-sized blocks of very resistant rocks originated by sliding of portions of a DGSD-affected slope. The contact between the Gruf Complex and the northern Tambò and Chiavenna units (Gruf Line) acted as a main predisposing factor for large mass-wasting movements on the southern slope of the Bregaglia Valley, which could still have been active after the Last Glacial Maximum (LGM) retreat (Tibaldi & Pasquarè, 2008). However, the DGSD collapse originating the slope surely predates the LGM (Tantardini et al., 2022), being covered by glacial deposits. The volume needed for the emplacement of this collapsed mass leaves room for speculations about the original morphology of the valley and the processes related to its formation.

Crosta G.B. et al. (2013) - Deep seated gravitational slope deformations in the European Alps. Tectonophysics, 605, 13-33, https://doi.org/10.1016/j.tecto.2013.04.028.

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Tantardini D. et al. (2022). The Last Glaciation in Valchiavenna (Italian Alps): maximum ice elevation data and recessional glacial deposits and landforms. Ital. J. Geosci, 141(2), 259-277, https://doi.org/10.3301/IJG.2022.13.

Sedimentary dynamics and biological-anthropic processes on the seafloor: the natural laboratory of Taranto seas (northern Ionian Sea, southern Italy)

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Keywords: marine geology, seafloor mapping, CARG.

This study is focused on the marine geology of the Taranto area (northern Ionian Sea) which is particularly interesting for several reasons. It includes three different marine basins: a semi-enclosed, shallow basin (Mar Piccolo), a deeper open basin (up to 1500 meters - northern Ionian Sea) and a circular basin with intermediate characters of hydro-dynamism and depth (Mar Grande). It is also a marine area which hosts a large biodiversity, but also deep anthropogenic impacts.

The followed interdisciplinary approach provides a specific study of the seabed in offshore area, highlighting the relationships between physical-geological features, like sediments distribution, bathymetry and degree of light penetration, and bio-ecological ones like distribution of habitats or the degree and type of anthropogenic impact. The main objective of the study is trying to obtain a complete evaluation and mapping of these processes.

In fact, this study fits in a national cartographic project at 1:50.000 scale (CARG). A detailed survey with multi and mono-channel seismic, Sub Bottom Profiler, Side Scan Sonar and Multibeam was performed, as well as some preliminary sampling operations.

The acquired data have been analyzed separately to obtain different information:

Seafloor DTMs from the MBES data processing, in order to recognize the depth and morphology of seabed;

High resolution images of seabed surface from the SSS acquisitions, which have been analyzed to obtain information about the distribution of sediments and rocky substratum outcrops, linked also to the distribution of biotic communities and bioconstructions;

Seismic sections to analyze the geometric and stratigraphic relationship between the deposits, recognized underneath the water-sediments interface.

All data have been implemented in a Geographic Information System to realize complete and updated thematic maps of the seafloor system, showing the lithology of the seabed, the distribution of habitats and the widespread of anthropogenic impacts. These maps give the basis to establish the relationships between physical, biological and anthropic processes. Finally, the dataset allows also to correlate the seismic units with the framework of the Quaternary evolution of the northern sector of the Ionian Sea.

The Mesozoic stratigraphic succession of Mt. Massico ridge in the southern Apennines (northern Campania, Italy): new data from geological mapping (Sheet 429 Mondragone - CARG Project)

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Keywords: geological mapping, stratigraphy, Apennine Carbonate Platform.

The Mt. Massico ridge (812 m a.s.l.) is an isolated relief in northern Campania. The SW to NE morpho-structural orientation of the ridge is the result of Quaternary normal faults that identify the Mt. Massico ridge as a horst block between the Garigliano river plain to the north and the Volturno river plain to the south. A 1:10,000 scale geological mapping was performed in the Mt. Massico area as part of the CARG Project, Sheet 429 Mondragone of the Geological Map of Italy at a 1:50,000 scale. In this area, the Mt. Massico ridge represents the only relief where a well exposed Mesozoic shallow-water carbonate platform succession crops out.

The ridge can be divided into two main sectors. In the southwest, Cenozoic rocks mainly crops out, except for Mt. Petrino, consisting of Cretaceous rocks, which is interpreted as an out-of-sequence thrust (Vitale et al.,2018; Smeraglia et al., 2019). The northeast sector consists of Mesozoic rocks. Although the southwest portion of the ridge has been recently investigated from a tectonic perspective by several authors, the latest stratigraphic studies on Mt. Massico date back to the 1960s (Cestari,1966; Vallario,1966).

The Mesozoic succession of the Mt. Massico ridge, in the portion falling within the Sheet 429 Mondragone, consists of shallow marine carbonates belonging to the Apennine Carbonate Platform, a paleogeographic domain that developed at the southern margin of the Tethys Ocean from the Late Triassic to the Late Cretaceous. Along the slopes of the Mt. Massico ridge, there is an excellent and almost continuous exposure, albeit with some gaps due to tectonic activity, starting from the Lower Jurassic in the northeast sector and ending with the Upper Cretaceous in the southwest sector.

The aim of this work is to provide new data on the Mesozoic succession of the Apennine Carbonate Platform in the Mt. Massico ridge. Lithostratigraphy, biostratigraphy and depositional environments have been defined by integrating field observations with thin section microfacies analysis.

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Vallario A. (1966) - Geologia del Monte Massico (Caserta). Boll. Soc. Natur. in Napoli, 75, Napoli.

Vitale S. et al. (2018) - Polyphase out-of-sequence thrusting and occurrence of marble detritus within the wedge-top basin deposits in the Mt. Massico (southern Apennines): insights into the late Miocene tectonic evolution of the central Mediterranean. Int. J. Earth Sci., 108, 501-519, https://doi.org/10.1007/s00531-018-1664-0.

New geological evidence in the Miocene successions of the eastern part of the Catanzaro Strait (Calabria-Southern Italy)

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Keywords: Catanzaro Strait, Calabrian Arc, Miocene succession.

The Catanzaro Strait is a sedimentary basin characterized by a thick sedimentary succession (up to 2000 m) ranging in age between the Miocene and the Quaternary. This basin is located in the central part of the Calabrian Peloritan Arc, between the Serre Massif and the Sila Massif, covering an area that goes from the Tyrrhenian offshore, Sant' Eufemia Basin (southern Tyrrhenian Sea), up to the Calabrian onshore, represented from the Catanzaro Basin.

The geological survey has been carried out during the realization of the Geological Sheet 745 "Catanzaro" as part of the CARG Project and it leads to new insight of the arenaceous-pelitic successions found below the Messinian interval of the "Calcare di Base". In the eastern edge of the Catanzaro sheet siliciclastic terrains outcrop with good exposure above basement rocks, we propose that they can be distinguished in different formations that have clear sedimentological and stratigraphic features, although in contrast to what reported in the geological cartography at a scale of 1:25.000 (Cassa del Mezzogiorno). It's noteworthy that these sedimentary bodies are affected by different tectonic activity where terrains characterized exclusively by normal faulting, in accordance with the geological literature of the area, occur with other successions strongly deformed by compressive tectonics. Field observations during the CARG project were useful to better understand some aspect of the geology of the Catanzaro Strait. Together with dating data of different geological formations can provide a new picture of the age of the tectonic deformation in this area of the Calabrian Arc.

Biostratigraphic data in the Pliocene-Pleistocene sediments from the CARG Project surveys in the Central Apennines (Italy): new evidence from the Sheet n. 370 "Guardiagrele"

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Keywords: CARG Project, Plio-Pleistocene, biostratigraphy.

The combination of detailed field data and biostratigraphic analyses based on calcareous nannofossils and foraminifers from Plio-Pleistocene successions sampled during the ongoing geological mapping of the Sheet n. 370 "Guardiagrele" is presented. This sheet is part of the CARG Project (Geological map of Italy at 1: 50,000 scale) and, for its realisation, a total of 700 samples have been collected so far. Micropaleontological analyses of about 70 samples have revealed an age ranging from the Pliocene (Zanclean) to the Lower Pleistocene (Calabrian). The post-Miocene (i.e., post-Messinian) deposits are characterised by the Pliocene reflooding with a return to normal marine conditions, due also locally geodynamic contest, as testified by generally well preserved and very diversified foraminiferal assemblages (occurrence of *Globorotalia margaritae* and/or *G. puncticulata*) and calcareous nannofossils species (among others, first occurrence of *Reticulofenestra zancleana*, *R. pseudoumbilicus*, occurrence of *Amaurolithus delicatus*, *Ceratolithus acutus, Discoaster brouweri, D. pentaradiatus* and *Sphenolithus abies;* MNN12-MNN14 Zones, Di Stefano et al., 2023). Therefore, it was possible to identify the Piacenzian stage (Upper Pliocene), with *Globorotalia crassaformis* and *G. bononiensis* among planktonic foraminifers and *D. brouweri,* small *Gephyrocapsa* spp., small *Reticulofenestra* spp*., Helicosphaera carteri* and *H. sellii* among nannofossils (MNN15 Zone). The Pleistocene sediments are also recorded in the area: some of these can be attributed to Gelasian for the presence of *Globorotalia inflata* specimens, *D. brouweri,* medium *Gephyrocapsa* spp. and *Pseudoemiliania lacunosa*, while the Calabrian sediments contains *Globigerinella calida*, *D. brouweri, D. pentaradiatus,* medium *Gephyrocapsa* spp., small and medium *Reticulofenestra* spp. with the absence of *Discoaster*. The Calabrian deposits are the most recent marine sediments recognised in the "Guardiagrele" sheet. The paleoenvironmental reconstruction shows bathymetric changes from the bathyal (Zanclean) to the infralittoral-circalittoral (Calabrian) zones, indicating a clear marine regression. The micropaleontological analyses have also permitted to recognise the presence of deposits referable to Piacenzian-Gelasian (Calabrian?) stages, previously not recognised (Festa et al., 2014; Patacca & Scandone, 2021) inside the orogen into the "Guardiagrele" sheet. These deposits represent a fundamental constraint for the reconstruction of recent tectono-sedimentary evolution of the area between the Maiella Mountain and the Molisane Units.

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Quaternary faulting in the NE sector of the Hyblean Plateau (SE Sicily): new insight from survey within the CARG project (sheet N. 646 Siracusa)

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Keywords: CARG, field mapping, Quaternary faulting.

The Hyblean Plateau (SE Sicily) is deformed by three main faults systems showing locally complex cross-cutting relationships. An NNW-SSE, dip-slip system, coaxial to the Malta Escarpment in the offshore, is observed to occur along the Ionian coastal sector. A NE-SW system affects the north-western and south-eastern sectors of the Plateau and has been interpreted as result of the crustal flexuration under the Sicilian folds and thrusts belt (Billi et al., 2006). Lastly, a NW-SE system, interpreted as a transfer zone between the main NE-SW systems (Cultrera et al., 2015), controlled the deposition of Quaternary series within a basin located west of the city of Siracusa, the so-called 'Floridia Graben'. Instrumental and historical seismicity point to the eastern coastal sector of the Hyblean Plateau as a zone prone to release earthquakes with strike-slip and subordinately normal focal mechanism (Musumeci et al., 2014). New geological fieldworks performed in the frame of the CARG project - sheet 646 "Siracusa" - have allowed to the revision of the geologic-structural setting of the north-eastern sector of the Hyblean Plateau, where most of the outcropping rocks are represented by Miocene reef to slope limestones growth/deposited over Cretaceous volcanic seamounts. The study allowed a better characterization of the above-mentioned faults highlighting the occurrence of a further faults system roughly trending ENE-WSW, which clearly displaced Middle-Upper Pleistocene sediments, whose topographic expression is still limited or absent. Our results provide new insights on the recent activity of Quaternary faults and may help on redefining seismic potential of faults in the area.

Billi A. et al. (2006) - Magnetic and structural constraints for the noncylindrical evolution of a continental forebulge (Hyblea, Italy). Tectonics, 25(3).

Cultrera F. et al. (2015) - Fault reactivation by stress pattern reorganization in the Hyblean foreland domain of SE Sicily (Italy) and seismotectonic implications. Tectonophysics, 661, 215-228.

Musumeci C. et al. (2014) - Foreland segmentation along an active convergent margin: New constraints in southeastern Sicily (Italy) from seismic and geodetic observations. Tectonophysics, 630, 137-149.

Tectono-sedimentary evolution of a Meso-Cenozoic slope from south-western Sicily (Italy)

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Keywords: tectonically controlled slope, paleogeographic reconstruction.

The geological mapping carried out within the activities for the Sheet n.628 "Sciacca" of the Geological Map of Italy (CARG Project) provided relevant information to understand the geological evolution of the south-western sector of Sicily. The data collected on field were of fundamental importance for the reconstruction of the stratigraphic and structural setting of sectors that, framed at a larger scale, help explain the evolution of part of the Sicilian Fold and Thrust Belt (SFTB). The field surveys were carried out at scale of 1:10.000 using digital tools (Field Move software) to obtain georeferenced data that have been represented on the digitized map at scale of 1:50.000.

In the Rocca Nadore area, located in the north-western sector of the Sheet, outcrop the Meso-Cenozoic succession pertaining to the shallow to deep water carbonate facies domain. Here we identified a E-W-trending sharp erosional unconformity between the Hettangian-Pliensbachian weakly dolomitized carbonate platform limestones (Inici Formation) and the Middle-Upper Jurassic reddish nodular-texture calcilutites, rich in ammonites (Buccheri Formation). We interpreted this angular unconformity as an extensional tectonically controlled depositional slope. We conducted a detailed stratigraphic analysis of the deposits lying above the unconformity enabled the identification of the time interval of sedimentation and evidenced various reactivations events. This time span is comprised between the Early Jurassic and the late Oligocene and is recorded in a stratigraphic succession with a maximum thickness of 25 meters. Similar depositional patterns were identified toward north along the Rocca Ficuzza carbonate ridge. In this latter sector, some bodies of carbonates megabreccias consisting of Meso-Cenozoic carbonates fragments in a reddish silty matrix, due to the gravitational collapse from a pre-existing slope, were identified.

This deformation pattern (age, geometry, and orientations) observed in the geological Sheet 628 "Sciacca," allowed to obtain information useful for regional paleogeographic and paleoenvironmental reconstructions. Furthermore, the analyzed sector consists of alternating paleo-structural highs and lows formed by Meso-Cenozoic shallow to deep water carbonate deposits, respectively. Recognition of the stratigraphic patterns and three-dimensional development of carbonate bodies, including boundaries and relationships with surrounding units, can have several spin-offs, including their possible use in support of hydrogeological studies.

New constraints on the southernmost portion of the Ligurian and Sub-Ligurian Domains: insight from the Sheet "363" Civitavecchia

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Keywords: External Ligurian Domain, geological mapping, stratigraphy.

The importance of large-scale geological mapping projects, like the CARG project, lies in the fact that field geologists are not only confronted with topics of local interest, but they must necessarily tackle broader issues. This is the case with the Sheet "363" Civitavecchia where the outcropping Mesozoic-Quaternary sedimentary succession helps deciphering the tectonic-stratigraphic evolution of a wider sector of the Apennine chain, from the earliest phases of compression and chain building, to the extensional phases related to the opening of the Tyrrhenian Sea, *via* the development of wedge top basins.

The Sheet 363 "Civitavecchia" is now about to enter its third year of operations. Parallel to an advancement of knowledge with respect to previous studies, our new findings raise a number of open questions that we believe may impact on the reconstruction of the southern closure of the Ligurian/Sub-Ligurian Domains.

The study area, located in Northern Latium, falls within one of the innermost portions of the Apennine Chain, a troublesome area where different paleogeographic Domains (Internal/External Ligurian, Sub-Ligurian, Tuscan, Epiligurian) meet. In contrast to southern Tuscany, the stratigraphic and tectonic relationships among these elements are buried or poorly exposed and some of the lithostratigraphic units differ from those traditionally associated with both the Ligurian and Sub-Ligurian Domains, making their assigning to either domain problematic.

We propose a reinterpretation of the Mesozoic-Palaeogene stratigraphy, based on our new field survey and a novel dataset mainly covering biostratigraphy (integrated microforaminifera, larger benthic foraminifera and nannofossils analyses) and sedimentology (facies analysis of siliciclastic and calciclastic units; petrographic analyses for provenance studies).

Structural style and compressive structures have been investigated through meso- and micro-structural analyses.

Our results are as follows:

in the study area, the base of the succession is always the Pietraforte, consisting of two diachronous lithofacies (as in the External Ligurian Domain);

With few remarkable exceptions, this unit overthrusts the Flysch della Tolfa, that in our view differs significantly from the "Sillano Fm/Santa Fiora Fm" and from the so called "Helminthoid flysch" (pertaining to the external and internal Ligurian Domains, respectively), as well as from the "Canetolo fm" (Sub-Ligurian domain).

A clastic lower Eocene unit (Cipollari et al., 2024) is unconformably covered by a previously undetected arenaceous/marly Oligocene/Aquitanian unit, similar to equivalent units known in the Sub-Ligurian Domain. These two units are deformed as one coherent body, suggesting a post-Aquitanian age of compression, not comparable to a Ligurian phase.

We are thus dealing with a challenging "hybrid" lithostratigraphic succession sharing features with both the Ligurian and Sub-Ligurian Domains.

Cipollari P. et al. (2024) - "il Casone-Monte delle Fate" olistostrome in the middle Eocene of the Eastern External Ligurian Unit (Monti della Tolfa, northern Latium, Italy): new constraints on the geodynamic evolution of the northern Apennines. Ital. J. Geosci., 143(1), 155-172.

Pre to syn orogenic evolution of the European margin: clues from the Flysch units of the Ligurian Alps (CARG Project - Ormea sheet 244)

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Keywords: European Margin, Ligurian Alps, Flysch Units.

Taking advantage of the ongoing new geological fieldwork for the 1:50.000 scale "Ormea Sheet" (n.244, CARG Project), the general aim of our work is to integrate existing data and observations for the reconstruction of the structure and evolution of the European (alpine) margin. The study area is located in the Ligurian Alps (i.e., the SE termination of the W Alps) which represents a key region where the contact between lithological units from two distinct paleogeographic domains, i.e. the Briançonais domain (European passive margin) and the Piedmont-Ligurian sedimentary covers (oceanic domain), is preserved. Here, the arrangement of the nappes pile and the internal structures of the tectonic units (including stacks of thrust sheets, superposed non-cylindrical folds, etc.) are evidence of a complex polyphase tectonic evolution accompanied by a low-grade alpine metamorphic imprint that partially overprint and reworks the original sedimentary structures and pristine features. In this poster we focus on the Flysch Units mapped in the Ormea sheet with particular emphasis on the Colla Domenica-Leverone unit. Previous works have hypothesized that these turbidite systems have been deposited in an abyssal plain, resulted from the Piedmont-Ligurian Oceanic rifting and spreading. These systems include basal complexes characterized by thinly bedded turbidites often containing olistostromes, succeded by sand- or carbonate-rich turbidite systems (Decarlis et al., 2014) that are interpreted as trench environment deposits (Di Giulio, 1992). As the accretionary wedge advanced towards the European foreland, these units underwent a migration and stacking process, resulting in an inverted stratigraphy with the oldest unit in the topmost part. Limited prior research on this unit revealed that a basal erosional boundary overlains two different units (Arnasco-Castelbianco and Borghetto units), contradicting previous assumptions of a tectonic surface. Additionally, geochemical analysis (XRF and ICP-MS) performed on basalt samples collected form the chaotic event within the basal complex of this unit (Colla Domenica Shales) suggest analogies with basalts form Balagne region, northern Corsica (data compared with Saccani et al., 2008). This preliminary evidence assumes that these units, resulting from a basement erosive sedimentary events and different source areas, filled the closing oceanic basin (as suggested by the model of Pandolfi et al., 2016). Petrographic analyses on thin sections of arenaceous samples will be performed to identify the sediment source areas, while geochronological analysis will be conducted withU/Pb analytical techniques on the zircons to compare the results with surrounding crystalline basements providing and additional time constrain limited to the poor biostratigraphic data. Concurrently, enhanced biostratigraphic analyses aim to refine the existing data.

Decarlis A. et al. (2014) - Salt tectonics in the SW Alps (Italy-France): from rifting to the inversion of the European continental margin in a context of oblique convergence. Tectonophysics 636, 293-314, https://doi.org/10.1016/j.tecto.2014.09.003.

Di Giulio A. (1992) - The evolution of the Western Ligurian Flysch Units and the role of mud diapirism in ancient accretionary prisms (Maritime Alps, Northwestern Italy). International Journal of Earth Sciences (Geologische Rundschau), 81, 655-668, https://doi.org/10.1007/BF01791383.

Saccani E. et al. (2008) - Corsica ophiolites: geochemistry and petrogenesis of basaltic and metabasaltic saltic rocks. Ofioliti 33(2), 187-207, https://doi.org/10.4454/ofioliti.v33i2.369.

Pandolfi L. et al. (2016) - Stratigraphic and structural features of the Bas Ostriconi Unit (Corsica): Palaeogeographic implications. C.R. Geoscience, 348, 630-640, https://doi.org/10.1016/j.crte.2016.07.002.

A geological dive from the western Alps into the Ligurian Sea: the experience of the CARG 245 - Albenga sheet

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Keywords: geological mapping, digital outcrop models.

We present the main outcomes from the three-year experience of mapping for the CARG 245 – Albenga sheet, which comprises emerged and marine areas. The Albenga sheet (located in western Liguria) displays ca. 450 km2 of emerged area hosting a wide variety of rock type, including: i) Paleozoic to Eocene metaintrusive, metavolcanic and metasedimentary sequences that experienced Pre-alpine and/or alpine orogenic deformation and metamorphism; ii) Oligocene to Pliocene post-orogenic sediments and a large Quaternary mixed marine-alluvial fan. The remaining one third (ca. 150 km2) of the sheet includes the continental shelf and the upper slope both intersected by well carved submarine canyons. The submarine survey is based on the integration of a new set of seismic reflection lines and high-resolution bathymetric data (MBES) with pre-existing available geological and geophysical datasets. On land survey has been performed through the integration of the classic, field-based approach with the analyses of Digital Outcrop Models (DOM) derived from digital photogrammetry and the use of Unnamed Aircraft Vehicles (UAV). We show two applications in orogenic and post-orogenic units/structures: a large Alpine fault zone and earthquake-related soft sediments deformation structures in the Finale Ligure basin. The combination of onshore and offshore observations provides new clues for reconstructing the morpho-structural setting and the (neo)tectonic evolution of the margin of this sector of the western Ligurian Sea. Moreover, our case history provides new insights for the up-to-date discussion about the methodological approaches in geological mapping applications.

CARG geo-tech revolution: digitizing geological maps with innovative tools (practical examples from the CARG project)

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Keywords: CARG, Innovative Tools, GIS.

In the current era, data collection and analysis are pivotal for informed decisions-making across all sectors, including geology. The structured management of this data has become integral to our daily operations. While geological information was traditionally stored in paper documents or unstructured digital formats, structured databases now serve as indispensable tools for organizing, managing, analyzing and interpreting such data.

Geological Geographical Information System (GIS) databases are innovative software solutions enabling integrated and standardized storage and organization of geological information, including geological units, mineral and water resources, geotechnical and geophysical characteristics, among others. These tools facilitate easy accessibility to information, reduce interpretative errors, and enhance analysis accuracy. In modern times, geological GIS databases have emerged as essential tools for natural resource management, geological risk assessment, and land planning. However, establishing design standards is crucial to ensure optimal usability and utility that meet the diverse needs.

The CARG Project, spearheaded by ISPRA*, endeavors to create and digitize the 636 geological and geotematic sheets at 1:50,000 scale, covering the entire national territory. Geological data acquired at 1:25,000 scale are stored in a complex database through specific guidelines and dedicated vocabularies.

This contribution seeks to identify and demonstrate various practical solutions to the primary challenges encountered in compiling the database requested in the CARG Project, utilizing practical examples from the Novi-Ligure and Tortona sheets. Special attention will be devoted to phases of work contributing from surveying to the digitization of the geological map. Particularly, leveraging the capabilities of the latest available tools (such as software: QGIS, QField; hardware: Tablet, Desktop office), innovative database compilation tools (dedicated Input/Output modules) will be presented.

Considerable space will be given for discussion on potential improvements and open issues, aimed to collaboratively establish a distinctive and exportable working methodology, applicable not only to other CARG sheets but also beyond.

* CARG webpage: https://www.isprambiente.gov.it/it/progetti/cartella-progetti-in-corso/suolo-e-territorio-1/progetto-carg-cartografia-geologica-e-geotematica/index

Multi-scale landscape evolution of Central Alps: another side of the Valchiavenna CARG project

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Keywords: Chiavenna, CARG project, morphometrical analyses.

The CARG project of geological mapping near Chiavenna (sheets 021 "Passo dello Spluga", 022 "Madesimo", 037 "Bodengo", 038 "Chiavenna") investigate an area with a complicated topography, resulting from pre-Quaternary Alpine tectonics and Quaternary evolution. The study area is in the Italian Central Alps and is composed of pre-Alpine basement rocks intruded by Permian and Oligocene granitoids, and of Permo-Mesozoic metasediments of the Penninic and Austroalpine domains characterized by a complex deformation history (Steck et al., 2013). The metasediments include quartzite, calc-schists, marbles, and occasionally ophiolites. To the south, these tectonic units are separated from the Southern Alps by the EW dextral strike-slip Insubric Line; to the north, they are separated from the European foreland by the Penninic Front, a SW-NE oriented thrust. Other important structures are the Forcola Line, a NW-SE normal fault located at the eastern border of the Lepontine dome, and the Engadine Line, a NE-SW sinistral strike-slip fault located between the Engadine Valley and the Bregaglia Valley (Ciancaleoni, 2005). Quaternary glaciations heavily influenced the topographic evolution of the area, while gravitative processes continuously shaped the valley flanks. The aim of this work is to define the controlling factors on landscape evolution through a combination of field survey and morphometric analysis. Field survey permitted to collect lithological, structural, and geomorphological data at various scale and highlighted the interplay between several factors (e.g. lithological and structural properties, gravitational, fluvial glacial, and karst processes). Morphometric analysis helps in quantifying the evolution of topography and channel network development through various indices, calculated from a DEM ALOS with a 30m resolution, such as the χ-mapping (the calculation is based on the comparison of two channels originating at the same position x and terminating at the same base level xb, A(x) is the drainage area upstream of x, while A0 is a reference area and m/n is the concavity; the χ-mapping highlights drainage migration direction) and the knickpoint detection (a geometric approach based on the comparison of the actual flow profile against an ideal one; knickpoint detection allows to identifies breaks in slope; Diercks et al., 2021). The interpretation of such indices suggests that regional scale-drainage divides migrate northward. This could be tuned by several processes, namely the gravitational ones. At the local scale of the Val San Giacomo and Val Bregaglia valleys the development of the rivers' pattern is primarily controlled by changes in lithology and structures, as evidenced by differences in knickpoints. Applying morphometric analysis validates the methods and supports the data collected during fieldwork, enhancing the interpretation of the role of the main controlling factors on landscape evolution in this portion of the Central Alps.

Ciancaleoni L. (2005) - Deformation processes during the last stages of the continental collision: The brittle-ductile fault systems in the Bergell and Insubric areas (Eastern Central Alps, Switzerland-Italy) (Doctoral dissertation).

Diercks ML. et al. (2021) - Quaternary landscape evolution and tectonics in Central Germany–A case study of the Harz. Geomorphology, 388, 107794, https://doi.org/10.1016/j.geomorph.2021.107794.

Steck A. et al. (2013) - Tectonics of the Lepontine Alps: ductile thrusting and folding in the deepest tectonic levels of the Central Alps. Swiss Journal of Geosciences, 106, 427-450.

Rock avalanche deposits along normal-fault and thrust-fault-related tectonic slopes: new insights from CARG Project surveys in the Majella-Porrara ridges (central-eastern Apennines, Abruzzo Region)

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Keywords: Quaternary continental deposits, geological-geomorphological mapping, rock avalanches.

The morphostructural evolution of the Abruzzi central Apennines chain resulted primarily from widespread tectonic uplift and the formation of tectonic intermontane basins generated by Quaternary normal faults. The chain features tectonic slopes with high energy relief, largely influenced by intensely jointed carbonate rocks and active Quaternary normal faults, predisposing the area to large mass movements such as rock avalanches, mainly during the Pleistocene.

In previous geological maps of the area, rock avalanches were poorly represented or mapped as different lithofacies deposits due to the lack of detailed multidisciplinary studies. In this work, as part of the ongoing Quaternary deposits geological mapping for the CARG Project (Sheets 379 Capracotta and 370 Guardiagrele), several large rock avalanche landforms and deposits were identified through remote and in-field investigations (detailed field surveys, lithofacies analysis, aerial photograph analysis, 1-meter-resolution LiDAR mapping, and morpholitostratigraphic profiles).

The mapped rock avalanches affected the western slope of Majella Mountain - Cretaceous carbonate platform to slope rock facies and Paleogenic carbonate ramp facies, part of a large-scale NNW-SSE plunging anticline - and the eastern/western slopes of Mt. Porrara – high-angle east-dipping sequences of Cretaceous carbonate platform and Cenozoic carbonate ramp rocks, overthrusted onto Miocene arenaceous-pelitic turbidite successions-.

Along the western side of the Mt. Porrara runs a 9 km long N-S striking west-dipping active normal fault system, the Porrara Fault, whose northern segment ends in a highly faulted/jointed zone crossed by NNW-SSE oriented normal faults that border the western slope of the Majella Mountain (i.e., the Caramanico Fault) and NW-SE oriented thrusts (eastern Mt. Porrara thrust zone). Evidence of deep-seated gravitational slope deformations is widespread along the ridges and slopes, often acting as predisposing factors for large-scale mass movements.

The source areas of the rock avalanches often correspond to amphitheatre-shaped scarps that face the slopes. The landslide deposits show different arrangements: from asymmetrical to elongated shape, with surface area up to >6 km2, thickness up to 75-80 m and runout distance from 1 km to >4 km.

This study presents a geological-geomorphological map of the detachment, sliding, and accumulation zones of the rock avalanches, serving as a starting point for a more accurate study and chronological attributions.

Geological mapping of submerged areas withing the CARG project. The example of "Asinara" sheet (n. 425)

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Keywords: geological mapping, CARG, submerged areas.

The Geological Survey of Italy-ISPRA, thanks to the new funding received in the past few years, has resumed the realization of the geological mapping CARG Project, coordinating the Project at national scale. The survey of more than eighty geological sheets at the 1:50,000 scale was started; among them more than twenty maps include submerged areas, two of them (Bracciano and Varese) with lake areas.

The Geological Survey of Italy realizes directly, in collaboration with colleagues of other research institutes and universities, the geological sheets "Torretta Granitola - Pantelleria" and "Isola Asinara", for both the emerged and submerged areas.

According to the 1:50,000 scale CARG guidelines, criteria adopted to characterize units in submerged areas are as much as possible the same used on land. Data in submerged areas are acquired at the 1:25,000 scale, mainly by indirect surveys carried out by geophysical methods, which however have to be groundtruthed by samplings, video inspections or scuba diving.

Geological information to be represented on the maps refer to the surface distribution of the deposits cropping out on the seafloor. Unconsolidated sediments are characterized by age, environmental/depositional systems, grainsize, biogenic and mineralogical content. Rocky outcrops are correlated to their on land counterparts whenever possible; alternatively, they are identified as undetermined rocky substrates according to their seismic characteristics. Additional features represented in the maps are: tectonic elements, morphological features (such as shelfbreak, sandwaves, canyons, gullies) and the main biocenoses (such as phanerogam meadows and bioconstructions) that are relevant from a sedimentological point of view. The thickness of the late-Quaternary depositional sequence is also identified, subdivided where possible into systems tracts (high stand, transgressive, falling stage and low stand).

The study area, comprised in sheet 425 "Isola Asinara", is located in the north-western part of Sardinia. Bathymetric data were obtained by the Hydrographic Institute of the Navy (IIMM) complemented by multibeam surveys performed by the National Institute of Oceanography and Experimental Geophysics (OGS) and the Institute of Marine Sciences of the National Research Council (ISMAR-CNR).

Backscatter data, acquired by the Sassari University, ISMAR-CNR and OGS, were used to identify the distribution of acoustic facies which were successively interpreted on the base of the analysis of several grab samples collected to characterize sediments grainsize. Moreover, seismic-stratigraphic surveys were addressed at investigating the buried substrate; high resolution but low penetrative seismic lines were acquired by a sub bottom profiler, whereas, for the investigation of deeper structures, a sparker source was adopted for the seismic surveys.

Tectonic imprints on Quaternary landscapes: insights from morphometric analysis and new luminescence dating in Southwestern Sicily

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Keywords: landscape evolution, optically stimulated luminescence, crustal deformation.

Despite being shaped by uniform, although variable trough time, climatic forcing, the late Pleistocene coastal landscape of southwestern Sicily between Capo S. Marco and Capo Bianco exhibits significantly different landforms across its various sectors. The western sector features a portion of the Grande Terrazzo Superiore (GTS), a gently sloping Quaternary polycyclic surface extending approximately for a 100 km long stretch of the area. This landform terminates abruptly east of Sciacca, where deeply incised, V-shaped valleys dissect the remnants of a 20 km long flight of late Pleistocene paleoshorelines.

The southwestern coastal sector of Sicily is characterised by a complex segment of the Sicilian Fold and Thrust Belt, located at the collisional boundary between the African and European plates, in the central Mediterranean. This area, characterized by an active Plio-Quaternary frontal fold and thrust system, has been extensively surveyed through the ongoing 1/50k geological mapping of the Foglio n. 628 (CARG Project). This mapping has revealed two distinct orientations of the main thrusts: the roughly N-S trending and W verging blind thrust of the Gela Thrust Front (GTF) and the NNE-SSW and ESE verging thrust outcropping in front of the carbonate ridges San Calogero mountains.

Our study aims to discriminate and differentiate the morphometric signatures of these main thrust systems to understand better their differences and determine which set of structures has most significantly driven the landscape evolution in the area and has been more active in recent history. To achieve this result, we interpret how marine and fluvial geomorphic markers have recorded regional and local tectonic activity across the GTF and the ESE verging thrust systems.

This research utilizes new optically stimulated luminescence ages of the fluvial and marine sediments sampled in the area, which help define the ages of the geomorphological markers extracted using the methodology described by (Parrino et al., 2023). The findings have been integrated into the general seismotectonic setting of the study area. The results of this research are expected to provide new insights into the structural and seismotectonic framework of the area, thereby enhancing our understanding of its complex geodynamic context.

Parrino N. et al. (2023) - Plio-Quaternary Coastal Landscape Evolution of North-Western Sicily (Italy). Journal of Maps, https://doi.org/10.1080/17445647.2022.2159889.

Digital structural analysis from outcrops and VOMs: case studies from Umbria turbiditic successions

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Keywords: digital field mapping, virtual outcrop models, geological map.

The advent of modern technologies in the geosciences has enhanced the development of new advanced methodologies for geological survey. Digital devices equipped with GPS systems allowed to increase the precision of data sampling and cartography of geological elements.

Moreover, photogrammetric techniques from drones and terrestrial laser scanner allowed the construction of Virtual Outcrop Models (VOMs) to integrate fieldwork-based analysis and to provide access to remote outcropping rocks. VOMs are becoming widely used in geological sciences and are the result of recostructions of a 3D object through the analysis of multiple, partly overlapping images of the same outcrop taken from different points of view.

The studied area is located in a part of the Umbria region (Italy), between the NW sector of the Mt.Subasio and the main calcareous ridge of the Umbria Apennines. This area is characterized by wide outcropping turbiditic successions of the Miocenic foredeep (Marnoso-Arenacea Fm.) and by foreland-ramp hemipelagic deposits (Schlier Fm.).

A structural geological survey has been conducted in both physical accessible and inaccessible well exposed outcrops. Fieldwork has been performed by using mostly digital methods, in order to have detailed observations of the studied area.

In accessible outcrops, geological survey has been carried out on FieldMove Pro (from Petroleum Experts Limited) and Strabospot2 (from Kansas University). These two app works on portable devices (tablet and smartphones) equipped with digital clino-compass, that allows to measure georeferenced planar and linear elements.

For inaccessible outcrops, more than 200 partly overlapping photos obtained from drone have been imported into licensed Agisoft Metashape Professional, in order to create the VOMs.

The generated models have been then exported to open-source software Cloudcompare to extract structural data such as bedding and fractures orientation.

Both datasets (from fieldwork and drone) have been analyzed in order to compare the two acquisition methods. Structural data have been obtained by using Steronet 11.

Preliminary results shows that both acquisition methods give similar results. The studied turbiditic sequences, from outcrops and VOMs, shows structures related to the compressional tectonics, that are comparable with the regional field stress that developed the Apennines chain.

We present a section of the geological map with the relative structural and microstructural study that allowed to define the tectonic setting and the deformations of the area of interest.

Fracture network analysis in a polyphasic tectonic framework: the importance to integrate field-based structural data in the era of digital geology (CARG Project 245-Albenga)

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Keywords: poly-deformed rocks, digital outcrop model, slope stability.

The Ligurian Briançonnais represents a key point to unravel the Alpine evolution. Indeed, the Ligurian Alps structure is the result of the staking of paleogeographic domains belonging to a passive margin. The Ligurian Briançonnais represents the innermost portions of the Paleo-European margin. Its intricate framework is interpreted as the result of inherited pre-collisional structures influence and a polyphase deformation (Vanossi et al., 1984; Bonini et al., 2010). The simpler example is the inversion of pre-Alpine normal faults that could be preferentially reactivated as thrust during the collisional stacking (Butler et al., 2006). The polyphasic deformation is characterised by the main thrust and folds development during SW-vergent phase (D1), a subsequent NE-vergent back-thrusting phase (D2) and following faulting phases (D3-D5) (Maino et al., 2013). Moreover, to reconstruct the kinematic evolution of this domain, each structure should be analysed considering the summation of the contribution of overlapping multiple deformation phases, both fragile and ductile, as well as the continuous feedback between pre-existing conditions and changing stress domains. However, how the early fault and fracture network influences the following evolution of brittle structures is poorly quantified. Close to Finale Ligure (Mt. Caparazoppa), a tectonic element part of the Castelvecchio-Cerisola unit, displays a km-sized recumbent fold characterised by a curvilinear fold axis resulting in a sheath-like fold morphology. These structure records fold imputable to the D2 phase too and it is unconformably covered by post-collisional deposits of Pietra di Finale formation. This peculiar fold is an ideal place where to study the influence of the early deformation features (folds and faults/fractures) on the development of the following stages.

The aim of the research is to understand if (and how) the early fracture sets, associated with the first folding phases (D1), control the development of the successive fracture orientation. A classic field-based structural investigation has been coupled with the analysis of an Unmanned Aerial Vehicle (UAV)-based Digital Outcrop Model (DOM). The dataset is large and provides a statistically sounding definition of fracture sets, the variation in orientation of which correlates with the different structural locations throughout the fold 3D geometry. We highlight the importance to integrate the digital workflow with a fully comprehensive field-based characterization of the local litho-stratigraphic and structural setting to prevent misusing of the opportunity to treat large amounts of data with partially automated procedures.

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Butler R.W.H. et al. (2006) - Structural inheritance in mountain belts: An Alpine-Apennine perspective. Journal of Structural Geology, 28, 1893-1908.

Maino M. et al. (2013) - Tectono-sedimentary evolution of the Tertiary Piedmont Basin (NW Italy) within the Oligo–Miocene central Mediterranean geodynamics. Tectonics, 32, 593-619.

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The medium- to high-grade metamorphic basements of NW Sardinia: the example of the Sheet n. 425 "Isola Asinara"

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Keywords: geological map, Variscan basement, CARG Project.

The Asinara Island (NW Sardinia) represents an area where it is possible to investigate the medium- to high-grade metamorphic basement which formed the inner part of the Variscan orogen and a km-scale transpressive shear zone, *i.e.* the Posada-Asinara shear zone, that drove the exhumation of the metamorphic core of the belt (Carosi & Oggiano, 2002). Even though Asinara island offers good exposure of the main tectonic units building up the Sardinian Variscan belt, because of the former limitation of access that lasted for many years, only recently structural-geological map of the island was made (Carosi et al., 2024).

The island falls in the area covered by the geological sheet "424 - Isola Asinara" of the CARG Project. The sheet, currently under production, is based on existing data integrated with a new detailed survey. It offers the opportunity to test the modern approach and standards to map crystalline basements suggested by the new project normative (Simonetti et al., 2022) provided by the Italian Geological Survey. This basement is characterized by two tectono-metamorphic units, *i.e.* the Medium- and High-Grade Metamorphic Complex (Carosi et al., 2004), and three intrusive units, *i.e.* the Castellaccio and Punta Sabina intrusive unit and sheeted dykes complex.

The Medium-Grade Metamorphic Complex consists of i) albite/oligoclase bearing micaschist; ii) garnet and staurolite bearing micaschist; iii) quartzite; iv) amphibolite; v) Cala Reale orthogneiss; vi) sillimanite bearing micaschist.

The High-Grade Metamorphic Complex consists in i) mylonitic sillimanite bearing micaschist; ii) Cala d'Oliva ortogneiss; iii) amphibolite, and iv) migmatite.

The two complexes are separated by the Posada-Asinara Shear Zone that, in agreement with the new normative of the CARG project, was mapped taking into account the occurrence of both high-grade metamorphism (appearance of sillimanite) and evidence of non-coaxial deformation.

The Castellaccio Intrusive Unit consists of inequigranular granodiorite-monzogranite characterised by large laths of K-feldspar, which often define a magmatic foliation. The Punta Sabina Intrusive Unit consists of peraluminous granitoid with stromatic enclaves, and finally, the sheeted dykes complex consists of peraluminous micro-leucogranite and pegmatite from decimetric to plurimetric thickness. From a structural point of view, four ductile deformation phases are recognized (Carosi et al., 2004): i) D1 is locally preserved and the S1 is visible in D2 hinges; ii) D2 is the most pervasive deformation phase and S2 is the main foliation that progressively becomes a mylonitic foliation approaching the Posada-Asinara shear zone (Carosi et al., 2004); iii) D3 is weak and produces upright folds, mainly developed in the central and northern parts of the island; iv) D4 is associated with a sub-horizontal crenulation cleavage.

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Inheritance of pre-orogenic faults in Miocene foredeep evolution in Southern Apennines, Italy

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Keywords: Southern Apennines, foreland basin systems, CARG project.

Foreland basin systems can be characterized by a rather intricate paleogeography especially those developing oblique to the main orogenic front. The morphologic complexity of such a "broken" foreland system is due to the reactivation of pre-existing tectonic structures, leading to a mosaic of topographic and bathymetric highs and lows. Such a configuration causes the compartmentalization of sedimentary pathways and depositional areas within the foredeep on short to very short distances. We here document how the Cenozoic reworking of Late Cretaceous normal faults fragmented the subsidence of the Southern Apennines foreland system in the Alburni Mountains, leading to strong local sedimentary facies variations and erosional features. The whole Alburni area was mapped as part of the CARG project (Sheet 487 "Roccadaspide"). In this carbonate platform carbonate massif, the synorogenic drowning succession does not conform to the typical one characterizing the associated Alburni-Cervati-Pollino tectonic unit, elsewhere in the region. Calcareous breccia unconformably crops out atop the Late Cretaceous platform, likely representing epi-breccia deposits while the Eocene platform carbonates of the Trentinara Formation are barely present, often replaced by outer margin and ramp calcarenites. The Early Miocene Roccadaspide and Bifurto formations are lacking whilst coeval deeper basinal marls and cherty calcilutites, fill small scattered depocenters few hundreds to kilometers apart. These laterally and vertically discontinuous sequences are blanketed by a matrix-supported polymictic conglomerate with a yellowish calcareous matrix and successively covered by Middle/Late Miocene deposits containing large crystalline rounded blocks, possibly deposited in an alluvial to coastal environment. This complex deposition environment discontinuously developed since the Cretaceous-Paleogene boundary as suggested by the first calcareous monomictic breccia only containing Late Cretaceous clasts. The unconformable contact between the Late Cretaceous platform and the epi-breccia is sharp as well as the boundary with the overlying Miocene basin-fill succession which is also marked by the occurrence of a diagenetic overprint of cherty nodules and oxidized crusts right onto the paleo-escarpment surface. These paleo-escarpments developed as the outcome of extensional tectonics since the Early Paleogene and were revitalized when the migrating foreland-related subsidence reached the area in the Early Miocene leading to further deepening of the succession

Rosso Ammonitico Veronese (Bajocian - Tithonian, Jurassic) from the Trento Platform to the Belluno Basin: can we really map it?

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Keywords: Jurassic, Southern Alps, Rosso Ammonitico.

The Venetian Prealps were marginally involved in the rifting stage of the Piedmont-Ligurian ocean during the Early Jurassic, and then were part of a passive margin during the Middle-Late Jurassic. The near 100 km wide region between Lake Garda and the western Grappa Massif was part of a structural high and shallow water carbonate platform known as "Trento Platform", while from the eastern Grappa Massif to the Cansiglio Plateau, a ca. 50 km wide deep water basin existed (Belluno Basin: e.g., Winterer & Bosellini, 1981).

The Jurassic Trento Platform drowned near the end of the Early Jurassic; above, the renowned <50 m thick Rosso Ammonitico Veronese formation, ARV, covers a time span from the Bajocian to the Tithonian, with several long hiatuses in between (Martire et al., 2006). Meanwhile, in the Belluno Basin, a >= 600 m thick succession deposited, made of oolitic calciturbidites (Vajont Oolitic Limestone, **OOV**) and micritic limestones with chert and minor clay (Fonzaso Formation, FOZ).

This lithostratigraphic framework is the result of centuries of studies, and hence, it should result in a stable and undisputed nomenclature. With the geological sheet 063 Belluno (1992), it was found however that above the Fonzaso Formation, the Rosso Ammonitico is atypical, being gray rather than red, having nodules of chert and yielding little or no ammonites. It was noted that east of the mapped area, the two units could not be separated, and may belong to a unified unit called Soccher Formation. The transition between Fonzaso and Rosso Ammonitico Veronese formations on the west, and Soccher Formation on the East, was left unresolved. The name "Soccher" (SOC) has been recently reinstated in the CARG sheet 046 Longarone but with a different meaning respect the original definition, standing for a variegated unit above ARV and encompassing a Tithonian p.p. - Santonian interval.

We present a ca. 50 km long transect of Bajocian - Tithonian carbonate units cropping out from the top of the Grappa Massif to the deepest part of the Belluno Basin, highlighting how the nomenclatural confusion between Fonzaso Formation and Rosso Ammonitico Veronese is still not resolved enough for mapping according to CARG standards. We propose a new lithostratigraphic framework that makes sense of Jurassic nomenclature in this critical portion of the Alps. Less studied intervals may hide even more convoluted problems, which might take most of the lifecycle of a geological sheet production to be disentangled. We advocate an action to frame - if not resolve - lithostratigraphic and nomenclatural issues before - and not during - the mapping of geological sheets, otherwise the consistency of adjacent maps is unlikely to be maintained.

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3D reconstruction of an integrated onshore/offshore geological model: the example of geological sheet 628 Sciacca (Southwestern Sicily)

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Keywords: 3D geological model, Sheet 628 Sciacca, CARG project.

The CARG project allowed to collect new useful multidisciplinary data for the reconstruction of subsurface geological model. For the Sciacca area (Sheet 628) data from geological survey (collected through advanced digital tools and processed through FieldMOVE) were used to reconstruct the geological map at 1:50,000 scale from which the geological sections of the onshore sector were reconstructed. The obtained data were integrated with those derived from seismo-stratigraphic and structural interpretation of 2D seismic reflection profiles, collected from both from public and non-databases of submarine regions, calibrated with stratigraphic well-logs provided by ISPRA. By working in a combined 2D/3D environment, data as surfaces and lines (from 2D seismic interpretation) were cross-checked with dedicated software to ensure that all interpretations were consistent. Depth conversion have been performed using velocities derived from sonic well-logs and literature data to identify the correct geometries and thicknesses of the layers in depth (m) interpreted in time domain (TWT).

The integration of multidisciplinary data was challenging to obtain a continuous interpretation from onshore to offshore sector. The major stratigraphic levels and the tectonic surfaces affecting them were represented in a 3D view with the aim of determining the large-scale structural framework, joining the onshore and offshore sectors interpretation. The combined onshore/offshore geological reconstruction was also used to depicts the isolines of the main stratigraphic/structural layers derived from 3D surfaces.

Field data restitution and 3D map visualizations are essential for understanding the development of the geometries of fundamental structures in depth. Such data are a key tool for proper geological information restitution that ensures both development and environmental sustainability at the same time. A well-defined subsurface geological model, guided by geological reasoning, provides the key tools to identify, characterize and manage georisks and georesources.

Field preliminary data to reconstruct the tectono-stratigraphic evolution of the Mt. di Muccia-Mt. Val di Fibbia area (Northern Apennines, Italy)

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Keywords: geological surveys, structural analysis, resedimented shallow water deposits.

We carried out a critical review of the previous geological maps, new detailed geological surveys, sedimentological and biostratigraphic studies, combined structural analysis of the main tectonic lineament in the Mt. di Muccia-Mt. Val di Fibbia area. It extends for about 150 km2 in the SW sector of the sheet 313 "Camerino" (still in progress) within the National Geological Map of Italy Project, at 1:50.000 scale (CARG Project; https://www.isprambiente.gov.it/Media/carg/index.html). The area is located in the Umbria-Marche Apennines, the external sector of the Northern Apennines, which is a thrust and folds NE verging belt, resulting from Neogene deformation related to the convergence of the African-Adria and European continental margins.

The outcropping Late Jurassic-Late Miocene lithostratigraphic units are part of the thick calcareous-marly siliceous pelagic succession of the Umbria-Marche Basin, and are characterized by resedimented shallow-water deposits derived from the Latium-Abruzzo Carbonate Platform.

In the mapped Cretaceous-Neogene lithostratigraphic units, we observed great variations in thickness, even over short distances, and variations in the presence, abundance, and composition of resedimented shallow water deposits. which are not closely related to each other. This suggests an articulation of the palaeotopography of the basin, probably related to tectonic events.

Our studies provide preliminary constrains to reconstruct the tectono-stratigraphic evolution of this sector of the chain.

Jurassic evolution and paleogeography of the Fiastrone gorge (Marche, Italy): new data from detailed geological mapping

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Keywords: Jurassic, Sibillini Mts., Apennines.

A new geological mapping project at 1:10,000 scale allowed to re-interpretate the geological evolution of the Fiastrone gorge. The study area is located in the Marchean ridge, one of the most external structural elements of the Northern Apennines, where the Meso-Cenozoic rocks of the Umbria-Marche sedimentary succession crop out. Sedimentation of this succession was strongly influenced by the complex paleogeography derived from the Early Jurassic rifting of Western Tethys. At the eastern end of the Fiastrone gorge, a portion of the Sibillini Mts. Thrust spectacularly crops out. Here, the Calcare Massiccio overthrusts the Scaglia Cinerea with the interposition of Maiolica and Scaglia Rossa duplexes. Over the years, most authors have interpreted the study area as a Jurassic structural high covered by a condensed pelagic succession represented by the Bugarone Group, in tectonic contact with younger Jurassic units. New field data revealed that the contact between the Calcare Massiccio and the overlying Jurassic units coincides with a complex unconformity, and no horst block-top condensed units occur in the area. Exceptions are represented by rare, scattered patches of condensed epi-escarpment deposits. The unconformity surface is marked by pervasive silicification of the Calcare Massiccio, due to silica-rich fluids circulation provided by the siliceous basinal pelagic units, and by the centrifugal attitude of the pelagic beds abutting the onlap surface as a result of differential compaction. The youngest Jurassic unit onlapping and burying the Calcare Massiccio is the Bajocian-Kimmeridgian Calcari Diasprigni, which means that this structural high was less elevated than the main highs in the UMS domain (commonly buried by the Lower Cretaceous Maiolica). The Fiastrone Jurassic high describes a cusp-shaped geometry rather than a flat-topped pelagic carbonate platform. Pre-orogenic, post-Jurassic (since they also cut the Maiolica and Scaglia Rossa), faults with limited throw (cumulatively about 100 m), have lowered some portions of this high towards the west, and are cut by the Sibillini Mts. Thrust. At present, the Fiastrone High is in hanging wall ramp with respect to the Miocene thrust and the paleotectonic reconstruction of this Jurassic horst-block, coupled with the analysis of geometrical relationships between Tethyan inheritances and compressive deformations, permitted to infer that the Sibillini Mts. Thrust may have reactivated a paleostructure, potentially a Jurassic domino fault bounding a wider Jurassic high to the east in present-day coordinates (now at the footwall of the thrust).

A previously unknown loess deposit in the Quaternary Gubbio basin (Umbria, central Italy): a stratigraphical record of the paleoenvironment of the area

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Keywords: Gubbio basin, Loess, Quaternary deposits.

Recent mapping and description of the basin-fill of the Gubbio intermontane basin (Umbria, central Italy) has identified a weathered, decimeter-thick, fine-grained, ochre-colored deposit that mantles ridges in the southern and northern, incised portion of the basin that we interpret as a late Pleistocene loess. These deposits lie directly on the middle Pleistocene (?) clay unit of the basin infill, which is particularly enriched in Fe-Mn concretions near the topographic surface. Grain size analyses returned a predominant percentage in silt (> 65%) and the total absence of gravels. Analyses with a scanning electron microscope (SEM) and energy-dispersive X-ray spectroscopy (EDS) were conducted to determine the textural and chemical characteristics of the samples, showing the presence of poorly rounded granules and silica as the predominant element (quartz granules). These results, in conjunction with the extensive areal distribution observed in the Gubbio basin, suggest that these deposits may be associated with aeolian processes, as a wind-transported deposits that might does not undergo abrasive processes (Liu et al., 2006). The sources of these deposits can be multiple, including glaciofluvial deposits, fluvial deposits (dry riverbeds), local silty sediments from bare slopes in hilly lands, and Saharan dust (Costantini et al., 2018). In central Italy, loess deposition is documented during the glacial and stadial periods of the late Pleistocene, which occurred between approximately 70 and 35 kyr BP (Cremaschi et al., 2014). The distribution of this loess, with pending luminescence ages, is emerging as a key stratigraphic interval that helps us construct a regional age model for the deposits that constrains both the tectonic subsidence history of the basin and drainage integration through this part of the northern Apennines.

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Liu J. et al. (2006) - Eolian origin of the Miocene loess-soil sequence at Qin'an, China: Evidence of quartz morphology and quartz grain-size. Chinese Science Bulletin, 51, 117-120.

Late Pleistocene eustatic variations and fluvial terrace development in the Carboj River catchment, Southern Sicily

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Keywords: luminescence dating, fluvial-marine terraces, eustatic variations.

We present a comprehensive chronological framework of a flight of marine and river terraces, derived from integrated luminescence dating and geomorphological, sedimentological, and stratigraphical analyses in the Foglio n. 628 “Sciacca”, surveyed during the ongoing 1/50k geological mapping CARG Project (southern Italy, central Mediterranean Sea). The optical luminescence dating of the river terraces, belonging to the Carboj R. drainage network, revealed a correlation between late Pleistocene eustatic sea-level fluctuations and fluvial aggradation and incision phases (Erturaç et al., 2019). Our results indicate that the fluvial incision of the Marine Isotope Stage (MIS) 7 marine terrace, which began during MIS 6, resulted in the subsequent formation of a series of fluvial terraces in the Carboj River channel network between 146-134 ka. This process extended to the lower reaches of the trunk stream until about 120 ka. The terraces formed during this time interval exhibit varying stream power levels, as evidenced by an alternation of nested sedimentary deposits. These range from high-energy, matrix-supported gravels to low-energy fine and coarse sands, showing at least two transitions between marine and continental environments (Antoine et al., 2000; Blum & Törnqvist, 2000). The presented data highlight, for the first time in Western Sicily, the presence of sea inlets within today’s river valleys and that the sediment flux and terrace development were primarily driven by episodic small-amplitude eustatic sea-level oscillations, and by a tectonic controlled regional lowering of the base level that significantly forced the Late Quaternary landscape evolution of this Sicilian coastal sector.

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From onshore to offshore, from outcrop to subsurface: an innovative multi-scale approach to the geological mapping of the Sheet 628 Sciacca (southwestern Sicily)

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Keywords: Sheet 628 SCIACCA, subsurface, offshore.

The Sheet 628 "Sciacca" is located in an onshore-offshore sector of SW Sicily where the external segment of the Sicilian Fold andthrust belt- develops. This Sheet is composed by 1:50.000 geological and subsurface maps and a 3D geological model, obtained by field survey in the onshore sector and seismoacoustic investigation in the offshore sector.

The data collected during the marine and field survey, integrated with the subsurface data coming from the interpretation of wells and multi-channel seismic profiles made available by ENI S.p.a, have made it possible to reconstruct the 3D geological model up to the depth of 4 km by correlating the emerged with the submerged sector, as well as the kinematics and chronology of the main deformation events that affected this region.

The Lower Jurassic-Pleistocene successions were studied with stratigraphic, sedimentological and palaeontological methods: the latter allowed for an accurate dating of the lithostratigraphic units, which for the late Quaternary deposits was integrated by absolute dating with OSL methodology.

In the western outcropping-sector and south-western offshore areas, a Meso-Cenozoic shallow to deep water carbonate succession (locally named Saccense) crops-out and it is covered by Neogene-Quaternary syntectonic deposits.In the north-easternsector, a Meso-Cenozoic deep water carbonate succession (known as Sicanian) crops-out.In the eastern and south-eastern sectors deformed Neogene syntectonic deposits (Gela Thrust Wedge) are covered by Upper Pliocene - Lower Pleistocene syntectonic terrigenous deposits.

The tectono-sedimentary analysis highlighted a multi-stage tectonic evolution, characterized by: a):- a Meso-Cenozoic extensional tectonics responsible for the formation of thick slope deposits, cropping-out along the southern slope of the main carbonate reliefs; b)- a Messinian compressional event during which the Eocene-Oligocene portion of the Saccense succession was shortened and detached from its Mesozoic carbonate substrate; c)

- a Late Pliocene-Early Pleistocene compressional event, during which low- and high-angle thrusts were responsible for the exhumation of the main carbonate reliefs and for the building of the Gela Thrust Wedge; d)

- a post-Early Pleistocene compressional-transpressional event, responsible for the activation of the two most important tectonic lineaments recognized in the Sheet: (i) the NNE-SSW-oriented, left-lateral transpressive fault that develops across the Sheet, displaying a southward continuity in the offshore; (ii) the northern dipping thrust, bounding the carbonate reliefs in the northern sector of the Sheet.

Both tectonic structures allowed for the overthrust of the Meso-cenozoic carbonate tectonic units (Sicanian and Saccense) on the Gela Thrust Wedge.

The small-scale problem: loss of significant geological features in small scale geological maps. The case of the northern sector of the Murgia Materana, South Italy

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Keywords: geological maps, Murgia Materana, CARG project.

In this work we compared 1:5.000 scale geological map of the northern sector of the Murgia Materana with three geological maps of the same area at a much smaller scale: the 1:25.000 scale geological maps presented by Radina (1973) and the sheets 187 "Altamura" (Servizio Geologico d'Italia, 1968) and 201 "Matera" (Servizio Geologico d'Italia, 1971) of the Geological Map of Italy at a 1:100,000 scale.

The comparison clearly shows the need of several simplifications, such as:

The grouping of different informal units, recognised by Festa et al. (2018) within the Calcare di Altamura Fm (Senonian), in only one informal member, named "Matera Member" by the same authors. This leads to the loss of the different facies and environmental significance of each single unit within the member;

The mapping of only main structural features, which leads to the loss of information about the relations between smaller, but not less important, tectonic structures outcropping in the area;

The tracing of the boulders between the Calcarenite di Gravina Fm (Late Pliocene – Early Pleistocene) and the Calcare di Altamura Fm can-not be very detailed, leading to the loss of information in small boundaries zone of specific significance.

The problem of the scale of "small" units, structures and contacts in the Matera area deserves special attention, especially in view of mapping of the Sheet 472 "Matera" of the Geological Map of Italy at 1:50.000 scale (CARG Project). In fact, the adoption of the above simplifications prevents the mapping of all the features that can lead to fundamental interpretations on the geological evolution and environment development of the area (e.g. the intraplatform basin in the Calcare di Altamura Fm and the relations between his evolution and the tectonic contest). This means that the adoption of a large scale implies a loss of relevant features that are fundamental to reconstruct the geological evolution of the area.

Festa V. et al. (2018) - 1:5.000 geological map of the upper Cretaceous intraplatform-basin succession in the "Gravina di Matera" canyon (Apulia Carbonate Platform, Basilicata, southern Italy). Ital. J. Geosci., 137(1), 1-13, https://doi.org/10.3301/IJG.2017.12.

Radina B. (1973) - Saggio e note illustrative di una carta geologico tecnica (Tav. 189 III SE "Matera Nord"). Geologia Applicata e Idrogeologia, Vol. VIII, pt. II, Bari.

Servizio Geologico d'Italia (1968) - Carta Geologica d'Italia alla scala 1:100.000, F. 187 Altamura. ISPRA, Roma.

Servizio Geologico d'Italia (1971) - Carta Geologica d'Italia alla scala 1:100.000, F. 201 Matera. ISPRA, Roma.

Sheet 158 "Casale Monferrato"of the Geological Map of Italy at 1:50.000 scale (CARG Project): preliminary results

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Keywords: CARG, geological mapping, sedimentary geology.

Field work for the realization of Sheet 158, "Casale Monferrato," of the Geological Map of Italy (CARG Project), started in winter 2024. The sheet is located in the eastern part of Monferrato, one of the tectono-sedimentary domains that compose the Tertiary Piedmont Basin. This domain is made up of an upper Eocene to Pliocene succession that unconformably overlies a lower-middle Eocene calcareous flysch known as the Casale Monferrato Formation of the External Ligurian Units. The succession has been divided into 4 unconformity-bounded stratigraphic units (UBSU), which are delimited at the bottom and top by regional-scale unconformity surfaces. The criteria used to identify these surfaces in the field include the erosional truncation of underlying strata and the vertical superposition of sedimentary facies, in contrast to Walther's rule.

The first UBSU consists of the hemipelagic marls of the Monte Piano Formation (Upper Eocene). Locally, thick beds of bioclastic turbidites, which record the dismantling of a shallow water carbonate platform, were observed. The Monte Piano Formation is sharply overlain by fan delta conglomerates and shelfal sandstones and mudstones of the Cardona Formation (Rupelian). These are, in turn, overlain by slope marls of the Antognola Formation (Chattian-Aquitanian). These sediments make up the second UBSU, which is strongly deformed by approximately west-northwest-striking transpressive faults. These faults are overlain by a prominent angular unconformity that marks the base of the third UBSU. The third UBSU consists of Burdigalian to Serravallian carbonate ramp deposits and hemipelagic marls, namely the Pietra da Cantoni and Mincengo Formations. These sediments are gently deformed at a regional scale by east-west-directed open folds. The lateral and vertical stacking pattern of these formations suggests a westward deepening of the ramp and a transgressive trend leading to the drowning of inner ramp sediments, which are composed of rodhalgal carbonates.

The fourth UBSU is delimited at the base by another angular unconformity, overlain by Tortonian-Lower Messinian hemipelagic fine-grained sediments of the Sant'Agata Fossili Marls. This unit is followed by sulfate evaporites of the

Vena del Gesso Formation, which record the onset and development of the Messinian salinity crisis. These evaporites consist of primary bottom-grown gypsum beds interbedded with shales, as observed in the nearby Moncalvo gypsum quarry. The end of the Messinian salinity crisis is finally recorded by Zanclean marine marls of the Argille Azzurre Formation, which grade upwards to inner shelf sandstone of the Sabbie di Asti Formation.

Future work will focus on more detailed stratigraphic, sedimentological, and structural analyses aimed at reconstructing the tectono-sedimentary evolution of this sector of the Tertiary Piedmont Basin.

S13.

Geomorphology in the Anthropocene: from human-landscape interaction to geoheritage and geohazard management issues

CONVENERS & CHAIRPERSONS

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Geomorphological evolution and activity of some large earthflows in southern Italy

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Keywords: earthflows, gullies, state of activity.

This study presents an analysis of the state of activity of fourteen earthflows in the Southern Apennines of Italy, located in Campania, Basilicata, Calabria, Molise, and Abruzzo regions, with the aim of elucidating how earthflows respond to change in rainfall regimes and sediment availability (i.e. distance from watershed). These events, generally occurring within silt- and clay-rich structurally complex formations (examples are the Varicoloured clay, San Bartolomeo flysch, or Faeto flysch formations), have been selected because of their significant size, typical hourglass-shaped form with an amphitheater-like source zone, an elongate narrow transport zone, and a lobate depositional area and the availability of previous data about evolution and activity (in a number of cases). Employing a combination of high-resolution satellite imagery from Google Earth Pro and aerial photographs from Terraitaly, a comprehensive analysis of the geomorphological evolution of each earthflow was conducted for the last 20 years. Such analysis was based on the visual interpretation of historical imagery to discern morphological elements indicating earthflow boundaries and terrain features indicating their state of activity (ordinary active, extraordinary active, suspended, and dormant). Starting from the reference earthflow evolution model of Mackey & Roering (2011), elements such as crowns, scar zones, scarps, pressure ridges, flank ridges, shear surfaces, backtilted surfaces, ponds, gullies, lobate compressional deposits and watershed were considered for the analysis. Distribution of such elements were used for identifing earthflow areas and their state of activity, as well as duration of activity phases, including the identification of the occurrence and eventually the number of paroxysmal/surging reactivations (extraordinary activity). In this sense, the temporal persistence of the axial gully was used as a proxy of the duration of the suspended/dormant phases, often interspersed between the extraordinary and ordinary activity phases. Understanding the interconnectedness of gullies and earthflows is crucial for assessing landscape stability, erosion processes, and earthflow evolution. To supplement the analysis, rainfall data from stations nearest to the selected earthflows has been acquired and analysed to identify potential correlations between the activation of earthflows and hydrologic forcing. The occurrence of surges in relation to sediment availability in the form of distance between earthflow crown and main watershed was also analysed. The results of this study provide a comprehensive overview of the activity of earthflows in the Southern Apennines, contributing to the understanding of underlying geomorphological processes and the assessment of associated hazard. The analysis highlighted a diversification in the kinematic behaviour of the events, some of them characterized by a long period of quiescence (with the well-recognizable development of axial gullies) and others characterized by alternation of active and inactive phases (thus characterized by the formation and obliteration of axial gullies). Additionally, some earthflows have remained mostly active with a total absence of axial gullies. The conducted analyses allowed verifying how a significant portion of landslides exhibited a decrease in activity (highlighted by the persistence of axial gullies) in the last decade and emphasized the importance of rainfall in this context.

Mackey B.H. & Roering J.J. (2011) - Sediment yield, spatial characteristics, and the long-term evolution of active earthflows determined from airborne LiDAR and historical aerial photographs, Eel River, California. Bulletin, 123(7/8), 1560-1576, https://doi.org/10.1130/B30306.1.

The Derna dam collapse erased a century of urban sprawl

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Keywords: urban geomorphology, hazard, remote-sensing.

Between September the 10th and 11th 2023, the heavy rainfall brought over North Africa by the storm Daniel triggered the failure of two dams in northeastern Libya, resulting in the accelerated discharge of 30 million m3 of water and debris. The flood destroyed a large part of the city of Derna and caused more than 10000 fatalities and the displacement of thousands of people from their homes. Here, we present the geomorphological interpretation of the effects of such calamitous event whose effects were increased by the Derna urban sprawl occurred in the last century. Our geomorphological assessment is based on the analyses of old cartographic sources, allowing the reconstruction of the evolution of the settlement of Derna, and high-resolution remote-sensing data. The latter permitted to assess the general settings of the local drainage system and the geomorphological effects of the event, also quantifying the volume of transported sediments through DEM of Difference analysis. Our analysis suggests that the effect of the flood was strictly connected to the urban sprawl and the destruction mainly affected the more recent areas of urban expansion.

Distinguishing between Medicanes and common seasonal storms using microseism

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Keywords: microseism, Medicane, climate change.

Microseisms, the most continuous and ubiquitous seismic signal on the Earth resulting from interactions among the hydrosphere, atmosphere, and solid Earth, can be used as an indicator for understanding climate change. Numerous studies have explored the connection between microseisms and sea conditions, as well as cyclonic activities, focusing particularly on tropical cyclones, hurricanes, typhoons, and the more recent Medicanes (small-scale tropical cyclones in the Mediterranean Sea). In this work, we explored various meteorological events occurring in the Mediterranean Sea between November 2011 and February 2023 from a seismic point of view. Specifically, we investigate nine Medicanes and four more common seasonal storms. Despite their distinct characteristics, all these events led to intense rainfall, powerful wind gusts, severe storm surges with significant wave heights typically exceeding 3 meters, and damage along the exposed coastal areas. Some of these events also resulted in fatalities and injuries.

We analyzed the seismic data acquired from 104 stations installed along the coasts of Italy, Malta, Greece, and France, as well as 15 stations in the Etna area, primarily used for array analysis. Our analysis focuses on the correlations between the meteorological events and microseism features in terms of spectral characteristics, spatiotemporal amplitude variations, and source locations identified using two methods: a grid search based on seismic amplitude decay and array techniques. Comparing the microseism source locations from our study with storm surge areas from hindcast data, we found an agreement for 10 out of 12 events analyzed (two Medicanes show low meteorological features, and the microseism amplitude remained relatively stable).

Furthermore, we conducted two analyses to obtain the seismic signatures of these events using a method that exploits continuous seismic noise coherence and a measure termed Microseism Reduced Amplitude to assess their seismic intensity. By combining insights from these approaches, we can distinguish between Medicanes and more common seasonal storms based on seismic data. This highlights the potential for developing a novel monitoring system for Mediterranean meteorological events by integrating microseism data with other commonly used techniques like wave buoys and HF radar. Additionally, given that seismometers were among the earliest geophysical instruments deployed, digitizing old seismograms and analyzing historical data could offer new perspectives on extreme weather events within the context of climate change.

Geoheritage along the high rocky coast of Eastern Liguria: an emblematic case of interaction between natural hazard and human impact

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Keywords: geomorphological risk, anthropogenic impact, coastal areas.

As part of research on the geoheritage of the Ligurian coast and the assessment of the impact/risk resulting from settlements and infrastructure, the main aspects related to the dynamics of the rocky coast between Marina di Bardi in the municipality of Zoagli and the Tigullio Rock locality in the municipality of Chiavari, in the eastern sector of the Metropolitan City of Genoa, are presented.

In light of its great environmental and natural value, the area is included in the Natura 2000 network and includes, in the terrestrial part, the Sites of Community Interest (SIC) "Pineta Lecceta di Chiavari" and "Rio Tuja Montallegro"; in the seaward sector, it includes the SIC "Fondali Golfo di Rapallo," split into further subsites corresponding to remnants of a vast Posidonia Oceanica meadow. For its cultural and landscape value this stretch of coast also is included in the preliminary perimeter of the Portofino National Park, which has in its geological and geomorphological heritage one of its strengths.

This stretch of rocky coast, developed for about 3 km in the central-western sector of the Gulf of Tigullio, represents a significant example of geomorphological evolution of a coastal slope shaped in the limestone-marly flysch and affected by natural hazard due to marine, slope and running water processes and a high vulnerability related to buildings and infrastructure, from which significant geomorphological risk scenarios are derived (Brandolini et al., 2009).

Natural hazards seem to show an increase in frequency in recent decades partly due to climate change evidenced by an increase in mean annual air temperature, a change in rainfall patterns (Faccini et al., 2017), and an intensification of sea storm surges.

In this territorial context, the relationship between geomorphological hazards, related to cliff retreat phenomena and slope gravitational processes (De Vita et al., 2012), and tourist and residential settlements, road infrastructure (railways, roads and footpaths) and bathing areas, which have had significant expansion in high hazard areas over the past decades, have been analyzed and investigated in depth.

Brandolini P. et al. (2009) - Dinamica geomorfologica della costa alta rocciosa e valutazione del rischio geo-ambientale nel Golfo del Tigullio (Riviera di Levante, Liguria). In: P. Coratza, M. Panizza (Eds), Il Patrimonio geomorfologico come risorsa per un turismo sostenibile, SAP Società Archeologica s.r.l. Mantova, 49-66, ISBN 978-88-87115-64-2.

De Vita P. et al., (2012) - Detailed rock failure susceptibility mapping in steep rocky coasts by means of non-contact geostructural surveys: the case study of the Tigullio Gulf (Eastern Liguria, Northern Italy). Nat. Hazards Earth Syst. Sci., 12, 867-880, https://doi.org/10.5194/nhess-12-867-2012.

Faccini F. et al., (2017) - Heavy rains triggering flash floods in urban environment: a case from Chiavari (Genoa metropolitan area, Italy). Italian Journal of Engineering Geology and Environment, 51-66, https://doi.org/10.4408/IJEGE.2017-01.S-05.

Evaluating the effectiveness of "River Morphodynamic Corridors" for flood hazard mapping: insights from an application in the Cordevole River catchment (Italy)

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Keywords: channel dynamics, alluvial plain, Vaia Storm.

In dynamic rivers the assessment of flood hazard related to geomorphological dynamics assumes crucial importance. Recently, some geomorphological approaches have been developed to assess channel dynamics in response to floods. In this study we explore the River Morphodynamic Corridors, which can be defined as planform domains that include the current active channel and portions of the adjacent alluvial plain that have been or may be affected in the future by its lateral dynamics (Rinaldi et al., 2015). The procedure for the delineation of the morphodynamic corridors includes: (i) reconstruction of historical planform positions of the active channels; (ii) definition of potential future erosion on the basis of the mean rate of bank retreat; (iii) delineation of the alluvial plain by identification of natural elements of confinement; (iv) identification of structures preventing lateral channel mobility. These procedures involve the use of remote sensing imagery, historical maps, digital terrain models and field surveys.

In order to assess the effectiveness of such corridors for mapping flood hazard, we delineated the morphodynamic corridors along a river network of 74 km in the Cordevole River catchment (Italy) and compared the corridors with the channel changes that were triggered by a high-magnitude event (Vaia Storm) that hit the study area in October 2018. We observed that the morphodynamic corridors are capable to define areas where localized channel dynamics are most likely to occur and have proven satisfactorily effective in predicting abrupt channel widenings triggered by a severe flood. The results show that it is crucial to adopt different procedures for corridor delineation based on channel width, i.e., for small streams (width < 30 m) a more precautionary approach should be adopted that considers the entire alluvial plain as an area potentially affected by channel dynamics. The study also highlighted an inherent limitation of the approach, since erosion that can affect valley slopes or fluvial terraces (i.e., widening of the alluvial plain) is not taken into account.

This application represents the first extensive validation of the River Morphodynamic Corridors approach by comparison with geomorphic effects produced by a large flood event. Through this analysis, it can be inferred that, notwithstanding its relatively simple procedure, the approach allows a robust mapping and delineation of flood hazard due to river channel dynamics. The River Morphodynamic Corridors, when applied jointly with traditional hydraulic model for assessing inundation processes, allow an overall assessment of flood hazard, particularly in dynamic river contexts. Given the effectiveness of such geomorphological tools, their use should be widely adopted by competent agencies for an effective territorial planning and management.

Rinaldi M. et al. (2015) - A methodological framework for hydromorphological assessment, analysis and monitoring (IDRAIM) aimed at promoting integrated river management. Geomorphology, 251, 122-136, https://doi.org/10.1016/j.geomorph.2015.05.010.

How the interplay among geological and geomorphological factors, land use, and changing climate can bias very short-term landscape evolution: an example from Basilicata, southern Italy

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Keywords: climate change, landscape evolution, anthropic impact.

Erosion is a complex phenomenon influenced by relevant factors such as climate, morphology, hydrology, vegetation, and excessive human intervention in shaping landscape.

In recent years it has been observed an increase in extreme events related to climate change whose effects are directly proportional to the vulnerability of the territory. Climate change, variations in land use, and anthropogenic pressure have caused land degradation and incipient desertification phenomena rather significant in the Mediterranean areas which are becoming drier and even more vulnerable to drought. Basilicata region, in southern Italy, represents one of the most exposed to geomorphological risk and desertification processes Mediterranean areas.

The increasing number of weather extreme events represents the trigger and driving factor, as well as agricultural practice, of fluvial erosion (Scorpio et al., 2015; de Musso et al., 2020, among others) and mass-wasting processes, in terms of efficiency and rates, and contributes to the alteration of slope stability. During times of global change, it is of interest to properly analyse different stages of gully erosion processes, which constitute the most severe form of soil erosion (Stark et al., 2020). The importance of extreme events in controlling erosion and sediment transport in semi-arid areas has long been appreciated but their effects on specific landforms are not widely recognized.

The analysis of some categories of markers, such as the geomorphological and sedimentary ones, in key areas where climate changes combined with wrong land management may cause environmental hazard seems a best practice for the territory safeguard. The application of semi-quantitative methodologies for the estimation of erosion processes constitutes a valuable tool for the application of sustainable land management policies and for the definition of interventions for risk mitigation. This work proposes an example from Basilicata (in the surroundings of Matera town) of how land cover and climate can influence accelerated erosion and landscape evolution. Preliminary analyses of rainfall and temperature multi-temporal series and aerial photos ranged from 2001 to present day have been combined with GIS-based techniques for the estimation of such erosional processes.

de Musso N.M. et al. (2020) - Channel Changes and Controlling Factors over the Past 150 Years in the Basento River (Southern Italy). Water, 12(1).

Scorpio V. et al. (2015) - River channel adjustments in Southern Italy over the past 150 years and implications for channel recovery. Geomorphology, 251.

Stark M. et al. (2020) - Calanchi badlands reconstructions and long-term change detection analysis from historical aerial and UAS image processing. J. Geomorph.

Ancient slate quarries as geosites: degradation risk and enhancement issues

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Keywords: geoheritage, geosites, degradation risk.

Among geosites of anthropogenic origin, ancient abandoned quarries have multiple interests. In some cases the quarry faces expose particular rock formations or stratigraphical sequences that are not well visible in natural outcrops. On the other hand, they are also important from the point of view of cultural geology: they reflect the techniques and the expertise of quarrymen who worked on them, and the stone material extracted from the quarry can be used as building stones or ornamental stones, contributing to the cultural identity of a region (Pijet-Migon & Migon, 2022).

Around the Tigullio Gulf, in the central-eastern part of the Liguria region (NW Italy), slate is one of the most common and used stone resources in architecture and construction. Slate extraction in this area probably began as early as the pre-roman times, but the first solid information on the presence of quarries dates back to the late Middle Ages. Quarrying activity was particularly flourishing between the 19th century and the first half of the 20th century, concentrated mainly in two poles: the Mt. Capenardo massif and the Fontanabuona Valley. From the second half of the 20th century, the activity steadily declined.

In recent times, a number of initiatives have arisen to enhance some of the old abandoned slate quarries for tourism purposes (Brandolini et al., 2007). In the area there are two geosites concerning ancient slate quarries, recognised at the regional and national level: the Tribogna 'theatre-quarry' and the Mt. San Giacomo quarries.

The aim of this work, in addition to a summary of the main geoheritage values of these two geosites, was to perform an analysis of their risk of degradation. The main issues concerning the possible tourist use of the two sites were then analysed, taking into consideration the objective risks for visitors and the state of the routes to get there. In the case of the quarries of Mt. San Giacomo, a detailed analysis was carried out on the practicability of the network of ancient paths used by quarrymen and slate porters.

The results of this work may be useful for planning a correct management and enhancement of the two geosites concerning ancient slate quarries, as well as for the mantainance of the existing trail network and for identifying new proposals for themed trails in the surrounding area.

Brandolini P. et al. (2007) - Valorizzazione geoturistica degli antichi siti estrattivi di ardesia sui monti San Giacomo e Capenardo (Liguria). Atti 3 Congresso Nazionale Geologia e Turismo, Beni Geologici e Geodiversità (Bologna, 1-3 marzo 2007),169-176.

Pijet-Migoń E. & Migoń P. (2022) - Geoheritage and cultural heritage—a review of recurrent and interlinked themes. Geosciences, 12(2), 98, https://doi.org/10.3390/geosciences12020098.

Geomorphological reconstruction of the Umm al-Quwain (UAE) coastal-lagoon system and effects of the present-day human impact

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Keywords: coastal geomorphology, Umm al Quwain, Anthropocene.

Coastal lagoon systems are highly sensitive environments currently experiencing the impact of climate change and human pressure. Lagoons are quickly reacting to such factors through changes in biodiversity and alterations of their geomorphic dynamics. Climate- or tectonic-induced changes in sea level – even the small ones – and/or shifts in the base level and/or flow rate of rivers connected to inlets heavily affect the balance of lagoon ecosystems, triggering ecological changes and/or alterations in landforms. For instance, the coastal region of the Arabian Peninsula, stretching from the Red Sea to the Persian/Arabian Gulf, are dotted by coastal lagoons that are undergoing deep transformations. Across the Holocene, Arabian lagoons underwent subsequent phases of modification triggered by sea level changes, modifications of ocean circulation, and post-post-Last Glacial Maximum shifts in the discharge of main rivers (e.g., Tigris and Euphrates rivers). These factors reshaped the geomorphology of such contexts, promoting the evolution of fresh ecosystems along the shorelines of the United Arab Emirates (UAE) and influencing the growth of extensive mangrove forests. In recent years, human agency has disrupted the pristine dynamics and ecosystems of coastal-lagoon systems between Abu Dhabi and Ras al-Khaimah. In fact, local lagoons have undergone significant changes due to urban expansion involving land reclamation initiatives along the coast to expand coastal areas, including the construction of artificial islands and the consequent changes in circulation and reduction of mangrove forests. The lagoon of the Emirate of Umm al-Quwain (UAQ), thanks to the slower rate of urban sprawl and limited land reclamation operations, still preserves an extensive mangrove ecosystem, pristine landforms, and almost unspoilt tidal dynamics. For that reason, it constitutes the ideal context for a geomorphological assessment based on a combined multi-temporal remote sensing (from 1968 to 2023) and field validation approach, aimed at achieving a deep understanding of the formation and dynamics of tidal-lagoon and coastal systems and landforms. Furthermore, a detailed geomorphological reconstruction of specific sectors of the UAQ lagoon traced its evolutionary history, informing interpretations of past human communities' adaptation strategies and resource exploitation patterns.

Relationships between fluvio-lacustrine landscape, human occupation and historical earthquakes: a multidisciplinary study of the Santa Gada archaeological site (Pollino Geopark, southern Italy)

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Keywords: geoarchaeology, archaeological excavation campaigns, Pollino geopark.

Recently, a multidisciplinary working group started an archaeological survey campaign in a wide sector of the Mercure-Lao River valley, southern Italy, which discovered an important archaeological site (i.e. the Santa Gada site) with evidences of a large settlement dated between the 6th and the 3rd centuries B.C. Apart from the extraordinary richness of the archaeological remains, the Santa Gada site is of particular interest from a geological and geomorphological viewpoint. It is located within the Pollino UNESCO Geopark and its setting shows a strong relationship with peculiar landscape elements. The study area is located in a Middle Pleistocene tectonic basin of the axial zone of the southern Apennines, Italy, filled by a thick fluvio-lacustrine succession. The landscape is featured by different orders of SSO-dipping low-angle surfaces that are separated by rectilinear scarp of variable height. Preliminary archaeological data highlight a close connection between these landforms and settlement patterns and a possible influence of destructive earthquakes on the sudden abandonment of the site. To solve this issue, geological and geomorphological investigations were mainly focused on the definition of the possible tectonic origin of the scarps. Indeed, although the border of the Mercure basin and, more in general, the Pollino area are featured by the presence of impressive Quaternary faults with clear geomorphic and structural evidences of a long-lasting tectonic activity, no significant seismic events are reported in the historical records. Strict relationships among fluvial landforms, active faulting, and settlement evolution have been investigated by the integration of geological, geomorphological, and geophysical data. Archaeological data revealed the sudden abandonment at the end of the 3rd century BC of a vast residential complex. The morpho-genesis of landform elements, the role of major faults as seismogenic sources, and the relationships between landscape and settlement location were discussed in the context of the long-term landscape evolution of the study area. The settlement was built up on the top of a fluvial terrace and is bounded to the north by a morphological scarp. Our investigations suggest a fluvial origin of the morphological scarp of the study area and a possible role of important seismogenic sources of the Pollino area for the sudden abandonment of the site.

Coastal erosion in urban areas and socio-environmental challenges: the case of São João da Barra, Rio de Janeiro, Brazil

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Keywords: rivers, costal erosion.

Coastal erosion affects several beaches worldwide in association with natural and human pressures, especially in urban areas. In recent decades, the coastland of São João da Barra city – near the Paraíba do Sul River delta - has been recognized as one of the main areas that suffer from this geomorphological process. Furthermore, the scientific literature, even if scarce, has pointed out that these dynamics are causing negative socio-environmental responses and making the area less resilient. In the last few decades, urban structures have become debris due to erosion caused by sea ingression, triggered by the coupling of environmental processes and dynamics occurring at different spatial and temporal scales. Therefore, the present research aims to analyze how the recent geomorphological changes on the coast of São Jão da Barra have become a socio-environmental challenge on the spatial planning, arising from the problem of coastal erosion. For this, anthropogenic pressures in fluvial-marine dynamics and multi-scalar (space and time) environmental factors are addressed to analyze this problem and propose possible mitigation solutions.

Urban geomorphology and geostructural aspects of Pozzuoli, southern Italy

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Keywords: urban geomorphology, coastaland, Phlegraean Fields.

The geomorphology and geostructure of Pozzuoli, in the active Phlegraean Fields volcanic area, are related to anthropogenic changes that occurred since 2200 years BCE. Late Quaternary pyroclastics from ~50 volcanoes, among which those of the last eruption of Monte Nuovo (1538 CE), modified the coastland through emplacements of deposits dislocated by volcano-tectonics and bradyseismic phenomena, forming the marine terrace of La Starza, 30-80 m a.s.l., on which the city partially founds. Despite the uplift of ~1.2 m since 2005 with daily earthquakes up to magnitude 4, in the long period, the lowering of the bay submerged the Roman age ruins of *Baie* down to ~6 m of depth.

The recent crisis modified physiography and littoral dynamics, controlled by marine waves and currents, triggering the seabed emersion and beach progradation. As a consequence, since the uplift acceleration of 2015, several buildings were damaged, slope gradient and runoff altered and the risk of flash floods increased, depth diminished and port accessibility reduced, new sandy beaches developed and others enlarged, and many underwater gas emissions transformed the mobile marine substrate into a softer and more erodible seabed. Mitigating these effects seems hard work, while urban structure adaption is a possible alternative.

Hiking trails for discovering the geomorphological heritage: fruition and related hazard, risk and impact scenarios

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Keywords: geomorphology, hazard, geoheritage.

Valorization of the local geoheritage is even more realized through thematic trails and paths (such as geotrails, glaciological trails, etc.) (Brandolini & Pelfini, 2010) supported by in situ or virtual informative materials (Perotti et al., 2020). These cultural routes in different kind of environments (natural, urban) often follow existing marked trails, or paths, with observation points. accessible in different ways and addressed to diverse audiences, ranging from the general public to students. Originally designed for hikers, these trails are now being adapted for e-bikers and e-mountain bikers as well (Senese et al., 2023). Geocultural trails may be located in diverse morphoclimatic environments, some of which exhibit high geomorphic dynamics that could pose hazards and risks to visitors and the geo-cultural sites themselves (Bollati et al., 2019) Additionally, tourism pressure may impact on geosites and related trails, accelerating their degradation and erosion. This study presents findings from prior research and new data regarding the interplay between geoheritage promotion and hazard-risk-impact scenarios, along with strategies aimed at mitigating tourism vulnerability. Specifically, it presents: i) results related to hazard census affecting trail networks in select mountain and coastal areas; ii) analyses of the path characteristics that are influenced by active geomorphological processes, affecting usability and user vulnerability; iii) analyses of the tourism-induced erosion on trails and, iv) a discussion on the importance of dissemination, including simplified thematic maps to highlight path features and geomorphological elements along the trail. (PRIN 2022 project (P.I. RS Azzoni - GEOTRes – Geoheritage threating and resilience: mapping the impact of geomorphic and human processes in sensitive morphoclimatic environments).

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GEOTRes - Geoheritage threats and resilience: mapping the impact of geomorphological and anthropic processes in sensitive morphoclimatic environments

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Keywords: geoheritage, anthropic geomorphology, geoscience.

Human activities affected geomorphic processes in all climatic contexts for millennia, resulting in several landforms directly and/or indirectly related to anthropogenic processes (Brandolini et al., 2020). Vice versa geomorphic processes and consequent natural hazards have wide impacts on the humankind, on infrastructures and human economy (Alcantara-Ayala, 2002), also affecting cultural and geological heritage (Pelfini & Bollati, 2014). Some environments are more sensitive than others to human action, requiring risk mitigation strategies and geoconservation initiatives when the vulnerable element is represented by geological and geomorphic heritage sites (geosites and geomorphosites). Since geodiversity bears witness to the evolutionary history of our planet, it is essential to safeguard geosites as elements of a territory's cultural heritage. For example, high mountain and coastal areas are particularly sensitive environments to geomorphic dynamics and climate change, and in both cases human interventions lead to erosive geomorphic processes. The GEOTRes project intends to propose a new holistic approach by investigating the close correlation between human activities and natural geomorphic processes in various morphogenetic and morpho-climatic contexts, on a selection of Alpine (Valtellina, Valle Anzasca, Val di Cogne, Val d'Ossola) and coastal areas in Northern Italy (Monte Portofino Promontory). Planned activities include the analysis of geomorphologically sensitive areas, the assessment of risk scenarios and the formulation of strategies for geoheritage conservation. This will be achieved through a multidisciplinary approach combining traditional survey methods, analysis of historical archives and innovative remote sensing techniques. The results, presented through thematic maps, will be available for territorial management and valorization, especially of nature reserves and geoparks, for which valorization can represent an economic resource, and to assist public administrations in the management and valorisation of geo-cultural heritage, helping to mitigate the vulnerability of tourists and hikers through training courses and environmental information on the territory.

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Historical and remote sensing analysis as an instrument for the delineation of erodible corridor area in the Serio River: a case study aimed to its sustainable and integrated managemen

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Keywords: historical analysis, geomorphological evolution, river management.

Climate change in recent decades is resulting in the increase of extreme events that often represent a risk for the population. In alluvial plains, among the most densely populated areas on the planet, frequent floods are increasing the instability of the riverbanks and promoting episodic or progressive changes in river morphology. The most significant risk in these areas is represented by the river system dynamics and their inadequate management.

This work aims to investigate the historical geomorphological evolution and the present evolutionary trends of the valley portion of the Serio River (Lombardia, Italy) - ~ 80 km long - in order to propose a sustainable management of its river corridor. We investigate the active channel dynamic since the mid-1800, and the possible future river evolution. We focus on (i) channel width changes, (ii) variation of channel morphological configuration, (iii) bank erosion rates, and (iv) bed level changes. Analyses were based on multi-temporal mapping of the active channel from historical maps (since 1889) and orthophoto (from 1954 to 2021) in GIS environment (with higher temporal resolution over the last 25 years); multitemporal DTMs and topographic cross sections comparison and field surveys.

Results show that multi-channel reaches are the most dynamic, they narrowed from a maximum of about 350 m in 1954 to a minimum of about 130 m in 1988, with decrease in braiding index. By the 1990s alternated phases of widening and narrowing (between about 10 and 40 m). Single-channel reaches - where the morphology configuration did not change over time - narrowed from a maximum of about 80 m in 1954 to a minimum of about 35 m in 1975. Starting from 1988 single-channel reaches did not exhibit significant variations over time, with maximum widening and narrowing of about 15 m. Correspondence between the widening and the occurrence of flood events was observed. The high river dynamic process results in bank erosion, that locally affects more than 40% of the banks (up to 95%). Bank erosion rates, calculated over the last 15 years at the reach scale, range from a minimum of 0.3 m/y to a maximum of 2.7 m/y. Analyses of bed level changes reveal widespread incision along the river, up to about 3 m.

The final outcome was the delineation of (i) the corridor of historical channel shifting, starting from the multi-temporal active channel mapping, and (ii) the future potential erosion areas, estimated by calculating the bank retreat rates. The combination of these two areas allows to define the erodible corridor area, the area where future channel dynamic is expected.

Future work, which includes the definition of a sustainable river management plan that mitigates geomorphic risks and improves the morphological state of the river, aims at the recovery of the Serio River channel within the erodible corridor area.

The contribution of toponyms to geomorphological hazard: hillslope processes and landslides highlighted by the Italian Military Geographycal Institute maps at 1:25.000 scale

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Keywords: geomorphological hazard, toponyms, historical maps.

Toponymy is a linguistic discipline, which has already been used as a tool for geographical studies not only in Italy, but also in international contexts.

Geographical studies have already classified the toponyms in main categories (Arca, 2004): physical geography, human geography and socio-economic geography. By selecting the place names connected to physical geography, we study those suggesting the presence of landslides or hillslope processes (Guimbatan-Fadgyas, 2021).

We focused on the Italian Military Geographic Institute maps at 1:25.000 scale, edited between 1936-1939 and related to a pilot-area in the Basilicata, Campania, Emilia-Romagna, Liguria, Piemonte and Valle d'Aosta region.

The place names tied to landslides or hillslope processes have been compared with the IFFI project (Italian Landslide Inventory), carried out by ISPRA and the Regions and Autonomous Provinces, which supplies a detailed picture of the distribution of landslide phenomena within Italy.

Terms attributed to the forms of soil erosion that trigger geomorphological hazard have been identified. If the frequency of terms such as "sasso" and "pietra" (to which "creta" with its derivatives should be added) spread throughout the country shows pathologically favorable situations for erosive action by exogenous agents, emblematic of the calamity represented throughout Italy by landslides are the terms "lama" with all its derivatives: lavina, lavanga, calanca, diroìta, rovina, ravina, motta e smotta, sciolle.

Frequent slope gravitational processes are identified by the terms: macereti, ghiaioni, brecciai, boe, mare, lama, calanchi, forra. In many parts of the territory, localities with place names related to the terms "campo" or "piano" are highlighted, clearly aimed at associating a form of the flat landscape on slopes ascribable to ancient and relict landslide deposits. Other terms linked to landslide are "moggia", "liggia" or "crosi" and similar, which respectively mean swampy deposits, landslides or gullies.

The comparison with the IFFI project gave satisfying results: we found a good correspondence between names and natural hazard.

The use of toponyms allowed a geographycal interpretation of the slope dynamics and it suggests a possible use of toponymys in land planning activities (Planas-Batlle et al., 2023).

Arca S. (2004) - Toponomastica. In: Italia, atlante dei tipi geografici, 148-152. Available at: https://igmi.org/italia-atlante-dei-tipi-geografici/consulta-latlante

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Geotoponyms as indicators of hydrogeomorphological features in the Portofino Promontory

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Keywords: Portofino Promontory, historical toponyms, hydrogeomorphological features

The analysis of toponymy provides keys to understanding the nature of the territory, revealing information on environmental and anthropic aspects and their evolution over time. This research identifies, classifies and discusses toponyms related to the geomorphological nature of Monte di Portofino, which extends over about 20 km2 in the eastern sector of Genoa. In particular, toponyms related to land morphology, orography, springs and surface dynamics were identified: coastal erosion, landslides and floods. Cartographic research was based on the 1:25.000 scale maps of the Italian Military Geographical Institute (1878-1939) and the Region of Liguria (1994), and the 1:10.000 scale Regional Technical Map (1984-2010). Historical maps from the end of the 18th and beginning of the 19th century (Matteo Vinzoni's Atlas and Minute di Campagna degli Stati Sardi di Terraferma) and the 1:2.000 cadastral map of 1966 were also analysed. Toponyms associated with the physical-geographical nature of the territory account for about 50% of the total, with an average density of 2 toponyms/km2. Toponyms associated with land morphology (e.g. Punta Chiappa, Pietre Strette, Poggio), land use (e.g. Fogliasso, Costasecca, Prato), and hydrography (e.g. M. Pollone, Cala dell'oro, Fosso dell'Acqua Viva) have been identified.

Other toponyms are indirectly linked to physical-geographical features and concern meteo-hydrological elements and vegetation and settlement patterns.Some toponyms are linked to the geo-hydrological hazard of the territory, both from landslides (e.g. Scogli Grossi) and from flooding (e.g. Fosso dell'Alluvione) and have proved useful within the Horizon 2020 Reconect project (Regenerating ECOsystems with Nature-based solutions for hydro-meteorological risk rEduCTion). In fact, the comparison with basin master plan provided encouraging indications, making it possible to verify a correspondence between toponyms and hydrogeomorphological conditions, confirming the usefulness of the use of toponymy in the field of land and city planning.

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S14.

Interoperable and multiscale geological data-analysis for landscape evolution monitoring by applying innovative remote sensing technologies

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Analysis tools for supporting the exploitation of MTInSAR products in monitoring landscape evolution

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Keywords: MTInSAR, tool, instability phenomena.

Multi-temporal SAR interferometry (MTInSAR), by providing both mean displacement maps and displacement time series over coherent objects on the Earth's surface, allows analyzing wide areas, identifying ground displacements, and studying the phenomenon evolution at a long-time scale. The analysis of MTInSAR-based displacement time series can provide useful information for long-term monitoring, management, and risk assessment at the regional level, when combined with planning tools, and support decision-makers at a local level in risk management. This analysis can be complicated due to the amount of data and, for this reason, it is essential to identify tools to accelerate the investigation of MTInSAR products.

This work presents the results obtained by using analysis tools of MTInSAR data in Rheticus® Safeland, developed by Planetek Italia, which provides prevention and mitigation services of land instability hazards. We tested two tools (density and distribution tool) aimed at assessing the reliability of the information provided by MTInSAR products and two automated procedures (Fuzzy Entropy indicator, FE, Nonlinear Trend Analysis, NLTA), recently developed (Bovenga et al., 2022; Bovenga et al., 2021; Refice et al., 2022), for the identification of a smaller set of coherent targets (CTs) showing nonlinear displacement trends related to instability phenomena.

The density tool concerns the percentage of surface of the study area covered by CTs. The tool combines the satellite geometry defined according to parameters coming from the MTInSAR processing (i.e. LOS direction and orbital state vectors), and the ground geometry obtained by exploiting geomorphic information (i.e. the average slope, the prevailing exposure, and the surface area). The distribution tool evaluates the spatial distribution of CTs: the velocity values derived from a dense spatial distribution of CTs covering uniformly the whole study area are more reliable than those derived from a few sparse targets.

The FE index is able to recognize displacement time series characterized by strong non linearities and jumps related to phase unwrapping errors, which should be corrected before further analysis. The NLTA, based on the Fisher statistics, allows classifying targets according to the degree of a polynomial function, which optimally describe the displacement trend.

Density and distribution tools were successfully exploited for assessing the reliability of the data provided by MTInSAR products, and, based on this, for identifying areas where the actual displacement is properly represented by MTInSAR data. FE and NLTA were very effective in supporting the analysis of ground displacements provided by MTInSAR, since they allow focusing on a smaller set of CTs corresponding to unstable areas or structures on the ground. Consequently, the integration of these tools within Rheticus® Safeland increases the level of information for users, who may respond more effectively to their needs.

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The isoradiometric shoreline extraction method as a proxy for Medicane impact quantification: a case study of Bals event along the Sciacca coast (southern Sicily)

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Keywords: remote sensing, medicane, shoreline dynamics.

The increase in the frequency of extreme weather events due to climate change is well known. Within the Mediterranean basin, a primary climate hotspot according to Giorgi (2006) and Trincardi et al. (2023), a rise is recorded due to the occurrence of Medicane, cyclones with characteristics comparable to those of tropical ones. These have a significant repercussion on the coastline evolution and pose a challenging task for coastal management. In this frame, remote sensing techniques could play a key role in shoreline dynamics analysis, enhancing earth observations through time series.

Here we propose the application of an Isoradiometric shoreline extraction Method (IM) (Maltese et al., 2023; Maltese et al., 2024) performed in the frame of the activities related to the development of Foglio n. 628 Sciacca, surveyed through the ongoing 1/50k geological mapping (CARG Project). In particular, we extracted the coastline of the Sciacca coast before and after the Medicane Bals that hit western and southern Sicily in November 2021. The research aims to compare the retrievals of two different near-infrared spectral bands, acquired by two optical sensors onboard Planetscope and Sentinel-2 satellites, with a spatial resolution of 3 and 10 m respectively. This method, with an accuracy of approximately one-third of the spatial resolution of the satellite products, allows us to distinguish the areas from which sediment has been removed from areas where it has instead been deposited, also allowing us to estimate the amount of material mobilized. This methodology has been applied along the coast of Sciacca (southern Sicily) in a sector about 40 km long with an alternation of wide beaches and rocky coast.

The results obtained demonstrate that IM has good performance for coastline extraction and coastline variability analysis so, by using this method, it is possible to estimate the impact of these extreme events. Moreover, this approach could be useful in preparing recovery plans that anticipate the interventions in Medicane occurrence.

Giorgi F. (2006) - Climate Change Hot-Spots. Geophysical Research Letters, 33(8), https://doi.org/10.1029/2006GL025734.
Maltese A. et al. (2023) - A Radiometric Contouring Approach to Map the Shoreline In: Remote Sensing for Agriculture, Ecosystems, and Hydrology, 12727, 57-66, SPIE.
Maltese A. et al. (2024) - On the Shoreline Positioning via Remote Sensing Imagery: An Isoradiometric Approach. Journal of Applied Remote Sensing, 18(1), 014529-014529, https://doi.org/10.1117/1.JRS.18.014529.
Trincardi F. et al. (2023) - Chapter 13 - The Mediterranean Sea in the Anthropocene. In Schroeder K., Chiggiato J. (Eds.), Oceanography of the Mediterranean Sea, 501-553, Elsevier, https://doi.org/10.1016/B978-0-12-823692-5.00013-3.

Systematic monitoring of river landform evolution across scales: from localized change detection to catchment connectivity

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Keywords: sentinel 2, network scale, river geomorphology.

Satellite imageries are starting to become for geomorphologists a new tool to monitor medium-large river dynamics at a high revisit time (i.e., from weekly to daily). The Sentinel 2 mission, in particular, provides a multi-spectral image of the Earth surface at 10 meters resolution every 5 days (cloud cover permitting). Machine learning algorithms can then classify automatically these images, discriminating those river macro-geomorphic features, i.e., water, sediment and vegetation classes, that describe how a river responds to different hydrological and sediment supply impulses, under specific boundary conditions. As part of the IRIDE project (ESA-founded), we used state-of-the-art algorithms to automatically detect and delineate rivers geomorphic active channel (i.e., a combination of water, exposed sediment and newly grown vegetation on sediment bars) across the Po River Catchment, in the Northern Italy. The active channel is divided into 500 m long sectors and the information about water, sediment and vegetation areas detected each month within each sector is systematically stored. This discretization of the river network allows analyses across scales, aggregating the information for single geomorphic units, such as sediment bars, up to catchment scales. This data can then be used, for example, to monitor changes of secondary channels or sediment bars around the removal of localized river infrastructures (such as river groynes), or to quantify the dynamics of different river types (e.g., braided vs sinuous river reaches) in response to seasonality or external drivers such as floods or droughts. Such systematic, uniform information across a whole hydrographic network and the associated monitoring of its geomorphological dynamics from upstream to downstream can eventually provide insights on the river sediment (dis)connectivity and identify hotspots of incoming long-term river morphological changes; an information that is key for a more informed river management.

A newly developed Shoreline Extraction tool from satellite imagery: case studies in Sicily (Central Mediterranean region)

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Keywords: shoreline extraction tool, FAIR principles, geosciences.

The recent development of the remotely sensed shoreline extraction technique improved investigations about Shoreline Change Analysis. These techniques, allow to quantify the recent coastal landscape evolution and facilitate inferences about its main driving forces, climate changes, tectonics, and anthropic processes improving and providing critical information for forecasting future coastal landscape scenarios for better coastal management and mitigating the natural hazard linked to erosion processes.

Here, we propose the use of a newly developed Isoradiometric shoreline extraction Method (IM) which allows delimiting the shoreline with subpixel accuracy using optical satellite imagery, and the production of time series (Maltese et al., 2024; Maltese et al., 2023).

Such a tool, was designed, tested and validated through a GNSS-delimited shoreline from field surveys on three sandy beaches in Sicily (Central Mediterranean), and was then applied on over than 60 km of Sicilian coastline using up to 40 years of freely available satellite products.

The tool is designed to be released in the frame of the Geosciences IR - National Recovery and Resilience Plan (PNRR) and will respect the FAIR (Findable, Accessible, Interoperable, and Reusable) data principles of the Research Data Infrastructures (RDIs).

The proposed shoreline extraction tool could represent a valuable task for coastal management and coastal erosion risk detection and mitigation and could also support researchers in data management and collaborative analysis.

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Maltese A. et al. (2024) - On the Shoreline Positioning via Remote Sensing Imagery: An Isoradiometric Approach. Journal of Applied Remote Sensing, 18(1), 014529-014529, https://doi.org/10.1117/1.JRS.18.014529.

Maltese A. et al. (2023). - A Radiometric Contouring Approach to Map the Shoreline. In: Remote Sensing for Agriculture, Ecosystems, and Hydrology XXV, 12727, 57-66.

External forcing on drainage divide evolution in rifted margins: case of Madagascar

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Keywords: landscape evolution, quantitative geomorphology, numerical modelling.

The landscape of Madagascar is characterized by tilted western plateau and two main topographic scarps on the western and eastern margins of the island. Generally, the western side, the topography is characterized by relict relief and a highly sinuous plateau edge. Conversely, the landscape on the eastern side is dominated by the great escarpment with a linear plateau edge. His simple morphology is locally perturbed by the formation of the active Alaotra-Ankay rift and emplacement volcanic complexes during the Cenozoic. These active processes control the rates of topographic changes and drainage divide location and may indirectly, promote the evolution and diversification of endemic species (*e.g.*, Liu et al., 2024).

Here, we explore the long-term relief and drainage divide evolution of the different morpho-structural domains of Madagascar. Although western and eastern margins display distinct topographic patterns and a general long-term westward divide motion driven by the the retreat of the eastern great escarpment, we observed a discrepancy between Gilbert-metrics and χ-metric in diagnosing the mobility of drainage divides in Central and Northern Madagascar. This discrepancy arises when tectonic processes and volcanic activity influence the topography and control the position of the drainage divide.

To test the hypothesis that late Cenozoic activity controls divide mobility, we conducted numerical modeling simulating a double escarpment retreat, focusing on the evolution of a divide-type and knickzone-type margin. We provide insight into the processes that lead to transient landscape and relief evolution of rifted margins and rejuvenated plateau landscape.

Liu Y. et al. (2024) - Escarpment evolution drives the diversification of the Madagascar flora. Science, 383(6683), 653-658.

Application of morphometric indexes aimed to the monitoring of surface processes within the hydrographic basin of the Ofanto river

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Keywords: Ofanto, connectivity, index.

This thesis work applies a geomorphometric analysis aimed to the monitoring of surface processes within a hydrographic basin. Specifically, the area of interest is the catchment of the Ofanto River, the most important river of the Puglia region.

The analysis is based on the computation of the sediment connectivity index, which describes sediment pathways from the upstream to downstream, estimating sediment erosion and transport on the surface, and the sediment supply to the hydrographic network (Zingaro et al., 2020). In particular, the Sediment Flow Connectivity Index (SfCI, Zingaro et al., 2019) has been calculated using a quantitative approach applied through Geographic Information Systems (GIS). The aim of this method is twofold: (1) to provide a detailed description of surface processes influencing the conformation of the hydrographic basin and (2) to analyze the interaction between these processes in order to understand the evolution of the catchment.

This approach is particularly relevant in the context of river monitoring in the Ofanto basin, as it improves the understanding and the management of hydrological and geomorphological risks, by allowing the application of SfCI in the analysis of other surface phenomena such as mass movements and the displacement of archaeological evidences useful in landscape archaeology investigation (Zingaro et al., 2023).

Zingaro M. et al. (2019) - Sediment mobility and connectivity in a catchment: A new mapping approach. Science of the Total Environment, 672, 763-775.

Zingaro M. et al. (2020) - Experimental Application of Sediment Flow Connectivity Index (SCI) in Flood Monitoring. Water, 12, 1857.

Zingaro M. et al. (2023) - Contribution of the Sediment Flow Connectivity Index (SfCI) in Landscape Archaeology Investigations: Test Case of a New Interdisciplinary Appr oach. Sustainability, 15, 15042, https://doi.org/10.3390/su152015042.

Web publication of multiscale geological data, methodology and processes

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Keywords: multiscale geological datasets, WebGIS, Interactive visualization.

Recently, the necessity to show data and charts referring to different scales and representations, thematic maps to link laboratory data, 3D or AR digital twins in conjunction with spatial analysis have become increasingly common. In all of these cases, it is necessary to contend with different paradigms of representation and well-differentiated information technologies in order for users to visualize and interrogate data on the web.

The aim of this contribution is to identify a methodology for publishing multiscale data on a website without using external providers. With a serverless approach, it is possible to generate easy-to-publish webGIS from geological surveys, 3D models, UAV surveys, and microstructural image analyses. The proposed methodology is developed with popular JavaScript libraries such as: Bootstrap and JQuery for layout, OpenLayers and LeafLet for geodata, THREE.Js for 3D models and Chart.JS for advanced features of microscale data. Through some purpose-built algorithms in Python, which can also be used on Qgis and ArcGIS, pre-configured HTML5 files can be generated for a quick publication on a blog or website.

The case study of the Palmi Shear Zone (PSZ) has been considered a good test site since it is amply supplied with ready-to-use multiscale data. The PSZ is characterized by the occurrence of mostly sub-vertical lying meso-Alpine mylonitic rocks well exposed due to continuous coastal erosion. The outcrops are scattered over a 400 m wide, 1500 m long area. The Ulivarella stacks, consisting of an alternation of mylonitic rocks formed at the expense of metasomatic metacarbonates, paragneiss and tonalitic granitoid rocks intruded by pegmatites, are the most iconic outcrops of the PSZ. Despite the good exposure, the kinematics of this shear-zone still remains controversial (Ortolano et al., 2020), also due to the formation of a complex sheath-folding system.

The main goal achieved with this methodology was to establish a standardized practice for the increasingly independent use of external services for multiscale data publication, from UAV surveys up to the digitized microfabric analysis of suitably oriented thin sections (Visalli et al. 2021).

As a result of this methodology, the role of the geoscientist and digital cartographer remains strategic throughout the data publication process to ensure an effective dissemination of results.

Ortolano G. et al. (2020) - Quantitative microstructural analysis of mylonites formed during Alpine tectonics in the western Mediterranean realm. J. Struct. Geol., 131, https://doi.org/10.1016/j.jsg.2019.103956.

Visalli R. et al. (2021) - Micro-Fabric Analyzer (MFA): A New Semiautomated ArcGIS-Based Edge Detector for Quantitative Microstructural Analysis of Rock Thin-Sections. ISPRS Int. Geo-Inf., 10, 51, https://doi.org/10.3390/ijgi10020051.

Integrating multispectral normalized difference vegetation index (NDVI) to analyze land cover changes in sediment connectivity analysis

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Keywords: sediment connectivity, NDVI, land use changes.

Land cover is a key factor in controlling surface sediment dynamics. Geomorphological processes such as sediment erosion, transportation and deposition are strongly conditioned by land cover type, which controls sediment production and mobility on the earth's surface. To analyze sediment connectivity through different indices and models, land use and land cover data are the significant variables. However, it should be considered that land cover changes can impact these processes, especially if they occur over a short period. In the present study, we analyzed the land cover changes in three different hydrographic river basins, such as Severn in the United Kingdom, Vernazza in northwestern Italy and Lama Camaggi in southern Italy, concerning their sediment connectivity patterns, as described by the Sediment flow Connectivity Index (SfCI) in previous works (Zingaro et al., 2019; Zingaro et al., 2020; Zingaro et al., 2023). The main focus of the study is to evaluate the land cover changes in sediment connectivity analysis by using a multispectral index. In particular, we have computed the normalized difference vegetation index (NDVI) in each study site through sentinel-2 multispectral datasets, considering the time frame from a reference year and the last year (2023). The results revealed the variations in NDVI values, highlighting land cover changes over a short period in many parts of the basins. Also, the integration of NDVI in SfCI on sediment mobility can affect sediment connectivity patterns. The use of NDVI can improve the analysis of sediment connectivity by providing more dynamism in the description of sediment pathways on both spatial and temporal scales. The present experimentation gives new insights into considering surface cover changes in SfCI contributing to updating the algorithm and investigating the possibility of its enhancement.

Zingaro M. et al. (2019) - Sediment mobility and connectivity in a catchment: A new mapping approach. Science of the Total Environment, 672, 763-775, https://doi.org/10.1016/j.scitotenv.2019.03.461.

Zingaro M. et al. (2020) - Experimental Application of Sediment Flow Connectivity Index (SCI) in Flood Monitoring. Water, 12(7), 1857, https://doi.org/10.3390/w12071857.

Zingaro M. et al. (2023) - Contribution of the Sediment Flow Connectivity Index (SfCI) in Landscape Archaeology Investigations: Test Case of a New Interdisciplinary Approach. Sustainability, 15, 15042, https://doi.org/10.3390/su152015042.

Experimental application of the Sediment Flow Connectivity Index (SfCI) n surface archaeological inter-site survey

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Keywords: sediment connectivity, geomorphology, landscape archaeology.

Geology and Geomorphology are essential for landscape archaeology to understand the relationship between the environment and human activities. Integrating geomorphological analysis in archaeological investigations could increase the capacity to identify the archaeological sites and to improve the reconstrucion of the historical landscape (Cremaschi et al., 2018; Herz & Garrison, 1998). The experimental application of sediment flow connectivity index (SfCI) in landscape archaeological researches is proven to be useful to recognize, monitor, and interpret the historical evidence in the evaluation of surface processes that condition landscape evolution (Zingaro et al., 2019; Zingaro et al., 2023).

This work describes the investigation applied in the basins of Lama Misciano and Lama Balice (area of interest, AOI) in the Apulia region (southern Italy), characterized by the presence of archaeological evidences found on the surface during inter-site field survey in 2023-2024 years. In particular, the research is aimed to evaluate the influence of the geomorphological processes (erosion, transport and supply of sediment) in surface displacement (and visibility) of archaeological record. Assuming that archaeological material, brought to the surface, can move as the sediment following runoff processes and then be deposited (on the surface or in alluvial or colluvial layers) or continue to move following the dynamics described by the sediment connectivity index, the SfCI was computed in AOI and the corresponding maps were compared with the archaeological evidence documented on the surface. The results show (1) the correlation between areas of medium-high sediment connectivity and areas with archaeological occurrence (i.e. surface findings and the archaeological site of Misciano that is characterized by the presence of a church with cemetery dated to 6-10th century); (2) the location of archaeological record on sediment paths defined by SfCI. This analysis demonstrates the contribution of SfCI in landscape archaeological investigations for the capacity of the index to identify surface processes that may potentially affect the readability of the archaeological records supporting data interpretation. These results confirm the advantage of applying an interdisciplinary approach in archaeology and opens innovative research scenarios

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Herz N. & Garrison E.G. (1998) - Geomorphology in Archaeology. In: Herz N. & Garrison E.G. (Eds), Geological Methods for Archaeology, Oxford University Press, 352 pp.

Zingaro M. et al. (2019) - Sediment Mobility and Connectivity in a Catchment: A New Mapping Approach. Sci. Total Environ., 672, 763-775, https://doi.org/10.1016/j.scitotenv.2019.03.461.

Zingaro M. et al. (2023) - Contribution of the Sediment Flow Connectivity Index (SfCI) in Landscape Archaeology Investigations: Test Case of a New Interdisciplinary Approach. Sustainability, 15, 15042, https://doi.org/10.3390/su152015042.

A two-stage river capture event in Corsica and its impact on erosion rates and offshore sedimentation revealed by geological and in situ ^{10}Be cosmogenic data

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Keywords: provenance, source-to-sink analysis, long-lived knickpoints.

An increasing number of source-to sink studies exploit the sedimentary archive to constrain landscape evolution and its response to tectonic and climatic forcing. Within this framework, sediment yield variations and quantitative analysis of fluvial topography are often independently used to detect major river capture events and episodes of drainage re-organization. The source-to-sink system of the Golo River, the largest catchment of Corsica, provides a well-established test-case for this kind of studies, where some authors have focused their attention on the onshore part of the system during the late Quaternary, and others have focused their attention on the offshore sink and highlighted major variations in sediment yield during the late Pleistocene and the last glacial cycle. In this study, we expand the analysis of the river network of Corsica back to the Miocene, and we provide evidence of major river capture events affecting the former Paleo-Ostriconi River in the late Neogene (Malusà et al., 2024). We document the impact of river piracy on offshore sedimentation and use a dataset of *in situ* ^{10}Be cosmogenic analysis on river sands to analyze the influence of disequilibrium inherited from river capture on pattern and rates of Holocene erosion.

Our results illustrate how the landscape of Corsica has reacted and is still adapting to the disequilibrium caused in the late Miocene by the uplift of Alpine Corsica. Tectonic uplift pushed the drainage divide, originally located on Variscan Corsica, eastward and generated a linear, fault-controlled valley that hosted the north-flowing Paleo-Ostriconi River. The landscape responded to the uplift via multi-stage river capture, and the divide eventually migrated back to the west to again become largely fixed on the resistant Variscan spine. In this framework, ~1300 km² of basin area originally draining towards the Ligurian Sea were abruptly connected, since the Pliocene, to the base level of the capturing Tavignano and Golo rivers. This led to the formation of a large Pliocene-Quaternary submarine fan offshore the Tyrrhenian coast, associated to an increased sediment yield that was three times greater than the average sediment yield in the same source-to-sink system during the Holocene. Concentrated erosion persists today around long-lived knickpoints that are still moving through the drainage system after millions of years. Our results demonstrate that a full consideration of landscape response times to onshore disturbances is a prerequisite for any reliable interpretation of the offshore sedimentary archive.

Malusà M.G. et al. (2024) - Impact of river capture on erosion rates and offshore sedimentation revealed by geological and *in situ* ^{10}Be cosmogenic data (Corsica, western Mediterranean). Earth Planet. Sci. Lett. (in press).

How long does the signature of tectonic events last in the landscape? Topographical analysis of Jebel Akhdar dome and surrounding Semail Ophiolite in the Al-Hajar Mountains (northern Sultanate of Oman)

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Keywords: landscape evolution, geomorphometry, Oman.

Earth's surface undergoes significant modifications due to tectonic events, which occur at different spatial and temporal scales with various deformation magnitudes and rates. Surface processes respond to these topographic modifications, striving to achieve a state of equilibrium. Active tectonic processes leave intense signals on the landscape, and, after their cessation, the responses become more litho-structurally and climatic controlled. Thus, understanding the overprint of tectonics on the topography and the preservation of this record is crucial to comprehend and describe how surface processes shape landscapes.

Morphometric analysis and field survey were employed to investigate the Jebel Akhdar dome (JAK) and surrounding ophiolites in the Al-Hajar Mountains (Sultanate of Oman). This orogenic belt, located in the NE-Arabian plate, is renowned for hosting the Semail Ophiolite, one of the most complete obducted ophiolite sequences globally (Searle, 2007). The obduction occurred during the Late Cretaceous, resulting in the emplacement of ophiolites over JAK autochthonous units, composed by pre-Permian sedimentary and volcanic sequence and Permian-Late Cretaceous carbonate platforms. The Late Cretaceous and subsequent Cenozoic tectonics have resulted in the doming of JAK and the deformation of its rock sequences by predominantly transtensional structures (Searle, 2007). Field survey shows that river networks, structural elements, and karst systems heavily influenced the topographic evolution. This has been confirmed by morphometric indices, such as terrain ruggedness index (TRI), topographic position index (TPI), hypsometric integral (HI), and swath profiles. At regional scale, TRI, HI, and swath profiles show higher values for JAK and lower ones for Semail Ophiolite, emphasizing tectonic windows in JAK with intermediate-lower values. At a more detailed scale, escarpments, faults, and canyons are underlain by differences in values of TPI and TRI. In this way, morphometric results permit to quantify the topographic evolution, suggesting the influence of multiple factors at the local scale, including litho-structural setting, karst, (neo)tectonic activity and base-level variations. The combination of field observations and geomorphometry permits to understand the evolution of the topography, controlled by litho-structural setting, that played an important role in the drainage and karstic network development, leading to the formation of narrow and incised canyons in JAK, and larger and dendritic valleys in the Semail Ophiolite. Furthermore, the results indicate that the regional landscape evolution may be influenced by ongoing geological processes, such as uplift related to rebound processes of the Arabian crust, overlapping the offshooting effects of JAK doming and orogenic collapse that have not yet reached a topographic equilibrium, while the Semail Ophiolite may have reached equilibrium because not involved in the doming processes.

Searle M.P. (2007) - Structural geometry, style and timing of deformation in the Hawasina Window, Al Jabal al Akhdar and Saih Hatat culminations, Oman Mountains. GeoArabia, 12(2), 99-130, https://doi.org/10.2113/geoarabia120299.

Geological Data and the concept of Quality. Theory and application

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Keywords: geoscience ontologies, geology data base, geological knowledge.

Sedimentary successions record the evolution of palaeogeographic domains and orogenic systems, which can be described referring to a sequence of Geologic Events (GeoEvents). The GeoEvents are preserved in the stratigraphic record in different ways, such as, unconformities, distinctive lithofacies, chronostratigraphic gaps, condensed successions, hardgrounds, paleoescarpments etc. The recognition of the GeoEvents gives a chance to correlate tectonic and paleoenvironmental processes at large regional scale across sedimentary basins and coeval orogenic belts (Piana et al., 2017; Mantovani et al., 2020). The GeoEvent concept is one of the main cornerstones of the Geologic Feature classification in the IUGS GeoSciML and INSPIRE (Data Specification on Geology) standard for geology, so it should drive the organization of the Map Legend and the design of the DataBase structure of the modern digital geological maps. The GeoEvent class has a specified geologic age and may have specified environments and processes. Even though the GeoEvent age can represent an instant in time and/or an interval of time, the GeoEvent approach can allow correlation between rock units of different geological domains, even if they were subjected to different, post-depositional, tectono-metamorphic conditions. Some examples of geologic correlation across the successions of syn-orogenic sedimentary basins and those scattered in coeval, adjacent orogenic belts are given, and a discussion on the scientific consistency of this approach is proposed.

GeoSciML version 4.1., 2017, http://www.geosciml.org.

INSPIRE - Data Specification on Geology, version 3.0, http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/INSPIRE_ DataSpecification_GE_v3.0.pdf.

Mantovani A. et al. (2020) - Ontology-driven representation of knowledge for geological maps: Computers and Geosciences, 139, 104446, https://doi.org/10.1016/j.cageo.2020.104446.

Piana F. et al. (2017) - Geology of Piemonte region (NW Italy, Alps–Apennines interference zone), Journal of Maps, 13(2), 395-405.

Landslide body segmentation from satellite imagery using artificial intelligence model: case studies Ischia island and Forlì - Cesena area

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Keywords: CNN, landslides, remote sensing.

In the study of ground instability phenomena, geo-spatial methods are widely used through per-pixel analysis of post-event images and cluster analysis of pre- and post-event images by applying a variety of machine and deep learning techniques to assess hazard connected to gravitative processes.

In particular, the deep learning approach with the U-net architecture (Ronneberger et al., 2015) has been widely used for landslide mapping, proving to be a fast, powerful and accurate tool for segmentation of landslide bodies even in complex detection conditions and in poor data scenarios (Nava et al., 2022). This model has been trained on large landslide dataset consisting of 3799 files, from the Iburi-Tobu Area of Hokkaido in 2018, Kodagu District in Karnataka in 2018, Rasuwa District in Bagmati in 2015, and Western Taitung County in 2009 (Ghorbanzadeh et al., 2022). Each file containing 15 data matrices 128x128 pixels, where first 12 matrices are for Sentinel-2 satellite spectral bands, matrices 13 and 14 represent the slope and the elevation derived from Digital Elevation Model (DEM) of ALOS PALSAR satellite mission. The matrix 15 is a landslide presence/absence map (i.e. a binary map in which a "0" value indicates the cell where a landslide is not present while the "1" value identifies the cell where a landslide is present). In this work, we present a test of first semi-automatic segmentation system to identify active landslide bodies. The main aim is to evaluate the performance of the algorithm in areas of Italy, by applying automation techniques and artificial intelligence and image processing technologies. The methodology is based on two main steps:

1. The code implementation of the algorithm by using python programming language;
2. The application of CNN U-Net model to satellite data from multi-spectral Sentinel-2 images (as RGB images and normalized difference vegetation index maps) and morpho-topographic data (as slope and elevation) extracted from the Italian DEM TinItaly 1.1 (Tarquini et al., 2023).

The model was tested in sites particularly exposed to hydrogeological instability in order to explore the capacity of the system to recognize active landslides triggered by extreme rainfall events. In particular, two areas were selected:

1. the island of Ischia (central Italy), located in the Tyrrhenian Sea;
2. part of Emilia-Romagna region (north central Italy), located in Po River Valley.

The predictions obtained showed a good performance of the U-Net model which proves to be suitable in the identification and segmentation of landslides in test areas, despite a lower accuracy (reaching 52%) than in the training phase (exceeding 82%) probably due to the lack of available data on geological setting that affect the optimization of the pre-trained model. The present research provides a useful contribution for future advances in the development of alert systems in landslide risk management.

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Tarquini S. et al. (2023) - TINITALY, a digital elevation model of Italy with a 10 meters cell size (Version 1.1). Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/tinitaly/1.1.

Full-coverage geomorphological mapping using opensource software: a tool for geomorphological risk analysis, management, and mitigation

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Keywords: Geomorphological mapping, GIS, Geomorphological risk analysis.

The drafting of geothematic cartographies is part of the Integrated Territorial Information System, which provides knowledge of the territory from a lithological, structural and morphological point of view representing a useful tool for land use planning.

Over the years, various mapping projects have enabled to uniform cartographic representation using a nationally interpretable language (the CARG project is an example) .

Nowadays, a new approach to geomorphological mapping with "full geographic coverage" becomes part of the tools for geomorphological risk assessment, management, and mitigation for proper land-use planning. Compared with the "traditional" cartographic approach, it does not involve the use of symbols and colors for the representation of morphogenetic data, but rather polygonal and point vectors. This new approach allows no point or areal to be missed during the interpretation process and each element to be discretized, providing a complete and dimensionally correct representation of the complexity of the physical landscape (landforms, deposits and processes) at different scales.

In order to support the visual inspection activities for digitize the morphogenetic features, data were collected and information layers were processed using GIS software. Starting from IGMI (Italian Military Geographic Institute) topographic base, the methodology involved the integration of various layers including orthophotos, hydro-geomorphological data, digital terrain models (DTM) (available at Integrated Territorial Information System - SITPuglia, see http://www.sit.puglia.it/portal/sit_portal) and LiDAR data. By exploiting the information contained in the terrain elevation, it is possible to derive, through GIS processing tools, maps of geomorphological indices to support the interpretation and mapping of landforms. Examples are the layers: (1) "hillshade", a raster that represents the surface using light and shadow, simulating a 3-D effect, and (2) "geomorphon", a raster that uses different classes (colors) to visualize the most common shapes of the landscape such as slope areas, flat plateaus, depressions, valleys, but also high points such as ridges and crests (Amatulli et al., 2018). Therefore, these layers play a pivotal role in delineating geomorphic-topographic units, contributing to the recognition of morphologies and enhancing comprehension of the morphogenetic mechanism that drive landscape dynamics.

In conclusion, these supporting elements are considered a key aspect of full-coverage geomorphological mapping, enabling the accurate discretization of landscape forms and processes by improving the assessment of geomorphological hazard and/or risk.

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Fluvial record interpretation for the extraction of climatic and tectonic signals in the Adriatic Piedmont Zone of the Apennines (central Italy, Marche region)

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Keywords: low-rate tectonics, climate change.

Fluvial terraces serve as an important continental record, functional to understand the influence of tectonics, varying climate, and base level change on landscapes (Merritts et al., 1994). A well-preserved staircase of fill terraces is present in the Adriatic piedmont of the Apennines (central Italy), generated by the cyclical alternation of fluvial aggradation and incision over the Middle and Late Pleistocene, in response to the combination of low-rate tectonic uplift and climate changes. Compared to strath terraces the use of fill terraces for incision rate derivation is complex, due to their cyclical nature, but they remain a thorough record of incision and deposition that allows to derive interpretations about both tectonics and climate (Pederson et al., 2006). While the staircase has been already described at length with examples from numerous valleys of the Adriatic Piedmont (see Delchiaro et al., 2024), there is a necessity to expand its geochronological constraints, especially for the older terrace levels, to enable the acquisition of reliable climatic and tectonic signals from terrace deposits.

This study presents the analysis of sedimentological and granulometric characteristics of fill terraces within the Tesino, Aso and Tenna River basins in the Marche piedmont zone of the Apennines, and includes the differentiation and correlation of terraces, with systematic tracing of morpho-stratigraphic sections. This was made possible by integrating semi-automatically extracted data on the altimetric and along-valley terrace distributions, with geomorphological field surveys for the identification of the geomorphic markers. The semi-automatic extraction of the treads of the terraces allowed a preliminary level classification as a function of the terrace height above the modern channel thalweg, isolated with the support of Relative Elevation Models (REMs) converted from 1 m/pixel Digital Elevation Models (DEMs) collected from a 1x1 LiDAR dataset. Additionally, Infrared Stimulated Luminescence (IRSL) data on terrace chronology have been incorporated, providing geochronological constraints for the regional-scale paradigm of cyclical formation and development of Quaternary fill terrace staircases within the slowly uplifting Adriatic piedmont of the Apennines. The main phases of fluvial aggradation appear to coincide with colder periods, followed by river incision and floodplain-channel abandonment during inter-glacial periods. This validates previous results from the last fluvial aggradation-incision cycle (Late Pleistocene) and, furthermore, the results demonstrate the persistence of this same formation mechanism in the older (Middle Pleistocene) terraces. The use of a dated fill terrace staircase allowed the estimation of a Middle Pleistocene long-term bedrock incision rate ranging from 0.3 to 0.5 mm yr^{-1}, that agrees with earlier studies in the central-northern sector of the Adriatic Apennines (Sembroni et al., 2020).

Delchiaro M. et al. (2024) - A fluvial record of late Quaternary climate changes and tectonic uplift along the Marche Piedmont Zone of the Apennines: New insights from the Tesino River (Italy). Geomorphology, 445, 108971, https://doi.org/10.1016/j.geomorph.2023.108971.

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Sembroni A. et al. (2020) - The uplift of the Adriatic flank of the Apennines since the Middle Pleistocene: New insights from the Tronto River basin and the Acquasanta Terme Travertine (central Italy). Geomorphology, 352, 106990, https://doi.org/10.1016/j.geomorph.2019.106990.

Rock outcrops classification by Sentinel-2 images: a new gis-based toolbox proposal

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Keywords: satellite imagery, multispectral analysis, GIS-based toolbox.

Multispectral satellite imagery is a powerful tool to drastically reduce geological survey time over large areas or to provide data from inaccessible localities. The images interpretation requires a preliminary accurate classification of reflectance of different rock-types. This can be obtained distinguishing on images the fresh rock outcrops from areas covered by vegetation, anthropic and soil. We here propose a GIS-based semi-automatic procedure for a rock-classification, including a first step to clean the images by the noise that mask the rock footprint and a second step to upgrade the resolution of the output.

We tested the method on satellite images of eastern Sicily, where large spectrum of lithologies, including sedimentary, volcanic and metamorphic rocks, are exposed.

The study was based on the free access Sentinel-2 imagery, covering the entire study region, with revisit times of 2-3 days. Sentinel-2 has 12 sensors, covering the entire light spectrum from ultraviolet to SWIR (Short-Wave Infra-Red), including four visible and near-infrared bands at 10 m resolution, six red-edge/SWIR bands at 20 m resolution and, finally, two atmospheric correction bands, at 60 m of resolution. The adopted source images, therefore, provide an opportunity to calculate the variability of reflectance values on the Earth's surface over a wide range of wavelengths, which is useful for discriminating the different footprint of rock outcrops.

To classify the rock types, we imported the images into ArcGIS Pro, where we used a new toolbox, developed by ModelBuilder, to clean up all the "noise" from the images, resulting in a residual that pertains only to rock outcrops. The method is based on comparation between the satellite images with a categorized ortophoto. To handle lightened output files, we performed the analysis on distinct adjacent 10 km2 wide areas. Within each of the selected areas of interest we create a point Shapefile which will be populated with 4 classes: Vegetation, Anthropic, Soil and Outcrops. This Shapefile will be used like a ROI (Region Of Interest) for a supervised automatic classification of the orthophotos of the area.

Once the pixels of the classified orthophotos have been sorted in the 4 classes of the ROI, we can exclude the 3 classes that are "noise" and obtain the residual pixel to refer as rock outcrop to relate to the reflectance values of the satellite images. The method requires that the cleaned orthophotos might be resampled at the same resolution of the twin satellite imagery, in order to minimize the errors, due to data missing or doubling. The pixels of our interest in the classified orthophotos were converted to point Shapefile that are populated with the reflectance value of the respective pixel taken from the multispectral imagery. With this methodology it is possible to select the actual values from rock outcrops, helping avoid errors in semi-automatic/automatic processes.

Unified Global Landslide Catalog - A single global-scale standardized landslide dataset

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Keywords: landslides, catalog, global.

Landslides are a serious threat to all communities due to their potential for property damage and loss of life. Triggered by different natural, climate and anthropic activities, their identification, monitoring and management is therefore very complex (Kirschbaum et al., 2010).

Mitigating landslide risk entails assessing the likelihood and consequences of landslides on communities through measures like land-use planning and early warning systems.

These proactive steps are essential for minimizing risk and protecting both lives and property from the impact of landslides (Gómez et al., 2023).

This study presents a single global scale standardized/harmonized landslide dataset, the Unified Global Landslide Catalog (UGLC), which can be a fundamental reference for land risk assessment and management (Virro et al., 2021).

The UGLC integrates multiple open-source landslide catalogs, and reports spatio-temporal data with landslides triggering factors. It is compiled from various sources including government agencies, universities, and researchers. Landslide occurrence data are collected from extensive field surveys, GPS data, GIS techniques, satellite imagery, and historical records.

The UGLC contains more than 1 million landslide events as point and polygonal data collected from circa 1700 to 2023, standardized according to 18 field attributes grouped into 7 categories, which are:

- UGLC Reference: uniquely identifies the event record within the new catalog;
- Source Reference: uniquely identifies the original event record from the source catalog, allowing record back-tracing;
- Spatial Accuracy: describes the spatial accuracy and geographic location of the event record;
- Temporal Accuracy: describes the temporal accuracy of the event;
- Geological Information: describes the geological characteristics of the area involved in the event and trigger information;
- Reliability: describes the inherent reliability of the record. The authors also intend to explore a validation method using radar data;
- Notes and information: additional information about the event, source links, authors, scientific publication, and other information.

The UGLC is intended as a robust dataset of standardized worldwide information on landslides. It will contain various types of data useful for global analyses and compensate for the shortcomings of small scale heterogeneous datasets. The objective is to provide a powerful, accurate, and user-friendly source for a global characterization of landslide occurrence. It will facilitate a deeper understanding of landslide phenomena in relation to the surrounding landscape, climate and impact on human populations and built environment (Kirschbaum et al., 2015).

Kirschbaum D. et al. (2010) - A global landslide catalog for hazard applications: method, results, and limitations. Nat. Hazards, 52, 561-575, https://doi.org/10.1007/s11069-009-9401-4.

Gómez D. et al. (2023) - Spatial and temporal landslide distributions using global and open landslide databases. Nat. Hazards, 117, 25-55, https://doi.org/10.1007/s11069-023-05848-8.

Kirschbaum D. et al. (2015) - Spatial and temporal analysis of a global landslide catalog. Geomorphology, 249, 4-15, https://doi.org/10.1016/j.geomorph.2015.03.016.

Virro H. et al. (2021) - GRQA: Global River Water Quality Archive, Earth Syst. Sci. Data, 13, 5483-5507, https://doi.org/10.5194/essd-13-5483-2021.

Geomorphic signature of the eastward marching of Quaternary extensional tectonics in the Northern Apennines (central Italy): the Colfiorito intermontane basins key area

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Keywords: Colfiorito basins, drainage divide evolution, drainage anomalies.

The Colfiorito basins that defines the drainage divide in the Umbria-Marche region are a well-known example of syn-orogenic uplift, shortening, and extension of the Apennines. Detailed mapping and construction of a synthetic stratigraphic age model, along with a synthesis of related topographic and erosional features including drainage patterns, wind gaps, alluvial fans, and paleo-surfaces are used to model the processes and timing of drainage transformation and disarticulation from a transverse, east-flowing river system to an internal, subsiding, hanging-wall basins by an active, segmented, normal fault system. The Colfiorito basins are bounded to the east by the SW-dipping Mt. Le Scalette normal fault, which separates them from the Adriatic drainage headwaters of the Chienti river. The progressive eastward migration of the Apennine watershed (Alvarez, 1999; Della Seta et al., 2017) has resulted in the dislocation of part of the headwater area of a paleo-Chienti river catchment into a series of tectonic basins. Some of these basins are connected by wind gaps, paleo-river valleys in which the incising river is absent. Anomalies such as streams piracy, elbow deviations, fluvial inversions, and headward erosions occur along the westernmost basins, which have already been subject to fluvial capture by Tyrrhenian-draining rivers. Beheaded valleys are characteristic of the Adriatic-draining rivers paleo-channels at the intersection with major normal fault lines. The study employed quantitative analysis of the areal extent of alluvial fans and respective drainage basins, plotting the values on bi-logarithmic graphs. These fans, which are directly fed by mountain fronts, represent excellent geomorphic markers in karstic environments. Pleistocene alluvial fans, which are no longer related to current morphogenetic and morphodynamic conditions, exhibited significant catchment area deficits in comparison to the areal extent of the deposits and when compared with the trend of Holocene alluvial fans values. The presence of fluvial saddles in their headwater areas provided evidence of drainage inversions, which allowed for the reconstruction of a possible catchment delineation of a paleo-river with eastern drainage. WSW-ENE oriented swath profiles also support this reconstruction, highlighting remnants of faulted paleo-surfaces slightly inclined towards the E-NE, in agreement with the paleo-drainage trend.

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Della Seta M. et al. (2017) - Relief, intermontane basins and civilization in the umbria-marche apennines: Origin and life by geological consent. In: Soldati M. & Marchetti M. (Eds.), Landscapes and landforms of Italy, 317-326.

Catchment-averaged denudation rates in the Northern Apennines and Ligurian Alps and implications for landscape dynamics

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Keywords: terrestrial cosmogenic nuclides, drainage reorganization, Northern Apennines.

In tectonically active areas, faulting and uplift lead to drainage reorganization. The Northern Apennines are an active orogenic wedge, where horizontal shortening and topographic advection lead to river capture and drainage divide migration. In contrast, the adjacent Ligurian Alps are a remnant of the Alpine orogen with little modern deformation. In this study, we combine geomorphic and stream profile analyses with 10Be-derived denudation rates from river sediments to quantify landscape dynamics in both orogens. Geomorphic metrics are asymmetric across the main drainage divide and associated divide asymmetry indices suggest main drainage divide migration from the Ligurian coast to the Adriatic Po Plain, accompanied by river captures. In the Northern Apennines, this suggested drainage divide migration direction is towards the NE, opposite that of the horizontal tectonic advection of topography. Geomorphic metrics show greater contrast across the main drainage divide in the Northern Apennines than in the Ligurian Alps. Our results allow us to quantify horizontal tectonic advection of topography and drainage divide migration. These quantitative constraints on landscape evolution help us assess how drainage divides evolve and provide insights into tectonically driven drainage reorganization, which may have important biodiversity implications, e.g., influencing the intraspecific genetic diversity of endemic riverine fish.

Deep learning to automatically map braided palaeochannels from optical traces in the Venetian - Friulian Plain (NE Italy)

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Keywords: geomorphology, deep learning, alluvial plains.

In the past 10 years, the rapid rise of deep learning algorithms such as Convolutional Neural Networks (CNNs) has dramatically transformed the field of remote sensing studies. Deep learning algorithms have been successfully adapted with the aim of classifying, mapping, and quantifying various geomorphological processes. At the same time, the increasing number of available remote-sensed data has encouraged significant advancements, particularly in alluvial plains geomorphology. Alluvial plains are mainly the product of fluvial systems but in many regions, as in Europe, the anthropogenic activities have significantly altered the original setting since ancient time. Generally, one of the key operations for reconstructing the evolution of these plains involves the recognition of optical and/or topographic traces related to abandoned paleochannels. An example is evident in the Friulian Plain (NE Italy) showcasing an abundance of braided palaeohydrographic traces related to LGM (Last Glacial Maximum, 29-19,000 years BP) rivers which drained glaciers in the Alps. Despite being widespread, the overlapping urbanization and complex cropland patterns, hinder any efforts to manually map them. In this work, we took advantage of available high-resolution (1 m) aerial photos to build an Attention U-Net deep learning algorithm, training it to detect and segment palaeohydrographic traces. The model, consisting of more than 500,000 trainable parameters, required 24,800 images to train. On the test dataset we obtained a F1-score, which measures the performance in terms of both precision and recall, of 0.79, and the overall accuracy of the model was 92%. Afterwards, the trained model was used to automatically map more than 250 km2 of braided palaeochannels traces in the apical portion of the alluvial plain. This map represents the first step in classifying different geomorphological units, quantifying past fluvial processes, as well as characterizing LGM landscapes. Moreover, to assess the generalization capability of our model, we selected satellite data from two other areas in North Italy and one area in Montenegro which showcase similar braided paleohydrographic pattern. In each new case study, the braided pattern was successfully detected and mapped by the algorithm, despite local differences and diverse source datasets. This work highlights the breakthrough potential of these kind of state-of-the-art algorithms to rapidly detect and map complex geomorphological traces in intensely urbanized plains. At the same time, it also addresses the many challenges and limitations of applying AI methods in these environments. As one of the first implementations in the scope of palaeohydrography detection and mapping, we also aim to encourage scientists working on late Quaternary alluvial plains to take advantage of similar deep learning algorithms in their research.

Incision rates into Quaternary lava flows of the Middle Atlas and Western Mesta (Morocco): implications for landscape evolution

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Keywords: incision rates, lava flows, Middle Atlas, Massif Central, morphotectonic evolution.

Understanding the rate of erosion plays a crucial role in characterizing landscape evolution and unravelling the relationships among tectonic activity, climate dynamics, and surface processes within active orogenic regions. Valley-filling volcanic rocks are valuable geomorphic markers for measuring fluvial incision rate and gain insight on the forcing mechanisms.

This study combines fluvial incision rates observed on dated lava flows within the valleys of the Moroccan Massif Central and Middle Atlas with geomorphic analysis using digital elevation models (DEMs). The findings reveal varying rates of incision, approximately 0.01 to 0.1 mm/yr for the Middle Atlas and the Massif Central, respectively. This spatial disparity aligns with geomorphic metrics, showing lower rates in areas of low relief and higher rates along more dissected margins.

Our analysis suggest that lithology and climate may not be the main determinants of spatial variation in incision rates between the Middle Atlas and Massif Central. Instead, surface uplift, possibly linked to flexural uplift of the Rif foreland and/or dynamic mantle-related processes, likely contribute to higher incision rates in the Massif Central.

Soil erosion assessment using the Revised Universal Soil Loss Equation (RUSLE) in Google Earth Engine in Bradano Basin

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Keywords: soil erosion, Rusle Model, Google Earth Engine.

Because of the potentially disastrous effects that global warming may have on the environment, society, and the economy, the issue of soil erosion has drawn attention from all around the world. Erosion poses a major threat to the integrity of soil stability, and fertility. Ultimately, it will reduce land productivity, threaten food security, and result in socioeconomic issues.

Traditional field measurements of soil erosion are expensive and time-consuming, even if they are precise and dependable. Consequently, a lot of scientists are currently employing predictive models that use satellite data to estimate soil erosion.

In order to assess the issue of soil erosion, the RUSLE model can be employed. It requires input data from geophysical and meteorological sources, such as slope, topography, rainfall patterns, soil erodibility, vegetation cover, and land use, even at different scales, such as regional, national, continental, and global, in order to forecast the long-term average rate of erosion (Hateffard et al., 2021; Luvai et al. 2022).

The RUSLE model is widely recognized as the most appropriate for estimating surface erosion. In the present work, the model was applied to assess potential soil erosion in the Bradano basin, located in southern Italy, using data provided by the Google Earth engine. Recent decade (2013- 2024) data from the RUSLE model, evaluated with the Google Earth engine, indicate that soil erosion has posed a severe threat to 94.4 percent of the basin, 4.4% of which has very high potential, and less than 1 percent of which has moderate to modest potential of soil erosion.

Hateffard F. et al (2021) - CMIP5 climate projections and RUSLE-based soil erosion assessment in the central part of Iran. Sci. Rep., 11(1), 7273, https://doi.org/10.1038/s41598-021-86618-z.

Luvai A. et al. (2022) - Soil Loss Assessment Using the Revised Universal Soil Loss Equation (RUSLE) Model, Applied and Environmental Soil Science, 2022(1), 2122554, https://doi.org/10.1155/2022/2122554.

S15.

Analysis and management of coastal areas, from risk assessment to perspectives arising from new technologies

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Vertical land movements and relative sea level rise scenarios up to 2150 along the Italian coasts: implications for multi-risk assessments

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Keywords: sea level rise, vertical land movements, Italy.

The coastal zone of the Italian region is highly exposed to multiple natural and anthropic hazards due to the ongoing sea-level rise triggered by global warming and land subsidence. Here we focus on the current and future relative sea level (SL) trends up to 2150 for this area which is affected by spatially variable rates of natural and anthropogenic Vertical Land Movements (VLM) (Anzidei et al., 2014). To estimate the current VLM rates we used geodetic data from about 27 years of continuous GNSS observations at a set of stations belonging to Euro-Mediterranean networks located within 5 km from the coast (Serpelloni et al., 2022), InSAR data from the Copernicus European Ground Motion Service (https://egms.land.copernicus.eu/) and additional InSAR data sets. Revised SL projections up to the year 2150 are provided for the entire coast and at the location of some tide gauges belonging to the PSMSL (https://psmsl.org) and ISPRA (https://www.mareografico.it/) networks, by including the estimated VLM in the SL projections released by the IPCC in the AR6 Report (www.ipcc.ch). Our results show that the current IPCC projections are often underestimated and not representative of the expected future sea levels since they neglect the effects of tectonics and local factors.

Here we show that revised multi-temporal sea level projections at 2030-2050-2100 and 2150 show significant differences with respect to those of the IPCC for different Shared Socio-economic Pathways and global warming levels (Vecchio et al., 2024). Finally, we present the first high resolution map of the expected flooding scenarios for 39 main coastal plains of the Italian region, based on the spatial analysis of LiDAR data available from the Ministero dell'Ambiente e della Tutela del Territorio. The geoprocessing analysis of territorial data highlighted that about 10.000 km2 are yet exposed to flooding risk, with enhanced impacts on the environment, human activities and coastal infrastructures. In this regard, land planners and decision makers should take into account these scenarios for cognizant coastal management and to support vulnerable populations to adapt to the expected relative sea level rise by 2150 and beyond.

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Serpelloni E. et al. (2022) - Surface velocities and strain-rates in the Euro-Mediterranean region: from massive GPS data processing. Front. Earth Sci., 10:907897, https://doi.org/10.3389/feart.2022.907897.

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Spheres vs. disks: real-time movement of pebbles in the swash-zone of coarse-clastic beaches

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Keywords: gravel beach, sediment transport, pebble shape.

In the past few years several scientific studies have been carried out to increase the knowledge about coarse-clastic beaches (e.g., Soloy et al., 2022). The focus on such a peculiar environment was driven by the need to get more details about the processes working, as gravel and pebble beaches have been frequently used as a form of coastal protection. The Radio Frequency Identification (RFID) proved to be the most reliable technique to analyze transport patterns of tracers both in the long- (e.g., Allan et al., 2006) and in the short-term (e.g., Bertoni et al., 2024). The results from these studies identified many interesting transport trends, in particular if sorted by the shape of the pebbles. Indeed, the shape controls the movement of the tracers in short timespans (hours): spheres tend to roll down the beachface, disks move longshore. Questions arising: What process is responsible for this separation? Is that attained immediately after the injection of the tracers or after a while?

A series of very short tracking experiments have been realized to respond to these questions. Fifty pebbles were sorted based on their shape: half were spheres, half were disks. The pebbles (ca. 4-7 cm intermediate diameter) were collected directly on the beach to avoid differences with the native sediment. As the aim of the study was highlighting the early response of the tracers to swash-zone processes, we decided to use a drone in stationary flight (at an elevation of ca. 10 m) continuously filming the movement of the tracers in the swash-zone of a coarse-clastic beach at Marina di Pisa (Italy). This methodology allows to provide information about the movement of the pebbles from the injection position to the recovery position. The pebbles were painted with bright colors to improve their identification: red are the spheres, yellow are the disks. Each video is 15 minutes long and clearly documents the early stages of movement immediately after the tracer injection.

Data acquisition was carried out under different wave conditions, but never during high-energy events due to visibility limitations. The videos were post-processed to reduce vertical tilts, horizontal shifts, and camera rotations through software such as HandBrake, DaVinci Resolve, and Tracker. This way every movement of the tracers could be tracked and easily measured in accordance with the wave state at the time of the filming. The preliminary results show that the first uprush flows already are capable to move the spheres, which roll down the beachface; gravity facilitates this process too. Disks are less prone to early movement. When the waves are very low, the tracers do not move significantly: burying processes prevail as some pebbles disappear after just a few minutes. This study fosters the use of autonomous vehicles not just for topographic surveying activities.

Allan J.C. et al. (2006) - The use of Passive Integrated Transponder (PIT) tags to trace cobble transport in a mixed sand-and-gravel beach on the high-energy Oregon coast, USA. Mar. Geol., 232, 63-86, https://doi.org/10.1016/j.margeo.2006.07.005.

Bertoni D. et al. (2024) - Pebble tracing experiment at the Promenade des Anglais (Nice, France): A contribution towards beach management efforts. Oc. Coast. Manag., 253, 107157, https://doi.org/10.1016/j.ocecoaman.2024.107157.

Soloy A. et al. (2022) - Spatio-temporal variability of the morpho-sedimentary dynamics observed on two gravel beaches in response to hydrodynamic forcing. Mar. Geol., 447, 106796, https://doi.org/10.1016/j.margeo.2022.106796.

Coastal land use transformation as a key driving factor for coastal erosion, the case study of Southern Sicily (Italy)

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Keywords: coastal erosion, coastal land use, DSAS.

Coastal zones are the most densely populated areas in the world and most of the human activities are developed here (i.e. transportation, manufacturing, energy production). As such, during the last decades, the rapid increase of population migration to the coasts has induced significant changes in coastal landscape and settings. For these reasons, understanding mid- and long-term past coastal changes and investigating coastal dynamics can support the increase of coastal community resilience and long-perspective coastal zone management and planning. The availability of free or low-expensive remote sensing data pushed forward the research on this field allowing the scientific community to seek a deeper comprehension of coastal geomorphological variations on a large or global scale (Paprotny et al., 2021). Even though global scale studies on coastal change posed the basis for identifying the main evolution trends worldwide, site-specific analyses, which also take into account local coastal behaviour, provide data and information for developing site-tailored strategies and actions for sustainablecoastal zone management. Indeed, coastal retreats are a long-term concern for coastal populations representing not only a risk for human life but also for compromising the environmental and socio-economic resources worldwide. Here, we present a combined methodology approach which couples shoreline change analysis with a detailed land cover/land use change pattern analysis along with the characterization of climate conditions. The Southern coast of Sicily (Italy) was chosen as the study case, due to the rapid population and urbanization growth which highly increased the pressures on rural and natural habitats leading to a significant change in the coastal landscape pattern. Moreover, this coastal area setting still maintains in some parts a natural geomorphological profile with a wide coastal wetlands system back to the dunes ridge and beaches thus providing a starting point for putting in place innovative coastal restoration strategies to increase the resilience of the coastal environment. The shoreline change analysis covered the period 1955-2022, the land cover/land use change analysis was performed by applying the Corine Land Cover of Coastal Zone (CLC-CZ, ref) nomenclature and codes to a 1966 map and by comparing these data to the 2018 CLC-CZ map. The analyses showed that significant coastal erosion occurred from 1955 to 2022 with negative rates up to -1.26 m/yr recorded at the beach of the touristic village of Granelli, which also underwent a significant land cover/land use change pattern passing from natural and semi-natural land cover/land use classes to artificial classes. Indeed, coastal behaviour is not uniform and the highest shoreline landward migration was registered in the correspondence of the most densely populated and urbanized areas, likely due to the reduction of inland sediment supply as well as to the decrease of the width and surface of dunes and beaches which act as buffers in responding more efficiently to landward shoreline migration.

Paprotny D. et al. (2021) - Future losses of ecosystem services due to coastal erosion in Europe. Science of The Total Environment, 760, 144310, https://doi.org/10.1016/j.scitotenv.2020.144310.

Relative sea level rise and storm surge scenarios along the coasts of Cinque Terre National Park (Liguria, Italy)

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Keywords: sea level rise, drone, coastal areas.

Global mean sea level (GMSL) is rising about 3.7 mm/year and by 2100 SL could be 1.1 m higher than the current level due to global warming (Fox-Kemper et al., 2021). Therefore, there is the need to understand the expected SLR scenarios for the next decades to mitigate the effects of coastal flooding, especially along the low-lying coastal zones which are the most exposed to SLR. In addition, increased frequency and intensity of extreme meteorological events that trigger high water levels, coupled with coastal erosion and saltwater intrusion into freshwater aquifers, are among the most critical environmental consequences of SLR (Cazenave & Le Cozannet, 2014).

Beyond the global SLR, local-scale assessment must include the contribution of vertical land movements (uplift and subsidence) due to natural and anthropogenic factors, that can produce significant local variations in relative sea levels. Therefore, the rates of VLM need to be included in SLR projections for accurate evaluation of the vulnerability of specific coastal areas exposed to flooding (Vecchio et al., 2023). To assess the impacts of sea-level rise triggered by ongoing global warming, we have conducted a thorough evaluation of the expected coastal flooding up to the year 2150 for the different sea-level rise projections released by the IPCC www.ipcc.ch in the AR6 Report. To this end, we included the current rate of local land subsidence (VLM), estimated via GNSS data collected by the available GNSS station located in the studied area. The assessment included high- and very high-resolution digital terrain and marine models extracted from topographic LiDAR data, photogrammetry surveys via UAV and high-resolution multibeam bathymetry. Through these efforts, we developed detailed multitemporal maps of expected inland extension of SLR for 2030, 2050, 2100, and 2150 of the three most exposed coastal zones of the Cinque Terre coast. The expected potential inundation scenarios, as well as in storm surge conditions, for return times of 1 and 100 years, were also modeled. In this work, we integrate ultra-high resolution digital terrestrial and marine elevation models obtained from state-of-the-art optical and acoustic sensing techniques framed within the National Reference System (RDN2008 and Italgeo 2005) on which we model relative sea-level rise scenarios according to the revised IPCC projections for VLM under ordinary and storm surge conditions. With these scenarios, there is an urgent need for adaptation strategies to address the social and economic losses due to the expected RSLR for this area.

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Fox-Kemper B. et al. (2021) - Ocean, cryosphere, and sea level change. In Climate Change: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; Masson-Delmotte, V., Zhai, P., Pirani, A., Eds.; Cambridge University Press.

Vecchio A. et al. (2023) - Sea level rise projections up to 2150 in the northern Mediterranean coasts. Environ. Res. Lett., 19, 014050, https://doi.org/10.1088/1748-9326/ad127e.

A new isoradiometric remotely-sensed shoreline extraction method: a time series case study in southern Sicily (Central Mediterranean region)

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Keywords: landscape evolution, remote sensing, isoradiometric method.

The recent development of remotely sensed shoreline extraction techniques significantly improved the understanding of the coastal Landscape Evolution (LE) supporting the management of the natural (e.g. climate change, tectonics) and anthropic processes shaping these areas. Improving our understanding of the past evolution could provide critical information for forecasting future coastal landscape scenarios for better coastal management and mitigating the natural hazard linked to coastal erosion processes.

Here, we propose a newly developed Isoradiometric shoreline extraction Method (IM) to accurately locate the shoreline using optical satellite imagery and for time series production (Maltese et al., 2023, 2024). We designed and tested our methodology along 10 km of sandy coastline in Sicily (central Mediterranean) and, subsequently, we applied it along 40 km of Southern-Sicily coastline. We extracted the shoreline using over than 40 years of publicly available satellite imagery, by also relating with rainfall and marine weather data. The IM application, characterized by a geometric accuracy of approximately one-third of the satellite product's resolution, allowed us to discriminate and quantify the coastal sectors affected by erosion and deposition processes.

Our results highlight that the IM by performing accurately for coastline positioning and coastal LE, could represent a valuable tool for coastal management and for the erosion risk detection and mitigation. Furthermore, relate the time series shoreline analysis to rainfall and marine weather data, could also represent a proxy for the quantification of the impact of extreme weather events which are increasingly affecting the Mediterranean region.

Maltese A. et al. (2023) - A radiometric contouring approach to map the shoreline. In Remote Sensing for Agriculture, Ecosystems, and Hydrology XXV, 12727, 57-66.

Maltese. A. et al. (2024) - On the shoreline positioning via remote sensing imagery: an isoradiometric approach. Journal of Applied Remote Sensing, 18(1), 014529-014529, https:/7doi.org/10.1117/1.JRS.18.014529.

Analysis of the sea cliff collapse and the subsequent fall of the Camogli cemetery on February 22th, 2021 (Liguria, Italy)

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Keywords: rocky coast, cliff collapse, Camogli (Italia).

On 22 February 2021, a portion of the rocky cliff in the north-eastern sector of the municipality of Camogli collapsed. The landslide phenomenon involved part of the cemetery structures that stand on the edge of the cliff, causing international media attention.

Camogli is a renowned Ligurian seaside village of touristic importance, located about 20 km east of Genoa; its territorial layout reflects the main features of the high, rocky Ligurian and Mediterranean coastline.

The cliff is made up of rock masses belonging to the Mt. Antola formation: marly limestones and marls with siltstones and shales interlayers. It is an active coastal landform, i.e. currently shaped by the sea.

The layout of the coastline in a north-west/south-east direction is a predisposing factor in terms of slope instability, as it exposes the rocky scarp to the SW wave action ("Libeccio" auct.), which in extreme conditions can have heights of more than 5 m.

The structure outlined leads to a dynamic of the rocky cliff in substantial retreat: collapse phenomena, from the escarpment to the sea, occur annually; in January 2014, a phenomenon similar to the one under examination occurred between Genoa and Bogliasco.

The widespread urbanization that has taken place since the second half of the 19th century, first slowly, by infrastructure building, and then rapidly, through the construction of buildings with different purposes, has made this stretch of coastal strip at high geo-hydrological risk.

This research presents information on the historical, recent and current morphological dynamics of the Camogli cliff obtained through a multi-temporal analysis based on cartographic comparisons, topographic surveys and remote sensing activities.

Particularly meaningful was the survey carried out in 1915 along the coastal strip during the planning of the railway extension: a comparison of the position of the cliff edge in 1915 and in 2014, from another survey, revealed a retreat of up to 5 m.

Finally, a detailed, change detection analysis, carried out on imagery from the last 50 years testifies cliff evolution.

Analysis of coastal retreat and slope movements on rocky coastal cliff between Sori and Pieve Ligure (Eastern Liguria, Italy)

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Keywords: cliff retreat, natural hazard, coastal monitoring.

About 80% of Mediterranean coasts are represented by the high rocky type, which is characterized by erosion phenomena; the cliff retreat rate is generally not constant due to the rock masses properties.

Ongoing climate change results in intensified hydro-meteorological hazards, including storm surges: the effect on high rocky coasts leads to significant energy impacts. This is evidenced in the Mediterranean area by the events that have occurred in recent decades, with often destructive effects on the coast, as in the case of Cyclone Vaia in 2018 and other storms that have affected the Mediterranean Sea in the third millennium (Borzì et al., 2024).

Also nationally, the coastal morphotype is about 2/3 high and rocky, for large stretches characterized by active geomorphological dynamics. In this area, in addition to the recognized hazard level, often related to different natural processes, high risk conditions are materialized too: in fact, the interaction of natural hazards with the presence and vulnerability of both strategic infrastructure, such as roadways and railway lines, and with anthropogenic activities and structures, such as buildings with different purposes, occurs.

This research shows the results of geomorphological evolution and monitoring activities of the high rocky coast between Sori and Pieve Ligure, less than 10 km from the city of Genoa.

The coastal sector under study consists almost entirely of cliffs, with small beaches at the mouths of streams (Provincia di Genova, 2004). The cliffs are shaped in the Mt. Antola Flysch, consisting of marly limestones, marls with sandstones and shales interlayers.

The cliffs are between 10 and 30 m high, in some areas more than 50 m; they are always active and have very steep gradients, sometimes they are vertical (Lucchetti et al., 2014).

Recent and current coastal dynamics were assessed both through original cartographic and photographic comparisons, and experimental surveys conducted by employing photogrammetric restitution techniques from aerial images taken by UAVs with the support of high-precision topographic measurements of known points on the ground and 3D surveys made by terrestrial laser scanners.

Borzì A.M. et al. (2024) - Long-term analysis of microseism during extreme weather events: Medicanes and common storms in the Mediterranean Sea. Sci. Total Environ., 915, 169989

Lucchetti A. et al. M. (2014) - Proposta di valutazione della stabilità delle coste rocciose (SCMR-Sea Cliff Mass Rating): il caso studio delle falesie tra Genova e Camogli (Liguria orientale). Studi Costieri, 22, 137-149.

Provincia di Genova (2004) - Studio dell'Ambito Costiero tratto tra Punta Vagno ed il Golfo Paradiso. Area 06 Difesa del Suolo, Opere Ambientali e Piani di Bacino, 256 pp.

Erosive effects of sea-storms, human pressure, and sea level rise on Volturno coastal plain (mid-Tyrrhenian area): present to future coastal hazard

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Keywords: storm surge, climate change, coastal vulnerability.

Climate and sea-level changes are some of the main topics mankind will have to face in the coming decades. This research focuses on an integrated approach based on using innovative modeling tools and technologies to estimate the effects of sea storms, whose frequency and magnitude are increasing due to climate changes, and sea level rise expected for 2150 on low-lying coastal areas. It is oriented to past storm surges, sea-level, and shoreline reconstructions to model future coastal changes driven by climatic forcing, taking into account anthropic impact and coastal subsidence.

Volturno coastal plain is one of the most populated coastal areas along the mid-Tyrrhenian Sea; it spans both sides of the namesake river and is the second widest river plain in Southern Italy. We will be monitoring this area as it is part of the PRIN project "GAIA", concerning the flood risk assessment of the most important plains and beaches along Italy's coastline.

The area is mostly exposed to meteo-marine forcings in the sector between 200 and 280 N°, therefore major storm surges registered by a near wave buoy were analyzed for this sector, to evaluate the coastal effect of the main flooding that occurred in the last 35 years. Peak Over Threshold (POT) methodology was used for this evaluation by considering events with a minimum significant wave height greater than the 90° percentile of total records and a duration of at least 12 hours. So obtained storms were divided into 5 categories, based on their energy index, and a frequency histogram was calculated for the obtained events to retrieve the return period referring to each category. A crucial step of this work was the calculation of shoreline movement trends, carried out in a GIS environment, for 3 zones: the northern sector, from Mondragone to Pescopagano, has remained stable over the last 20 years; the Volturno river mouth sector was strongly eroding before the year 2000, but this trend has inverted over the last 20 years thanks to the construction of two submerged breakwaters and substantial beach nourishment; the southern sector, from south of Pineta Grande to Lago patria, is substantially stable, slightly eroding with a rate of about 1,5 - 2 meters per year where the coastline is not protected by any breakwater.

Local basin authority reports classify this coastal area into four flood risk categories as a result of the combination of hazard level, erosion rates, and exposed value; flooded areas were evaluated as a function of wave runup and wave setup calculation for a storm surge with a return period of 100 years.

A similar approach was proposed to estimate how sea level variations will affect extreme events frequency and their impact: numerical modeling allowed the estimation of flooded areas, also taking into account sea level rise prediction reported by the IPCC in their last work. These refer to three different scenarios and provide, for each of them, the expected sea level rise, until the 2150.

Beach-dune systems in a transgressive domain along the Sardinian coasts

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Keywords: coastal dunes, sedimentologic analysis, geomorphological survey.

Coastal transgressive dune fields represent an unusual state of the beach-dune system in current temperate zones. Knowledge of the factors responsible for the transgressive activation is a tool for inferring similar conditions in the past and evaluating the potential of sand drift re-activation in the context of climatic change. The sole examples of active transgressive dune fields in Italy are on Sardinia's west coast, due to conditions of strong unimodal wind from the north-west. In the context of a project funded by the Italian Ministry of University and Research (MUR-PRIN 2022), we present a series of preliminary results regarding the land-sea continuum of the coast of Piscinas (Sardinia, Italy), where an active dune field develops, covering 132 ha. The main aim is to investigate the role of transgressive aeolian episodes as potential environmental indicators as part of a larger understanding of their significance on a local and global scale.

The first results, regarding the Piscinas site, are based on a detailed geomorphological description obtained by UAV and GPR surveys, as well as a stratigraphic survey of the Pleistocene aeolianites outcropping along the coasts. On the continental shelf facing the study area, geophysical data have been acquired in the last 15 years, including high-resolution morpho-bathymetric surveys, acoustic backscatter maps, and high-resolution seismic profiles. The main parabolic dune, aligned with the prevailing Mistral wind (from the northwest), extends from the coast for about 2 km inland to a maximum altitude of 113 m. Topographic sections and GPR profiles show the presence of a geological control due to the gradually sloping Paleozoic rocky basement over which the dune accommodated while climbing. Buried post-LGM (Late Glacial Maximum) aeolian deposits of partially consolidated sands were also recognized. These sands represent the sediment layer of the established transgressive dune field and serve as the sediment source of the current active dune lobes, migrating downwind. Extensive outcrops of Middle and Upper Pleistocene aeolianites throughout the coasts attested to extensive aeolian activity in the context of sea level rise variation and tectonic stability in the past. A preliminary examination of the marine landforms on the inner shelf reveals the presence of parabolic bodies at a depth range of 31-40 m. These relict coastal landforms attest to an aeolian pulse affecting the exposed continental shelf during the LGM, as a continuum to connect with the analogous signature on land.

The integrated analysis using direct and indirect stratigraphic information collected in the coastal area will allow reconstruction of the depositional palimpsest and order of accommodation of several aeolian transgressive bodies during the transgression, highlighting possible differences or analogies between the current transgressive domain and the climatic phases that drove aeolian activity during the late Quaternary.

Analyzing coastal cliff stability and recession rates along the Safi Atlantic Coast, Morocco

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Keywords: coastal cliffs, recession rates, DSAS method, Atlantic coast.

Coastal cliffs play a crucial role in the stability and sustainability of coastal regions, having an impact on infrastructure, settlements and economic activities. Understanding cliff recession rates and the underlying factors that influence them is essential for effective risk management. This study examines the evolution of coastal cliffs along a 48 km stretch of the African Atlantic coast in Morocco, from Cap Beddouza to Jorf Lihoudi.

The instability of these cliffs presents significant geological risks, as evidenced by the various types of landslides along the coastal cliffs. These landslides cause the cliff tops to retreat, while the collapsed blocks at the base of the cliffs offer some protection. Using aerial imagery, in particular aerial photography from 1954 and orthophotography from 2020, and GIS techniques, we calculated the rate of change of cliff tops since 1954. Spatial assessments using statistical methods such as LMS (Least Median of Squares), LRR (Linear Recession Rate), and EPR (End Point Rate) were used to estimate rates of coastline change.

Our results show that most of the coastal area of the Safi region has experienced cliff recession, with rates varying between 0.07 and 0.04 m/year. The central part of the study area showed the highest rate of recession, exceeding 0.10 m/year. This spatial variability in recession rates is influenced by geological and morphological factors such as the composition of low-strength clay rock formations, which favour large-scale gravitational movements.

The results of the study offer new perspectives on coastal hazards in this densely populated region of Morocco. Cliff recession has a significant impact on economic, social and environmental risks in the region. In addition, this research represents one of the first applications of the Digital Shoreline Analysis System (DSAS) on an African coastline and provides new information on cliff recession rates in Africa.

Mediterranean Sea surface response during the cyclone events: mpacts on physical and biogeochemical parameters

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Keywords: Mediterranean sea, cyclones, sea surface response.

The Mediterranean Sea is becoming a hotspot for intense tropical-like cyclones, called "Medicanes" (Scardino et al., 2024). The distinctive characteristics of the Mediterranean basin make it an important area of study for monitoring global environmental changes. Italy, Greece, and Malta perceive the most frequent cyclone landfalls among coastal regions and bear significant destructive impacts (Pytharoulis et al., 2018). However, the hazards associated with these events are escalating due to rapid urbanization, extensive socio-economic development, and global warming. Despite their advanced development, these regions remain susceptible to such disasters. The impact of cyclones, characterized by strong winds, heavy precipitation, and storm surges, leads to severe economic losses and casualties (Bakkensen, 2017). Consequently, this study aims to unveil the Mediterranean sea surface response during cyclone events, focusing on key variables such as sea surface temperature, significant wave height, surface currents, and the transport of dissolved nutrients influenced by upwelling processes triggered by these cyclones (Menna et al., 2023). Understanding these variables is essential for comprehending cyclones' complex dynamics and potential impacts on coastal geomorphology.

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Ongoing vs. Holocene morphodynamic effects of sea-level changes: a new perspective for the assessment of coastal resilience to climate changes

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Keywords: climate change, resilience to coastal flooding, relative sea-level rise.

In the context of ongoing climate changes, low-lying coastal areas certainly are the most vulnerable to accelerated sea-level rise and increase in magnitude and frequency of storm events (Zhongming et al., 2022).

This study reconstructs the Late Holocene morpho-evolution and relative sea level (RSL) changes to predict future morpho-dynamic trends taking into account IPCC predictions and recent coastal subsidence in a mid-Tyrrehnian sector along the Mediterranean shores. A RSL geodatabase was compiled according to international standards from direct geoarchaeological measurements, stratigraphic and palaeoecological interpretations of new borehole data, and reinterpreting bibliographic information.

Based on the collected data, a first stage of accelerated sea level rise between 8.0 and 6.5 ka BP, was evaluated with a mean rate of 25 mm/yr, during which the plains in the study area were progressively flooded. During the second stage with sea-level rise rates less than 5 mm/yr, the coastal progradation prevailed. In particular, geoarchaeological data demonstrated that RSL rise in the last 2000 years was no higher than 0.55 ± 0.29 m MSL (Caporizzo et al., submitted). Presently, the RSL rise is accelerated by coastal subsidence between -0.58 ± 0.94 mm/y and -1.23 ± 1.53 mm/y (https://egms.land.copernicus.eu/) inducing a progressive reduction of the progradation trend toward a coastline equilibrium (annual variations of less than one metre).

A statistical approach was applied to this dataset to evaluate the coastal response of these low-lying sectors to past and future climate changes. Specifically, a three-step procedure was applied to data analysis. Firstly, we computed the curve of RSL change rates using the model "Errors in Variables Integrated Gaussian Process" (EIV IGP, Cahill et al., 2015) that performs Bayesian inference on the sea-level change dataset. Secondly, we dated the morpho-dynamic inversion from submersion to progradation that occurred in the mid-Holocene when the rate in sea-level rise globally decreased due to glacio-hydro-isostatic effects. Finally, we compared the local curve of RSL change rates with the RSL rise rates expected up to 2100 according to the three most probable IPCC scenarios (i.e., SSP2-4.5, SSP3-7, SSP5-8.5), by correcting them with recent local coastal subsidence. The probability of flooding reaches 100% for the worst SSP5-8.5 scenario for all the low-lying sectors. Instead, in the case of SSP2-4.5 and SSP3-7.0 minor likelihood of resilience was measured.

In conclusion, the potential resilience to the climate-driven effects of expected sea-level changes was assessed along the mid-Tyrrhenian coasts through the comparison between past behaviours, future RSL rise and present morphodynamics in terms of shoreline movements.

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New approaches for coastal zone monitoring aimed at litter detection in emerged and submerged environments

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Keywords: Artificial Intelligence, marine conservation, litter detection.

This work presents cutting-edge research based on the application of artificial intelligence (AI), image processing, and computational intelligence methods to address the critical issue of marine and coastal ecosystem conservation, focusing on emerging and submerged environments.

Specifically for underwater debris detection, research is conducted using the ARGO drone equipped with onboard cameras and minimal computational resources for real-time data processing (Mattei et al., 2024). Central to the advancements is the ArgonautAI platform, which uses a distributed processing system on single-board computers, orchestrated via Kubernetes, to facilitate efficient marine debris detection. This setup enables real-time, accurate object recognition with minimal environmental impact, making it suitable for use in protected marine areas. Furthermore, the study incorporates image processing methods such as SeaThru for color reconstruction and SCOUTER (Li et al., 2021), a slot-attention-based classification, to improve the accuracy and explainability of underwater litter detection. In addition, a novel methodology that integrates Graph Convolutional Networks (GCN) with Explainable Artificial Intelligence (XAI) aims to significantly improve marine debris classification and provide transparency in the decision-making process of AI models.

Our research is dedicated to addressing the critical issue of beach debris management by applying state-of-the-art methods for detecting, classifying, and tracking debris. By integrating advanced technologies such as the SegmentAnything (SAM) (Kirillov et al., 2023) and the Vision Transformer (ViT) (Dosovitskiy et al., 2020), we aim to redefine the landscape of marine debris monitoring and conservation. These state-of-the-art algorithms enable us to achieve unprecedented levels of accuracy and efficiency in identifying debris in aerial drone imagery, facilitating targeted cleanup efforts and conservation initiatives. In addition to our focus on surface litter, we recognize the importance of exploring the underwater domain to gain a holistic understanding of litter distribution and dynamics. Through the use of optical flow techniques, we seek to meticulously track the movement of marine debris below the surface to shed light on its behavior and transport patterns. We are also actively involved in the development of advanced multi-object tracking algorithms tailored to the unique challenges of detecting and tracking moving debris in aquatic environments. These sophisticated algorithms allow us to monitor the movement of debris in real time, facilitating timely intervention to prevent further environmental degradation and protect fragile marine ecosystems.

The presented work aims to integrate these innovative methodologies to allow a synergy of work and research from the perspective of acquisition tools, data processing, and algorithms aimed at marine litter research, both emergent and submerged, and on beaches.

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Li L. et al. (2021) - Scouter: Slot attention-based classifier for explainable image recognition. Proceedings of the IEEE/CVF International Conference on Computer Vision, 1046-1055.

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Dosovitskiy A. et al. (2020) - An image is worth 16x16 words: Transformers for image recognition at scale. ArXiv preprint arXiv:2010.11929 .

Methodology for the assessment of coastal morphodynamics due to storm surges in the Mediterranean area using machine learning and remote sensing data

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Keywords: coastal moprhodinamics, machine learning, remote sensing.

The coastline is a dynamic environment that is subject to continuous changes induced by natural and anthropogenic factors. Understanding these changes is critical for sustainable management of coastal resources. In this study, we propose a methodology for assessing coastal dynamics in the Mediterranean Sea by combining Sentinel-2 satellite images and storm surge data. Sentinel-2 images were used to extract coastlines using the open-source CoastSat library (Vos et al., 2019). Storm surge data from Copernicus Marine "Med-WAW: Mediterranean Sea Waves Reanalysis" was used to assess the influence of storm surges on coastal morphology. To access the remote sensing dataset, it is possible to take advantage of the free endpoint service offered by Google Earth Engine to automatically download a set of multispectral images from Copernicus Sentinel-2. Individual scenes were classified by a neural network using the Python library scikit-learn; for each pixel of each multispectral scene, four classes were defined: sand, water, white water, and others. In addition, the 3 × 3 variance of each pixel and spectral index made it possible to improve the classification (e.g., to distinguish sand from some types of roofs or terraces). A pretrained neural network was freely available by the CoastSat project (Vos et al., 2019). In a subsequent step, the boundary between sand and water was determined by applying an index called MNDWI (Xu, 2006), after using a super-resolution border segmentation (Cipolletti, 2012) algorithm is possible to obtain *iso-values* and coastline for each scene. Knowing the slope of the beach, it is possible to correct the derived position using astronomical tidal data. In cases where the retreats or advancement of the shoreline due to tides are largely less than the geometric accuracy of the data extracted from Sentinel-2 images, these corrections can be omitted. Several sections orthogonal to the coastline, called transects, are defined, for each of which a time series of the coastline's position along its development can be derived by intersecting the previously obtained data. The Copernicus Marine dataset "Med-WAW: Mediterranean Sea Waves Reanalysis" (EU Copernicus Marine Service Information, 2024) offers the possibility of hindcasting analysis of weather and sea conditions. Through correlation analyses with shoreline movement, it is possible to assess the presence of physiological response phenomena to storm surges using the coastal dune system. We then proceeded to extract the extreme marine events that characterized the investigated area in the chosen period using a threshold for the significant wave height VHM0 parameter. Thus, the temporal "list" of extreme events was obtained. For each of these storm surges, it is possible to investigate the morphodynamics of the coastline due to extreme events through comparison with the transect time series.

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Using deep learning system-based for tide and surge measurement

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Keywords: deep learning, storm surge, coastal monitoring.

In recent years, the development of artificial intelligence and machine and deep learning techniques have attracted the attention of various research fields. Among them, the field of land and environmental study has seen some development in applications of this type by placing some interest in remote data acquisition, measurement of marine parameters and their automated analysis (Scardino et al., 2022; Sabato et al., 2023). This work focuses on the implementation of a deep learnig model based on Inception V3 capable of automatically measuring, after appropriate training, the height of tides and storm surge at a given site using fixed camera images. This solution is useful at sites where tide gauges are far from the measurement point and especially for calculating storm surge at the site of interest. The study was carried out on two different Italian locations, the first in southeastern Sicily, in the center of the Mediterranean and called Santa Lucia, and the second in the north of the country called Lignano Sabbiadoro. For convenience and better performance, the development environment was created on Google Colab. To train the deep learning model, a dataset of images was created for each site, and each frame was axed with the corresponding value measured by an in situ instrument. The dataset partitioning was done according to the literature, which as the best partitioning has 70% of the images used for Convolutional Neural Network (CNN) training and the remaining 30% for validation (Götz et al., 2022). Once the model was trained, prediction was performed on images of the site. The algorithm performed well with accuracy above 90% and Categorical Cross Entropy Loss less than 1. Confusion matrices also show good results and the calculated F1 score is above 0.9 (Huang et al., 2015). Finally, from the comparison of the actual values and those processed by CNN, it was possible to see that the values are very similar to each other and the corresponding time-sheets could be processed. In conclusion, the incorporation of systems such as the one presented in this paper could bring many advantages, such as having almost instantaneous feedback on the consequences from intense weather events and eliminating the need for in-person inspection by the operator. These findings underscore its potential to fill the data collection gap in challenging coastal environments, offering valuable insights for coastal management and hazard assessment. This study makes an important contribution to the rapidly growing field of remote sensing and machine learning applications in environmental monitoring, facilitating greater comprehension and decision-making in coastal areas.

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On the resilience to climate change of sites of community importance (SCI): the case of Cala del Cefalo (Southern Italy)

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Keywords: climate change, coastal resilience, dune system evolution.

On sandy shorelines, coastal dunes represent a reservoir of sand for waves during storm surges. Storm-cut erosion and recovery is a normal coastal process, but, in the last centuries, human activities have altered this natural balance, making coastal evolution studies crucial for sustainable management of the coast, particularly in areas with a relevant role in naturalistic conservation.

The aim of this research is the evaluation of coastal changes that occurred since 1954 along the sandy stretch belonging to the site of community importance (SCI) "Spiaggia del Mingardo e Scoglio di Cala del Cefalo" in the Campania Region (Southern Italy). The area is part of the PRIN project "GAIA", concerning the flood risk assessment of the most important plains and beaches in Italy.

Through an integrated GIS/Google Engine analysis of topographic maps, aerial and satellite photos, and new high-resolution photogrammetric data, a retreating trend of both the shoreline and the dune system has been observed. Shoreline trends show that the coast has retreated about 82 meters since 1954. Still, it is important to underline that the erosion trend has significantly slowed down since the institution of the SCI.

Dune shows a similar retreat trend, quantified over the whole period, with a maximum of 78,5 m in the northern sector; the highest degradation has been detected between 1998-2006 and 2011-2016, witnessing the great erosive effects of the two storm surges occurred in 1999 and 2014. The great influence of storm surges on the state of conservation of the coast is testified by wash-over fans and strongly degraded vegetation cover.

The Normalized Difference Vegetation Index (NDVI) clearly shows an intense alteration of dune toe vegetation, deeply stressed out by the increasing frequency of significant storm surges. Numerical modelling testified that even storm surges with significant heights of less than 5 m and long peak wave periods can strongly impact dune toe stability and flood the backshore area. Another result is the estimation of flooded areas and the calculation of the run-up for high-magnitude storm surges, which goes from 3 m to 7,5 m.

The inversion of the dunal succession has been observed thanks to a floristic transect carried out along the main Natura 2000 pathway, with the secondary vegetation present up to the hind dunes and the salinization of an entire swath of vegetation. The progressive retreat of the dune can be also observed thanks to the presence of pines along the secondary vegetation line.

This work provides evidence of the high impact of storm surges on beach and dune environments, showing the importance of an integrated approach for the analysis of coastal dynamics in a fast-evolving world, where human presence could strongly interfere with natural processes. The potential erosion risk is crucial for correct coastal management which considers the expected increase in storm surge frequency and magnitude strictly related to climate change.

Coastal flooding risk scenario for the city of Grado, northern Adriatic Sea

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Keywords: coastal flooding, storm surge, sea level rise.

Sea level rise, along with fast urbanization, has significantly raised flood hazards in coastal areas due to both increased population and the frequent urgent situations encountered in the urban context (Neumann, 2015). Rigid defensive systems along shorelines, backshore, and perimeter embankments at the lagoon border must therefore undergo structural verification and accurate elevation control, adapted to the expected sea level rise over which extreme events emerge.

In this regard, a thorough investigation was conducted on the city of Grado, located in the North Adriatic Sea and representing one of the most important coastline and heritage sites in Friuli Venezia Giulia. The city is located on a barrier island and is prone to flooding from both the sea and from the back lagoon.

The examination of the historical dataset of mean sea level and maximum levels recorded between 1991 and 2022 allowed us to first obtain local elevation estimates while also including subsidence. The study then looked at the duration of annual exceedance of the minimal threshold level of 110 cm, which marks Grado's first significant marine ingression. Annual extremes were then processed using the Gumbel-type distribution law (Gumbel, 1958; Coles, 2001), which modulated the level thresholds with their respective return times for the location. Finally, the reconnaissance includes a downscaling examination of the impacts on the urban fabric, which is divided into regions of different vulnerability. Inundated areas were compared from high-resolution DEMs using a GIS-based technique and a modeling approach utilizing MIKE software, analyzing both the magnitude and exposure of the urban setting to flood risk estimated for 2050 and 2100. As of today, approximately 56% of Grado's inhabited area is inundated with a sea level threshold value of 151 cm, which occurs during surge episodes with a 30-year return period. By 2100, with an optimistic forecast (SSP1-2.6) of local sea level rise of around +50 cm, the same threshold will be met with events with a 30 times shorter return time. As a result, by 2100, 56% of the land area will be submerged at least once a year due to 101 cm surges. Extreme levels linked with more catastrophic events with secular recurrence times will be achieved on a multi-year basis, flooding more than 70% of the urbanized area. This makes it more important than ever to develop proper adaptation measures from the outset. The simulations developed are thus essential for medium to long-term urban planning, with the goal of securing the city, which, like Venice, is indicative of the processes that may affect other coastal realities and historical cities of great national worth.

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Relative Sea Level Rise projections and flooding scenario for 2150 A.D. for the Panarea Island and Islets (Aeolian Islands, Italy) by Ultra High-Resolution terrestrial and marine Digital Elevation Models

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Keywords: sea level rise, DTM, Panarea.

The volcanic complex of the island of Panarea and the islets of of Bottaro, Lisca Bianca, Lisca Nera, Panarelli and Dattilo located in the Aeolian Archipelago (southern Tyrrhenian Sea), are undergoing sea level rise, variable land subsidence, coastal erosion and retreat of beaches and high coasts due to gravitational instability. To assess the expected coastal changes by 2150 according to the climatic scenarios reported in the AR6 Report of the IPCC (www.ipcc.ch), that predict a global sea level rise even more than 1 m, a detailed evaluation of the potential coastal flooding has been estimated in the frame of the PANDCOAST project, funded by the INGV.

Here we focus on the use of Unmanned Aerial Vehicles (UAVs) imagery combined with GNSS and high-resolution multibeam bathymetry data collected in different years for the generation of the very high-resolution Digital Terrain and Marine Model (DTMM) of the Panarea Island and its archipelago.

Scenarios are based on accurate high-resolution Digital Surface Models, vertical land movements and climatic projections released by the Intergovernmental Panel on Climate Change (IPCC) for the SSP2.6 and SSP5 climatic scenarios for this area, are used to map the expected multi-temporal sea level rise scenarios up to 2150.

In the analysis have been incorporated the effects of the vertical land movements (VLM) as estimated by local GNSS geodetic network located in the archipelago. Assuming constant rates of VLM for the next years, relative sea level rise projections provide values between 31±11 cm by 2050 and 104±27 cm by 2100 for the IPCC AR6 SSP8.5 scenarios and at 27±10 cm by 2050 and 73±24 cm by 2100, for the IPCC AR6 SSP2.6 scenarios, with small variations for the individual islets of the archipelago, depending on their VLM rates.

Moreover, detailed studies on Dattilo Island also show the importance of regional tectonic structures to enhance gradual island dismantling.

With the above scenarios, the low-lying sectors of Panarea Island and its archipelago are exposed to increasing coastal retreat that continuously threatens the stability of coastal areas (pocket beaches and cliffs) and local infrastructure.

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Coastal hazard in tuffaceous high coast in the Gulf of Naples (South Italy)

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Keywords: high coasts, coastal hazards, Gulf of Naples.

Italy boasts numerous volcanic regions along its coasts. In these areas, scientific interest is mainly focused on volcanic and seismic hazards, while natural hazards related to landslide phenomena and coastal erosion suffer less attention from the scientific community. Therefore, this study aims to identify the main predisposing factors to landslide phenomena (rockfall/rockslide) in tuffaceous coastal cliffs in the Gulf of Naples volcanic area (Southern Italy), to evaluate possible relations between the different predisposing factors (e.g., weathering, geomechanical characteristics of the rocks, ground deformation, etc.), and the triggering factors (e.g., seismicity, sea storms, rain, temperature, etc.).

In this area, pyroclastic deposits and fractured volcanic tuff form the coastal cliffs giving rise to significant erosion and landslide processes, such as the large one that affected the right side of Miseno promontory on March 25, 2015. The event resulted in the detachment of about 90.000 m3 of material from the slope reshaping the morphology of the coastline.

In order to determine and understand the predisposing factors for the occurrence of these large events a multistep analysis considering different datasets was carried out. The analysis started with a comprehensive literature review to obtain information regarding the number of events that previously occurred in the area, followed by a thorough geological and geomorphological field survey to identify and map key indicators of slope instability.

In a third step, a meteorological database was used to obtain accurate measurements of various meteo-climatic parameters (temperature, rainfall, wind, humidity, atmospheric pressure), with a time-frequency of 10 minutes over a four-year period (2014-2017). In the following step, the analysis provided a comparison with UAV survey carried out in different parts of the coastal sector and to define the failure mechanism of the tuffaceous cliff, field data from meso-structural stations were selected since discontinuity systems characterizing rock masses play a fundamental role in predisposing rocky slopes to failure processes. Finally, the morphological changes that occurred in the area in the last 200 years were analysed, by using ancient topographic maps, observing that large landslide phenomena have already been reported in the area since the 17th century.

The results of this research provide important advances in the knowledge of coastal hazards in volcanic high coasts in the Gulf of Naples area, leading to an accurate zonation of these coasts *i.e.* the division of the coastal area into sectors, and the relative ranking according to degrees of actual or potential hazard of coastal landslide occurrence. In addition, the analysis of the correlations between the different influencing factors could prove highly valuable for early warning actions and policies, especially considering that it is a densely urbanized area.

The drowned physical landscape of Porto Cesareo coastal area (southern Apulia, Italy)

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Keywords: LIDAR, collapse dolina, Salento.

The LIDAR survey of Porto Cesareo area (Ionian coast of southern Apulia) realized in the 2013 by Ministero dell'Ambiente allowed the morphology of the submerged physical landscape of this coastal area to be analysed in great detail.

As already surveyed by Sanso' et al. (2020), the present sea level reaches the outer margin of the lowest marine terrace, stretching from about 4 to -1 m above sea level. A submerged steep scarp divides this partly emerged terrace from a lower, submerged one placed stretching from -10 m to -26 m which roughly follows the present coastline. A wider marine terrace is recognizable at about 30 m of depth, bordered by two steep WNW-ESE trending scarps; as the higher one, also this surface shows a gently southestward dipping. The upper portion of the lowest platform has been surveyed at about 45 m of depth.

The LIDAR survey reveals a number of short river valleys which cut the scarp placed between the second and the third platform. More interestingly, a number of deep morphological depressions can be detected on the third platform; they cluster in an area close to the outer margin of the platform and in its northwestern sector. These depressions show a maximum length of 1250 m and the maximum depth from the marine surface of about 6 m.

These peculiar submerged landforms can be interpreted as collapse dolinas or bedrock collapse sinkholes (Waltham et al., 2005), similar to those ones which characterize the emerged part of this coastal area, locally named "*spunnulate*". The genesis of these landforms is due to effective solutional processes in the Pleistocene calcarenites. According to Bruno et al. (2008) solutional processes are related to the mixing of saltwater encroaching from the sea and fresh groundwater from the aquifer, that increases the aggressiveness and the dissolution capability of water. Furthermore, cavity roofs collapse may be also promoted by chemical and biological action at the surface due to the coastal swamp fauna and flora hosted in the topographic depressions which fill the surface karst features such as solution pans and grooves with soil and vegetation. This leads to three different types of erosion of the carbonate rocks: secretion of chemical substances, physical disintegration, and chemical processes caused by the decay of organic matter. These processes are responsible for the shaping of tabular cavities whose roof collapse produced subcircular, coastal lakes.

The morphological analysis of Porto Cesareo submerged physical landscape reveals that collapse dolinas similar to the present ones formed several time during the Middle – Upper Pleistocene underlining the necessity to achieve a better understanding of "*spunnulate"* genesis since they produce a significant geomorphological risk along this coastal area.

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Sansò P. et al. (2020) - Sand Ridges on Rocky Coastal Platforms as Markers of Tsunami Impact: A Multi-Disciplinary Analysis along the Ionian Coast of Southern Apulia (Italy). Geosciences, 10, 204, https://doi.org/10.3390/geosciences10060204.

Waltham T. et al. (2005) - Sinkholes and subsidence. In: Karst and Cavernous Rocks in Engineering and Construction. Springer Praxis, 382 pp.

S16.

Geomaterials for a Sustainable Development

CONVENERS & CHAIRPERSONS

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Characterization and use of biochar, a sustainable material, for water purification and carbon storage

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Keywords: carbon, sustainability, water.

Biochar is the solid material obtained for the thermal decomposition of biomass through pyrolisis. Its production process allows concentration of carbon in a very stable form. It is therefore a viable mean of carbon storage to support green transition. Due to its physical and chemical characteristics it has also been proven to be compelling adsorbent for contaminants in aqueous solution, such as heavy metals. Despite its potential little data are available about application in real case studies. Moreover, such data are often related to biochar produced solely for the sake of research.

The project aims to innovate, employing a hands-on approach based on the usage of widely available commmercial biochars for water purification in real scenarios. Characterization of nine different biochars through routine and novel analytical techniques acts as a tool to point out benficial properties to the selected application (e.g., removal of heavy metals).

The case study concerns the Malagrotta landfill area in the Lazio region, central Italy. A chemical survey on surface waters has been performed to assess their quality and evaluate remediation potential through biochar usage. Testing biochar in real case scenarios allows assessment of real world performance, hence promoting a sustainble alternative to traditional activated carbon for water purification.

The use of raw materials and residues for the manufacturing of sustainable lime mortars

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Keywords: lime mortar, raw materials, natural additives.

In ancient times, building systems and technologies were constrained mainly by the geographic situation, the climatic conditions of the area and the availability of the appropriate raw materials. Since the 20th century, almost all building materials are globally produced by means of contaminant industrial processes, whilst most of the natural and locally available raw materials have fallen into oblivion. Modern construction promoting the use of cement and synthetic polymer-based materials has become expensive for the society, unhealthy for people and contaminant for the environment. The environmental impact associated with the construction sector is high, especially if we consider that demolition and new construction still constitute a better economical option than rehabilitation. We believe that minimising the need for the production of synthetic and cement-based materials, replacing them with lime-based mortars is the initial breakthrough in sustainable construction.

Mortar is one of the most ancient and traditional artificial materials manufactured and used by man throughout history. A simple mix of three basic ingredients, binder (e.g. lime, gypsum), water and aggregate, gives rise to a huge variety of mortar types, due to the existence of binders and aggregates with different chemical, mineralogical and textural features. The variability of properties and characteristics typical of composite materials, achieved by adjusting the component types and proportions, is a distinctive feature of mortars, for example compared to natural stone or cob.

Despite lime has been largely neglected in the last century, in recent years its use is being recovered due to its unique properties: versatility, workability, breathability, low thermal conductivity, self-healing and durability, among others. As an additional strongpoint, using lime involves important environmental benefits, since it can be manufactured locally and on a small-scale (especially in specific cases such as developing countries, remote areas, and small local demand). Moreover, it is produced at lower temperatures with respect to other more common binders (e.g. cement), which implies less energy consumption, less pollution and reduced CO_2 gas emissions. Definitively, lime mortar is a versatile, traditional and sustainable building material. Even so, our commitment to sustainable development compels us to find even more sustainable solutions for the manufacturing and use of this material. To this end, we present the most recent investigations on lime pastes and mortars in which different kinds of raw natural materials and residues such as hemp shives, and waste shells of commercial bivalve mollusc species (as additives, admixtures, secondary binders and/or sands) have been used. The mineralogical and textural changes induced in the mortars by the use of these components are discussed in relation to their inorganic and/or organic nature, among other factors.

Application of pigmented geopolymers in Cultural Heritage conservation and aging studies on a geopolymer mock-up

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Keywords: conservation, geopolymers, mock-up.

Geopolymers are inorganic products made from powders of various types, mostly alumino-silicate, mixed and dissolved in an alkaline environment (Leonelli & Romagnoli, 2013). These materials are undergoing rapid development at the industrial and commercial level in recent years, proving to be very promising. The versatility of geopolymers makes them suitable for various applications in a wide variety of fields, including Cultural Heritage. Studies attest their application on polychrome surfaces of historical value and artistic interest, with various functionalities (Barone et al., 2020; Fugazzotto et al., 2023). In the past few months, thanks to the collaboration with the conservation company Piacenti S.p.a, it was possible to carry out a conservation work on the mosaic apparatus of the Cefalù Cathedral, which entered the UNESCO World Heritage List (UNESCO World Heritage Convention) in 2015. This Cathedral is famous for its magnificent Byzantine mosaic, considered one of the most beautiful in Italy. Piacenti S.p.A, recently carried out an extensive conservation intervention on the *lacunae* of the mosaic apparatus, and in this context it was possible to test the feasibility of conservation interventions based on geopolymer *tesserae*. Several formulations of pigmented geopolymers were preliminarily studied in the laboratories of the University of Catania, with the aim to obtain materials suitable to the original ones. The slurries were synthesised by using commercial metakaolin as geopolymeric precursor and by adding different kinds of commercial pigments, in different percentages. After a multi-analytical characterization of the raw materials, the cured geopolymers underwent colorimetric analysis at regular intervals of time, chemical and physical stability tests, and were characterized through a combination of spectroscopic and diffractometry techniques. Promising results are registered, particularly in terms of pigment stability in geopolymers and surface homogeneity. Inspired by one of the many decorations of the Cefalù Cathedral, a mosaic mock-up was made entirely of geopolymer *tesserae* and exposed to natural weathering for six months. A study of the aging was conducted to test both its physical-mechanical stability and its aesthetic performance over time. At the same time, among all the pigmented geopolymer sets, for the *in situ* application it was decided to select those that, after a curing time of 28 days, presented color coordinates most similar to the original *tesserae*, in order to ensure a good aesthetic compatibility. Then, the selected pigmented geopolymer *tesserae* were applied, with the help of the restorers, on the original mosaic apparatus of the Cefalù Cathedral to replace missing original *tesserae*, with an excellent result in terms of aesthetic performance.

Acknowledgements: The present research was founded by the Project PE 0000020 CHANGES – CUP [E63C22001960006] NRP Mission 4 Component 2 Investment 1.3, Funded by the European Union - NextGenerationEU".

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Fugazzotto M. et al. (2023) - Restoration feasibility study by using alkali activated mortars based on Mt. Etna volcanic ash: The case study of Monreale Cathedral (Palermo, Italy). Mater. Lett., 333, 133626, https://doi.org/10.1016/j.matlet.2022.133626.

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UNESCO World Heritage Convention, https://whc.unesco.org/

Role of the application method in the calcium phosphonate consolidation of pyroclastic rocks used in the environmental heritage

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Keywords: pyroclastite, silicate rocks, chemical treatment.

The various degradation processes affecting the geomaterials that make up the environmental heritage (historical and contemporary buildings) are usually due to their interaction with environment. Among the intrinsic features of materials, compositional and microstructural/textural characteristics can affect this process; in particular, porosity can increase the active surface. Due to their excellent workability, pyroclastites - volcanic rocks generated by explosive eruptions and consisting of a cineritic matrix in which crystal-clasts, pumices, cognate fragments, xenoliths and lithics are immersed - have been widely used as a building material. However, their high compositional heterogeneity results in a high porosity, especially in poorly welded facies which can reach up to 50 vol.%. Although pyroclastites feature a silicate composition, and are therefore more resistant to chemical alteration with respect to the carbonate rocks, they show low resistance to physical degradation. In this context, the study and research of new protective/consolidating agents capable of preserving this material, especially in the field of cultural heritage, become of fundamental relevance. So far, the progress made on the research of innovative consolidating agents has focused on lithoid substrates of carbonate origin (e.g., marbles, limestones, calcarenites, sandstones) (Columbu et al., 2017; Aragoni et al., 2021), while less has been done on pyroclastic materials.

In agreement with Norio et al. (2023), who focused on the protective/consolidating treatment of pyroclastites through the application by immersion of ammonium phenylphosphonate, in this study the implications of a possible method of field application (brushing) of the consolidant and the effect of an enrichment of the system with calcium ions are evaluated. In fact, although the results of Norio et al. (2023) shown that the treatment improves several physical-mechanical characteristics of the samples, the application of the consolidant by immersion is not feasible in situ. Regarding the new results, compared to the untreated samples, a decrease in porosity was observed (i.e.: -0.38% ΦO He, -0.43% ΦO H_2O), especially in the most altered samples. As compared to the samples treated by immersion, the open porosities to water and helium are larger in the brush-treated samples by 4% and 2%, respectively.

Lastly, the mechanical strengths measured by compression uniaxial tests shown a marked improvement (~22%) with respect to the samples treated by immersion-method, showing the positive effect of an addition of calcium ions towards the precipitation of calcium phenylphosphonate, thus favouring the consolidating action of the product.

Aragoni M.C. et al. (2021) - Ammonium monoethyloxalate (AmEtOx): a new agent for the conservation of carbonate stone substrates. New J. Chem. 45, 5327-5339, https://doi.org/10.1039/D0NJ06001A.

Columbu S. et al. (2017) - Physical-mechanical consolidation and protection of Miocenic limestone used on Mediterranean historical monuments: The case study of Pietra Cantone (Southern Sardinia, Italy). Environ. Earth Sci., 76, 148, https://doi.org/10.1007/s12665-017-6455-6.

Norio N. et al. (2023) - New conservative treatment based on a functionalized phosphate for silicate rocks: the study-case of the pyroclastic tuffs. SIMP-SGI-AIV-SOGEI 2023 Congress - Abstract Book, 443, https://doi.org/10.3301/ABSGI.2023.02.

Metakaolin - Blast furnace slag geopolymers as catalyst support for water treatment

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Keywords: geopolymers, blast fournace slag, catalysts.

Metakaolin-based geopolymers resulted promising support for heterogeneous catalysis finalized to the recovery of industrial waters (Clausi et al., 2023). However, for fulfilling the principles of *sustainability* ever more practices are necessary to support the efficient exploitation of natural resources and the conversion of wastes into resources.

This work is aimed at the study of geopolymer catalysts for wastewater treatments obtained from the partial substitution of a natural kaolinite clay with an industrial by-product, i.e. blast furnace slag.

To this purpose, a set of six different geopolymers was prepared using a heat-treated (700°C) kaolinitic clay and blast furnace slag in 1:1 ratio, varying the type of alkaline activator (NaOH or sodium silicate solutions) and the polymerizations modes. Porous geopolymer samples were also prepared using hydrogen peroxide (3 wt.%) as foaming agent.

A combination of characterization techniques (XRPD, FTIR, SEM-EDS) showed quite compact geopolymers microstructures, mainly characterized by N,C-A-S-H gels. Diffraction patterns showed the predominance of amorphous structures in which large humps, in the 20-35° 2θ range, were distinguished in addition to quartz, calcite and in some cases sodium carbonates. Samples showed a chemical and physical integrity after 10 days of soaking in water. Mechanical tests, performed on selected samples, achieved values ranging between 12 and 22 MPa.

Based on the obtained results metakaolin-slag geopolymers can be considered as promising supports in photo Fenton process for the removal of pollutants from water.

It is worth noting that the substitution of blast furnace slag to the clay, beside halving the use of natural resources and reducing the energy required for the thermal treatment of the clay, reduces up to 25% the consumption of alkaline activators.

Clausi et al. (2023) - Pollutants abatement in aqueous solutions with geopolymer catalysts: A photo fenton case. Chemosphere, 344, 140333, https://doi.org/10.1016/j.chemosphere.2023.140333.

The use of olive oil-modified geopolymers for municipal wastewater treatment

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Keywords: geopolymer, wastewater, depuration.

Municipal wastewater treatment plays a critical role in safeguarding public health, preserving ecosystems, and sustaining water resources. As the urban population increases, the volume of wastewater produced, laden with harmful contaminants to humans and the environment, also increases. Effective treatment processes are essential to remove pollutants, pathogens and nutrients from wastewater prior to its discharge into water bodies. In this perspective, absorption methods offer several advantages in water purification compared to conventional treatments and, in particular, activated carbon and geopolymers were found excellent sorbent for a a wide range of contaminants, including heavy metals, ammonium and organic pollutants, with respect to other sorbent materials such as activated alumina, zeolite, polymeric adsorbents, etc., which may struggle with selectivity, efficiency, or sustainability (Luukkonen et al., 2019). Activated carbon and geopolymers are both effective sorbent materials for wastewater treatment, each offering distinct advantages and limitations. Activated carbon, derived from organic sources, boasts a high surface area and pore structure, fostering high adsorption capacity for several contaminants. Its versatility and well-established performance in water purification processes have made it a stronghold in wastewater treatment over the years. However, activated carbon's higher cost and limited regeneration capabilities, pose economic and sustainability issues. Geopolymers are composed of inorganic precursors, possess adaptable properties such as porosity and chemical stability, making them efficient adsorbents. They can be tailored to specific treatment needs and may exhibit long-term durability in hostile environments (Amran et al., 2021). In this study porous geopolymers were engineered using hydrogen peroxide and a combination of hydrogen peroxide and olive oil. The materials underwent batch experiments in the laboratory to assess their performance concerning specific pollutants. Subsequently, their efficacy was evaluated in column studies using wastewater samples. Despite the use of vegetable oil for the preparation of porous geopolymers has been already documented in literature (Bai et al., 2016; Lertcumfu et al., 2020), the application of oil-modified geopolymers in wastewater treatment remains relatively unexplored. To ensure robust and reliable results, the synthesized geopolymers were systematically compared during the test with activated carbon, a well-established benchmark in wastewater treatment. This comparative assessment highlights the efficacy and potential of the geopolymers as a viable alternative to activated carbon in wastewater treatment applications. Such outcomes underscore the significance of this research in advancing sustainable and effective solutions for wastewater remediation, while also exhibit the promising capabilities of geopolymers in substituting conventional materials in environmental engineering contexts.

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Lertcumfu N. et al. (2020) - Effects of olive oil on physical and mechanical properties of ceramic waste-based geopolymer foam. J. Reinf. Plast. Comp., 39, 111-118, https://doi.org/10.1177/0731684419896852.

Luukkonen T. et al. (2019) - Application of alkali-activated materials for water and wastewater treatment: a review. Rev. Environ. Sci. Bio., 18, 271-297, https://doi.org/10.1007/s11157-019-09494-0.

Hydrated borates at non ambient conditions: pivotal experiments in the production of neutron-shielding concretes

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Keywords: hydrated borates, neutron shielding, phase transition.

Hydrated borates (e.g., colemanite, kernite, ulexite, borax, tincalconite) are the most common ore minerals of boron, an important geochemical marker, in pegmatitic and granitic systems, for petrogenetic processes and a strategic element in a series of technological applications. Hydrated borates have been listed as critical raw materials by the EU (EU Commission, 2017), and they could be used as aggregates in neutron-shielding Sorel or Portland concretes, enhancing their adsorption towards thermal neutrons. The main structural units in hydrated borates are Bφx fundamental building blocks (i.e., tetrahedra and planar trigonal groups where φ is an anion, O^{2-} or OH^{-}), connected in such a way to form clusters of polyions connected to alkaline/Earth alkaline (mainly Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}) polyhedra. In these structures, H_2O molecules and OH^{-} form a complex and pervasive hydrogen-bond network, which reinforce the connection between the polyions clusters and the cations coordination polyhedra, playing a paramount role in the stability of the crystalline edifice (Pagliaro et al., 2021; Comboni et al., 2021). In the last 4 years, a number of studies have been performed at high temperature and pressure unveiling the occurrence of phase transitions driving deformation mechanisms that lead to the formation of their high-pressure polymorphs. Critically, the pressure at which hydrated borates undergo a phase transition is related to the water content of the mineral itself. The aim of this contribution is to provide insights on the high-pressure behavior and structure evolution of selected hydrated borate minerals. These studies at non ambient conditions are pivotal to produce neutron shielding tiles of Sorel concretes.

Comboni D. et al. (2021) - Crystal structure of the high-*P* polymorph of $Ca_2B_6O_6(OH)_{10}\cdot 2(H_2O)$ (meyerhofferite). Acta Crystallogr. B, 6, 940-945, https://doi.org/10.1107/S2052520621009768.

European Commission (2017) - Study on the review of the list of critical raw materials – Final report. Publications Office, https://data.europa.eu/doi/10.2873/876644.

Pagliaro F. et al. (2021) - Thermal and compressional behavior of the natural borate kurnakovite, $MgB_3O_3(OH)_5\cdot 5H_2O$. Constr. Build. Mater., 266, 121094, https://doi.org/10.1016/j.conbuildmat.2020.121094.

Inderborite: a comprehensive reinvestigation of its technological features

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Keywords: inderborite, neutron shielding, phase transition.

Inderborite is a hydrated borate (ideal formula: $CaMg[B_3O_3(OH)_5]_2(H_2O)_4 \cdot 2H_2O$) often found in lower fractions alongside with the five most important boron commodities (i.e., colemanite, kernite, ulexite, borax, tincalconite) in Turkish mines which, nowadays produce more than 70% of the worldwide B-minerals (e.g., Sarikaya borate deposits, Baysal, 1973). Hydrated borates have been listed as critical raw materials by the EU (EU Commission, 2017), and, because of the high neutron cross-section of B-10, they could be used as aggregates in neutron-shielding Sorel or Portland concretes, enhancing their adsorption towards thermal neutrons. In the forthcoming decades, with the advent of fusion power plants, it is predicted that substantial quantities of neutron-activated elements (e.g., beryllium or tungsten), will be produced (Gonzalez de Vincente et al. 2022). The main goals of this projects are to: *i)* re-investigate, by means of a multi-methodological approach, the crystal chemistry (with a focus on the B isotopic composition and trace elements) and structure of inderborite (even based on a single-crystal neutron diffraction experiment), *ii*) assess the stability range of inderborite with respect to pressure and temperature even for potential industrial utilization of this borates, *iii*) describe the structural evolution of inderborite, at the atomic scale, with increasing pressure and temperature.

Baysal O. (1973) - New hydrous magnesium-borate minerals in kurnakovite, inderite, inderborite turkey. Bull. Miner. Res. Explor., 80, 93-103.

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Gonzalez de Vicente S.M. et al. (2022) - Overview on the management of radioactive waste from fusion facilities: ITER, demonstration machines and power plants. Nucl. Fusion, 62, 085001, https://doi.org/10.1088/1741-4326/AC62F7.

Incipient carbonate phases formation on brucite [$Mg(OH)_2$] single crystals surfaces during microwave-driven carbonation

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Keywords: carbon capture utilization and storage, mineral carbonation, brucite single crystals.

In the last decades, many studies have been focussing on carbon capture utilization and storage (CCUS) as possible solution to reduce the increasing of anthropogenic CO_2 concentration in the atmosphere. Among all, mineral carbonation (MC) has been recognized as the most promising route to achieve a long term almost irreversible carbon sequestration. In this respect, brucite [$Mg(OH)_2$] and layered Mg-bearing minerals containing brucite-like sheets, such as serpentine [$Mg_3Si_2O_5(OH)_4$], are targeted as best candidates for CCUS by water-mediated MC (e.g. Boschi et al., 2017; Rausis & Ćwik, 2021; Campione et al., 2024).

This reaction consists in a former dissolution step with formation of Mg^{2+} solvated cations, and a subsequent step with precipitation of Mg-carbonates and/or hydroxy-carbonate hydrates (Campione et al., 2024). Although spontaneous in nature, this reaction is hindered by activation barriers, reducing its capability to permanently store carbon, and consequently its exploitation in profitable applications.

All the above studies used powdered samples as starting materials to increase the reaction surface. In this work, we present preliminary results regarding brucite single crystals carbonation, used as model system for the reactive component of serpentine to better understand the mechanism of the carbonation reaction at the macroscale. The experiments have been carried out with the aid of a microwave-driven apparatus under controlled reaction time, temperature and pressure of a mixture of CO_2 and N_2 and water vapor.

Brucite single crystals surfaces are characterized before and after the experiments in order to identify any change occurred during the treatments. Optical microscope images are collected on the entire surface; on some selected areas, Atomic Force Microscopy (AFM) analysis in acoustic mode is acquired to identify dissolution features and/or incipient Mg-carbonate phases at micro/nano-meter scales. Moreover, these areas are analyzed with Raman spectroscopy and Scanning Electron Microscopy (SEM) to get both chemical and morphological information on the carbonate phases.

Boschi C. et al. (2017) - Brucite-driven CO_2 uptake in serpentinized dunites (Ligurian Ophiolites, Montecastelli, Tuscany). Lithos, 264-281, 288-289, https://doi.org/10.1016/j.lithos.2017.07.005.

Campione M. et al. (2024) - Microwave-driven carbonation of brucite. J. CO_2 Util., 80, 102700, https://doi.org/10.1016/j.jcou.2024.102700.

Rausis K. & Ćwik A. (2021) - Direct moist carbonation of brucite-rich serpentinized dunites: an alternative to the carbonation of heat-activated serpentine. Appl. Geochem., 127, 104851, https://doi.org/10.1016/j.apgeochem.2020.104851.

Geology and mineralogy of the Sa Pigada Bianca bentonite deposit (Sardinia, Italy): preliminary data

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Keywords: Sardinia, bentonite, montmorillonite.

Bentonite is a rock composed mainly of smectite, usually of the montmorillonite-beidellite series, which results from the in-situ alteration of volcanic material (usually pyroclastic products, more rarely effusive rocks), or followed by transport and re-sedimentation. Because of its physical and chemical characteristics, it is widely used in ceramics, foundry, water purification and clarification, wine clarification, refining of petroleum products, manufacture of transparent and translucent films, paper mills, soap factories, etc. In this study, the geological and mineralogical characteristics of the bentonite deposit of Sa Pigada Bianca, a deposit that is part of the bentonite basin of Northwest Sardinia, has been analyzed. The survey site is located 15 km southwest of Sassari, in the municipality of Ittiri, on a structural high formed by Cenozoic volcanic succession. The stratigraphy consists of glassy ignimbrite at the top and bentonite bank up to 50 meters thick below, which can be divided into two sub-banks according to the colour of the bentonite, pink at the top and red at the bottom. According to a detailed geological survey two mutually orthogonal fault systems are present, dislocating the mineralized succession. Twenty samples were taken, of which 6 subjected to clay fraction separation and XRPD analysis, both under open-air drying conditions and after treatment with ethylene glycol. The mineralogical assemblage includes Ca-bentonite, mica, kaolinite, and zeolite, with the occasional presence of quartz, calcite, and plagioclase. This preliminary study indicates, for this deposit, a continental genesis with in-situ alteration of tufitic flows, affected successively by distensive tectonics. Mineralogical analyses emphasize a classic mineralogical assemblage, resulting from the interaction between parent material and fluids in the system.

From field to laboratory: geo-inspired strategies for the enhancement of the water-mediated mineral carbonation for the reduction of its energy and environmental impacts

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Keywords: carbon capture utilization and storage, mineral carbonation, microwave chemistry.

Mineral carbonation (MC) plays a crucial role in Carbon Capture Utilization and Storage (CCUS), which is a technology approach aimed at better managing anthropogenic CO_2 emissions, also promoting the use of captured CO_2 for the production of secondary raw materials, in a system of Circular Economy. MC involves the chemical reaction in aqueous environment between CO_2 and magnesium and calcium rich minerals, in which CO_2 is converted into a stable and solid form.

In nature, listvenite rocks, mainly composed of Mg-bearing carbonates, quartz and Cr-muscovite (i.e., fuchsite), document a mechanism for natural CO_2 sequestration, potentially significant to develop effective geo-engineering strategies and mitigate CO_2 emissions (Hinsken et al., 2017). Listvenite rocks are the result of the extensive alteration of ultramafic rocks by CO_2-bearing fluids (i.e., carbonatation), which involved the substitution of olivine, pyroxene or serpentine by Ca and Mg enriched carbonates and silicates (Boskabadi et al., 2020).

Serpentinites from Zermatt-Saas Zone, in Western Alps of Aosta Valley (Italy), are natural samples studied in this work. These rocks might have undergone carbonation, which promoted the formation of carbonate-bearing lithologies (i.e., carbonated serpentinites and listvenites). Therefore, they represent valuable records of CO_2 sequestration, enhanced by fluid-rock interaction, observable in structural features from macro scale to micro one.

The aim of this work is the identification of accessory mineralogical phases and reaction mechanisms characterizing natural samples rich in carbonates, to recreate natural processes in laboratory, and enhance their efficiency through the use of microwaves (MW). Natural samples were characterized with optical microscopy and scanning electron microscopy (SEM), to identify phases and their mutual structural relationships. These results can improve the comprehension on performing MC experiments in laboratory. We studied MW effects on MC reaction of brucite [$Mg(OH)_2$], a model system of magnesium rich minerals, made of only two components ($MgO + H_2O$) (Campione et al., 2024). Though thermodynamically spontaneous for magnesium and calcium rich minerals in natural systems, MC reaction can be hindered by activation barriers. This limitation can be overcome by the use of MW, which promote a faster reaction rate compared to conventional heating methods.

Moreover, several combinations of temperature and reaction time, and chemical additives were explored, to fully exploit MW effects and fix the conditions of crystallization of magnesite [$Mg(CO_3)$] and magnesium hydroxide-carbonate hydrates (MHCH: i.e., nesquehonite [$Mg(HCO_3)(OH)\cdot 2H_2O$] and hydromagnesite [$Mg_5(CO_3)_4(OH)_2\cdot 4H_2O$]), minimizing energy expenditure.

Thanks to these MC products, considered secondary raw materials storing captured CO_2, a minor environmental impact can be achieved, also with a more eco-friendly outlay, compared to energy-intensive industrial settings.

Boskabadi A. et al. (2020) - Carbonation of ophiolitic ultramafic rocks: Listvenite formation in the Late Cretaceous ophiolites of eastern Iran. Lithos, 352-353, 105307, https://doi.org/10.1016/j.lithos.2019.105307.

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Hinsken T. et al. (2017) - Geochemical, isotopic and geochronological characterization of listvenite from the Upper Unit on Tinos, Cyclades, Greece. Lithos, 282-283, 281-297, https://doi.org/10.1016/j.lithos.2017.02.019.

Optimizing traditional materials: a systematic approach to formulate restoration mortars for improved substrate compatibility

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Keywords: restoration mortars, compatibility, pozzolana.

This study aims to enhance the understanding of compatibility criteria for restoration mortars, which are crucial for preserving ancient and traditional buildings. Given the various substrates encountered in restoration projects and the wide-ranging functions required of restoration mortars, a fundamental question arises: can mortars with varied properties in the fresh and hardened state be formulated using exclusively traditional components but with a deliberate scientific approach?

This inquiry underscores the vital role of consciously utilizing traditional materials to optimize them, enabling tailored mortars to meet diverse restoration demands. The choice of the constituents was informed by ancient mortar knowledge and historical references, such as Vitruvius, who highlighted the effectiveness of mortar comprising pozzolana from *Fondi di Baia* and lime, preferred by the Romans. Therefore, traditionally produced lime putty (CL90-S PL) was chosen as the binder, while a *Phlegraean* pozzolana was selected as the aggregate. An extensive preliminary characterization was conducted on both materials to elucidate the correlation between the raw materials and the mortars properties from minero-petrographic and physico-mechanical perspectives. Subsequently, to formulate restoration mortars, the approach involved varying binder-to-aggregate (B/A) ratios and grain size distributions. Based on detailed analyses of the mineralogical and chemical composition of the pozzolana particles, which revealed no substantial differences in the composition of the pozzolana itself, three fractions were identified: fine (< 0.425 mm), coarse (≥ 0.425 mm) and the total pozzolana. These three granulometric fractions were utilized to formulate mortars with B/A ratios of 1:2 and 1:3 by volume. Water content was maintained constant at 15% by weight of the total mass. The resulting six formulations were characterized at 28 days of curing using chemical, mineralogical and petrographic techniques (PLM, SEM-EDS, XRPD, XRF, FTIR, TG-DSC) and physical-mechanical tests (MIP, flexural and compressive strength, apparent density, hydric tests, ultrasounds). This systematic approach yielded encouraging outcomes for formulating mortars with diverse strengths, workability, and other properties, all accomplished using only two traditional components and without any additives. Thanks to the properties of pozzolana, which offer a wide range of characteristics in mortars due to its hydraulic properties and varying reactivity based on grain size. Furthermore, the study emphasizes enhancing compatibility through the critical substrate-mortar interface. To achieve this, composite specimens structured as substrate-mortar-substrate layers were developed, using bricks and tuff stones as substrates, and are currently under study. These tailored formulations met specific requirements for various functions and substrates, thereby making a significant contribution to the preservation of ancient buildings.

New materials for civil engineering through solidification and stabilization processes

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Keywords: solidification and stabilization, green material for civil engineering, waste utilization.

Contaminated soils as residue from old brownfield sites are a widespread problem today. Over the years, it has become apparent that through the solidification and stabilisation (S/S) process, it is possible to treat contaminated sediments (Wilk, 2004) and redevelop the interested areas. Specifically, the stabilisation phase serves to reduce the hazardousness of the waste by generating a change in chemical properties and the solidification phase provides a change in physical properties by modifying the waste. This work shows that the S/S process can be usefully employed to obtain new civil engineering materials, treasuring from previous studies that have proved it is a valid technique for the recovery of marine sediments (Todaro et al., 2023), and including in the process recycling materials such as, e.g., fly ash (Liang et al., 2024).

The proposed methodology involves several steps: the taking of soil samples, the application of the stabilisation and solidification treatment in the laboratory, the formation of the new materials and finally the testing phase during which the materials will be subjected to impact tests. The work presents some very promising initial results related to the use of the S/S process to form new materials to be employed in the construction of road surfaces (Salzano et al., 2022).

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Investigations on simultaneous Sb and As removal from mining drainages by Layered Double Hydroxides (LDHs)

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Keywords: Sb-As pollution, sorption processes, layered double hydroxides.

Layered Double Hydroxides (LDHs) are minerals characterized by a layered structure made up of brucite-like sheets ($[M_{1-x}^{2+} M_x^{3+} (OH)_2]^{x+}$), positively charged due to the partial substitution of bivalent metals (Mg^{2+}, Zn^{2+}, Ca^{2+}, etc.) with trivalent ones (Al^{3+}, Fe^{3+}, etc.), alternating with negative interlayers ($[(A^{n-})_{x/n} \cdot mH_2O]$) (Mills et al., 2012). Thanks to their structure, LDHs are able to trap anionic pollutants in solution by either anion exchange (untreated LDHs) or incorporation in the interlayer during reconstruction of the structure after calcination (the so-called *memory effect*).

Antimony (Sb) and arsenic (As) are considered pollutants of priority interest due to their toxicity for human health and the adverse effects for the environment. In the last decades, extensive investigations have been carried out in order to assess the LDHs removal capacity of these pollutants from waters. Several works show that both untreated and calcined LDHs with different composition can efficiently remove As, by incorporating the oxyanion (e.g., AsO_4^{3-}) in the interlayer (Wang e al., 2018). On the other hand, in the case of Sb, the cationic composition of LDHs affects the removal process; in fact, the hydrotalcite-like compound $Mg_6(Al_{0.5}Fe_{0.5})_2(CO_3)(OH)_{16} \cdot 4H_2O$ removes $Sb(OH)_6^-$ through the formation of the brandholzite-like compound (a non-LDH layered mineral, with general formula $Mg[Sb(OH)_6]_2 \cdot 6H_2O$), whereas the zaccagnaite-like compound $Zn_4Al_2(CO)_3(OH)_{12} \cdot 3H_2O$ removes Sb by means of the reconstruction of the zincalstibite-like compound (an LDH with general formula $Zn_2Al(OH)_6[Sb(OH)_6]$) (Kameda et al., 2011; Dore & Frau, 2018).

In the context of the project PRIN-PNRR2022 (MOLIERE - antiMony resOurce itaLy envIronmental Exploration cRitical matErial) we studied the simultaneous removal of dissolved Sb and As from a highly contaminated slag drainage sampled in the abandoned mine of Su Suergiu (SE Sardina, Italy) by calcined hydrotalcite-like and zaccagnaite-like compounds. Drainage water chemistry is characterized by oxidizing conditions, slightly alkaline pH (8.0 - 8.3), Ca(Na) – SO_4 composition and high concentration of both Sb (up to ~13 mg/L) and As (up to ~5 mg/L). Preliminary results are encouraging (more that 90% of Sb and As were removed), but showed that the removal capacity is affected by the competition effect of anions in solution and can be influenced by the precipitation of secondary phases (e.g., $CaCO_3$). Therefore, further investigations are needed in order to assess the most effective removal conditions (e.g., liquid/solid ratio, contact time, etc.).

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Effect of nano Mg-Al layered double hydroxides (LDHs) on chemical and physical properties of cement paste: preliminary results

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Keywords: layered double hydroxide, compressive strength, cement hydration.

Ensuring the sustainability of cement production holds significant importance within the construction sector. A key method to enhance this is by incorporating suitable additives and materials into traditional cement mixes. Essentially, understanding the physical and chemical mechanisms involved in the hydration of blended cement is crucial (Wu et al., 2018). Layered double Hydroxides (LDHs) present promising potential as additives, due to their capacity to capture CO_2, thereby enhancing the carbonation resistance of cement, and eliminate CO_2, SO_4 and Cl^- ions, which can compromise the durability of the cement paste. They are classified as ionic solids with layered structure and known as anionic clays with controllable supramolecular structure and unique physicochemical properties (e.g. anion exchange), which make them very interesting in the field of cementitious materials (Yazdi et al., 2023; Mishra et al., 2018). Nano Mg-Al-NO_3/$HCOO^-$ LDHs were synthesized by direct and ultrasonic precipitation methods. The nanometric size and purity of the LDHs were verified by X-ray powder diffraction (XRPD), transmission electron microscopy (TEM), scanning electron microscopy (SEM), dynamic light scattering (DLS) and Fourier-transform infrared spectroscopy (FTIR). The LDHs were mixed with Portland cement in different weight percentages (wt.%), ranging from 1 to 10 wt.%. First, the mixed dry cement powders were analysed using DLS, FTIR, XRPD and SEM to verify the actual homogenization of the powder that ensures the dispersion of the nano LDHs. The influence of LDHs on the hydration process of the cement paste as well as on the morphology and porosity of the hydrated samples is going to be studied after 1-, 7-, 14- and 28-days curing times, and analysed by XRPD, SEM, thermal (TGA/DTG) and spectroscopic analyses. This method makes it possible to explore the chemical impact of LDHs on the formation of calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (Afm) phases, as well as the potential anion exchange process during hydration. In addition, ongoing mechanical compression and flexural tests aim to assess the physical effects on the mixed cement paste. The initial results presented here help to understand the precise role of selected nanomaterials in the cement hydration process. They also highlight potential adverse effects and facilitate the refinement of the appropriate procedure for their incorporation into cement pastes. In addition, the use of waste material rates, such as construction and demolition waste, as additional additives will be investigated. The goal is to develop engineered cement with minimal environmental impact while respecting strict physical and mechanical standards.

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Optimization with slaked lime of alkali-activated pastes based on Mt. Etna's volcanic ash: rheological and physical-mechanical assessment

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Keywords: alkali-activated materials, recycle, volcanic ash.

In recent years, innovation in the development of sustainable alternatives in the construction material industry has increased exponentially, in line with the EU policies aimed at limiting the exploitation of natural resources and emissions in the manufacturing process. In this context, Alkali-Activated Materials (AAMs) have emerged as a viable solution thanks to their synthesis process without energy consumption (e.g., generally at room temperature) or the use of waste products (e.g., industrial by-products and natural materials), in line with the principles of the circular economy. The activation process requires the mixing of aluminosilicate powdered precursors with alkaline reactants.

Recently, volcanic ash from Mt. Etna, which would otherwise be considered as solid municipal waste if not used in innovative and safe processes, has been valorised through the alkaline activation process for different purposes, such as the realization of lightweight or fire-resistant pastes or restoration mortars (Finocchiaro et al., 2022; Fugazzotto et al., 2023; Occhipinti et al., 2023; Scanferla et al., 2023). The latter were realized and applied to restoration interventions carried out on a vertical mosaic area of the Cathedral of Monreale in Sicily (Italy), within the completed project "Advanced Green Materials for Cultural Heritage". Several in-situ applications were carried out in order to optimize the standard formulations prepared in the laboratory, which had a tendency to drip, thus hindering the engraving for the reproduction of the mosaic. The modification consists of adding 2 wt.% $Ca(OH)_2$ in the form of slaked lime to the standard mortar formulation.

This work provides experimental insights into the optimization of pastes applied in-situ during the restoration works of the mosaics of the Monreale Cathedral. A comprehensive comparison between the standard and modified pastes was carried out by evaluating their setting time and rheology, as well as by determining the microstructure of consolidated samples in terms of mineralogy, morphology and mechanical performance.

The results showed an accelerated setting times, alongside superior mechanical strength and rheological properties in the modified pastes. No relevant mineralogical difference was observed due to the negligible addition of slaked lime. Furthermore, the latter induced marginal changes in the gel morphology without affecting the chemical composition of the Na_2O-CaO-Al_2O_3-SiO_2-H_2O (N,C-A-S-H) type. These results have great potential for the development and improvement of building materials, especially for restoration works requiring specific and better physical and mechanical characteristics.

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"Cradle-to-cradle": waste geopolymers as precursors for new geopolymers in the restoration and construction sectors

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Keywords: geopolymers, ceramics, waste.

Geopolymers are recognized as promising eco-sustainable alternative to traditional materials for construction and restoration. Geopolymers, indeed, offer exceptional mechanical performance, making them ideal for use in construction, as well as their versatility in terms of both technical properties and aesthetic characteristics renders them the perfect choice for monument restoration. Furthermore, their aluminosilicate nature guarantees chemical compatibility with silicate substrates, which represent one of the most prevalent materials in cultural heritage.

However, as extensive research on geopolymers continues, the generation of geopolymer waste is on the rise. A new kind of global waste arises, that add to the huge volumes of industrial waste already in existence.

It becomes important to anticipate solutions for their management, in order to reduce the waste environmental impact. Nevertheless, few studies are available on geopolymer waste recycling. They are used as aggregates (Mesgari et al., 2020) or only partially replacing precursors for the production of new geopolymers (Hattaf et al., 2021). So far, little was the exploration of the possibility of creating new geopolymer materials by recycling up to 100% of geopolymer waste (Wu et al., 2023).

The present work aims to evaluate the feasibility of using ceramic-based geopolymer waste as precursors for new geopolymer products, suitable for the conservation of ceramic-based cultural heritage or as new potential building materials (blocks, tiles, bricks…). According to the principle of "cradle-to-cradle", various ceramic-based geopolymers resulting as waste from previous researches were as geopolymer precursors, solely or in binary mixtures with metakaolin. Following the mineralogical characterisation of the geopolymer waste, they were ground and employed in the synthesis of novel formulations. The synthesis parameters, including the type and ratio of activators and consolidation temperature, were maintained consistent with those of the original formulations. The evolution of the new geopolymer gel was confirmed by ATR-FTIR spectroscopy and X-ray diffractometry. Compressive tests showed strength values comparable to those of the geopolymers from which they originate, that are suitable for the desired applications. For restoration purpose, furthermore, colorimetric investigations were also carried out. Some applicative examples were realized, as tiles, blocks, decorative elements, reintegration mortars applied on pottery, fillers, etc.. The research demonstrates the recyclability of geopolymer waste, specifically of those obtained by ceramic waste. The promising results encourage further researches for the development of these innovative green products.

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Tadelakt: a thousand-year-old technique for the production of special plasters with unique properties

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Keywords: Tadelakt, lime, sustainable geomaterials.

Tadelakt is an ancient Moroccan lime-based decoration technique that has been handed down for over 5 centuries and which has evolved and perfected over time.

In particular, the lime used by Tadelakt is produced starting from the carbonate rocks of the quarries in the Marrakech area and has long been an essential conventional material in Moroccan buildings.

Marrakech lime was used to produce a special mortar with waterproofing and antibacterial properties. In fact, the particular processing of Tadelakt gives the material a high resistance to water, making it suitable for waterproofing cisterns and for decorating bathrooms, facades, hammams and fountains.

The installation of Tadelakt is a meticulous operation and the Moroccan master craftsmen, Maalem, undergo training that lasts many years in order to master the technique.

The Tadelakt technique has the particularity of being finished with cut and smoothed river pebbles which allow the finish to be closed and making it completely smooth, and of being treated with natural black soap of a pasty consistency, obtained from olive oil, which makes the surfaces of the material perfectly water-repellent and gives it a soft and fine appearance.

The materials used for Tadelakt essentially consist of lime, water, natural pigments for the mixture and of black soap deriving from olive oil residues and dust and natural bees wax to confer water resistance.

This traditional technique is conquering architects and designers to create bathrooms, SPAs, walls and environments with soft and warm tones.

There are not many studies in the literature on the properties and characteristics of the traditional Marrakech lime. This study is focused on the characterization of Moroccan limestone rocks and Marrakesh lime.

In particular, various characterization techniques were used: optical microscope of thin sections of original rock and of the plaster, tests physical and mechanical for performance evaluation, X-ray diffraction (XRD) and mineralogical analysis using scanning electron microscopy (SEM) for composition analysis.

Tadelakt can be considered a “sustainable” technique as it uses low-carbon construction materials and waste materials. It is for this reason that in recent decades, this technique has been reevaluated for the contemporary architecture.

The role of temperature on the pressure-mediated adsorption in natural zeolites: the case of leonhardite

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Keywords: zeolites, leonhardite, in-situ P-T X-ray diffraction.

While the high-pressure and high-temperature behavior of natural zeolites has been intensively studied in the last decades, to the best of our knowledge, no in-situ X-ray diffraction studies have been performed combining the effects of both. Experiments at these conditions could have crucial geological implications and potential applications at the industrial level (e.g., high-P/T adsorption of alcohols compounds in zeolites to promote methanol to olefins reaction). In this study, we present the results from the first pilot experiments, obtained with an easy and reproduceable experimental set-up, performed with one of the most common natural zeolite, i.e., laumontite ($[(Ca_{4-x}Na_x)K_x][Al_8Si_{16}O_{48}]\cdot(H_2O)_n$, with $n < 16$). This zeolite occurs in a wide range of natural environments, including sedimentary deposits or volcanoclastic sequences interested by burial diagenesis/metamorphism, as well as in hydrothermal vugs of volcanic rocks. Partially hydrated laumontite (i.e., with 15 H_2O molecules per unit cell) is often referred to as "leonhardite". The behavior and adsorption mechanisms of these minerals have been (already) well characterized at high-pressure by several authors (Gatta et al., 2018; Comboni et al., 2018), leaving unexplored the effect induced by temperature increase. In-situ high-pressure+high-temperature single-crystal synchrotron X-ray diffraction experiments were performed at the ID15-b beamline, at the ESRF, Grenoble (France). Saltwater (0.35 wt.% NaCl) was used as hydrostatic pressure-transmitting fluid. The DAC was placed in a resistive heater, which allowed to increase the T up to 100(2)°C. Temperature was defined using a thermocouple placed very close to the P-chamber; T value was consistent with what obtained by the analysis of the Au-powder pattern. In leonhardite, the temperature seems to enhance the H_2O adsorption, giving rise to a volume expansion at $P < 5$ kbar. Above this pressure, the compressibility becomes similar to that of fully hydrated laumontite (Comboni et al., 2018). Previous experimental findings proved that leonhardite experiences a full hydration, at ambient PT conditions, only after about 24 hours, whereas each data-point at high-PT required not more than 20 minutes: this further highlights the role played by temperature on the kinetics of the P-mediated adsorption process (i.e., speeding up the adsorption process).

Comboni D. et al. (2018) - Crystal-fluid interactions in laumontite. Micropor. Mesopor. Mat., 263, 86-95, https://doi.org/10.1016/j.micromeso.2017.12.003.

Gatta G.D. et al. (2018) - The effect of pressure on open-framework silicates: elastic behaviour and crystal-fluid interaction. Phys. Chem. Miner., 45, 115-138, https://doi.org/10.1007/s00269-017-0916-z.

Investigation on geopolymeric mortar production by using clay bricks waste

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Keywords: sustainable material, C&D waste, geopolymeric mortar.

Geopolymers, derived from a precursor composed of aluminosilicate-rich materials combined with alkali activators, represent environmentally friendly alternatives to ordinary Portland cement. Clay brick waste (CBW) serves as excellent reactive materials for producing geopolymer binders, given their chemical and mineralogical properties.

In this study, we explored the potential of reusing CBW to produce geopolymer mortars as an alternative to conventional fired bricks. Experimental work focused on producing geopolymer bricks using metakaolin (MK) as the raw material and sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as activators. Samples were prepared with various formulations, incorporating CBW both as aggregate and as a replacement for MK, up to 100%. Following molding, the geopolymer bricks were cured at 60°C for one day. Subsequently, demolded materials were sealed in plastic bags and maintained at room temperature in the laboratory for 7, 14, and 28 days before conducting physical and mechanical property measurements.

The results of this study demonstrate that geopolymer mortars produced using crushed brick waste exhibit favorable properties in terms of open porosity, water absorption, and mechanical strength compared to conventional brick materials.

First insights on the synthesis of cordierite from Sardinian raw materials

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Keywords: cordierite, synthesis, raw materials.

Cordierite, $Mg_2Al_4Si_5O_{18}$, is a ternary compound within the MgO-Al_2O_3-SiO_2 system. It is a widespread commercial material due for its unusually low coefficient of thermal expansion, low thermal mass, low dielectric loss factor, low density, volume resistivity and high resistance to thermal shock. These physical-mechanical properties give this mineral phase a high industrial value. Particularly high grade cordierite is widely used in various industrial fields such as automotive, catalysis, electrical devices, etc..

Cordierite can be synthesized from natural raw materials (e.g. talc, stony kaolinite, andalusite) or synthetic powders, which have high purity and are readily available (Gonzalez-Velasco et al., 1999; Khabas et al., 2003; Cao et al., 2016).

In this study, to synthesize cordierite, natural raw materials quarried in Sardinia and available at low commercial cost were used in the following first series of 15 syntheses:

1) talc + low iron bauxite + opal at 1250°C and 1300°C;
2) talc + low iron bauxite + quartz at 1250°C and 1300°C;
3) talc + low iron bauxite + opal + quartz at 1250°C and 1300°C;
4) talc + low iron bauxite + kaolin 1 at 1250°C and 1300°C;
5) talc + low iron bauxite + kaolin 1 + opal at 1250°C and 1300°C;
6) talc + low iron bauxite + kaolin 1 + quartz at 1250°C and 1300°C;
7) talc + kaolin 1 at 1300°C;
8) talc + low iron bauxite + kaolin 2 + opal at 1300°C;
9) talc + low iron bauxite + kaolin 2 at 1300°C.

The raw materials were milled to powder, placed into a closed crucible and sintered in an oxidizing furnace for 2h at designed temperatures (Succi, 2007).

To maximize the cordierite content in the synthesis product, both mineralogical and chemical analyses of the starting phases were carried out in order to precisely balance the chemical composition of the starting mixture for the synthesis.

The XRD patterns of the synthetized material specimens were analyzed by Rietveld method which allowed us to highlight the most reactive phases and the optimal mixtures, among the tested ones. Cordierite content exceeding 75% was obtained in the most promising synthesis.

Cao J. et al. (2016) - A study of synthesis of cordierite powder. 6th International Conference on Mechatronics, Materials, Biotechnology and Environment. Atlantis Press China, 344-350, https://doi.org/10.2991/icmmbe-16.2016.66.

Gonzalez-Velasco J.R. et al. (1999) - Synthesis of cordierite monolithic honeycomb by solid-state reaction of precursor oxides. J. Mater. Sci., 34, 1999-2002, https://doi.org/10.1023/A:1004578819314.

Khabas T.A. et al. (2003) - Low-Temperature synthesis of the cordierite phase in ceramic mixtures of natural raw materials. Refract. Ind. Ceram., 44, 181-185, https://doi.org/10.1023/A:1026360403004.

Succi F. (2007) - Sintesi di cordierite da materiali naturali. Bachelor's Thesis.

New insights in the optimization of sulfur dioxide flue gas desulfurization (FGD) using porous materials in a semi-dryer system

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Keywords: flue gas desulfurization, 13X zeolite, semi-dryer system.

The reduction of sulfur dioxide emissions has led to significant research into gas desulfurization methods. Techniques for reducing sulfur dioxide emissions can be classified into dry, semi-dry, and wet flue gas desulfurization (FGD). Limestone is widely used in FGD due to its availability and cost-effectiveness, but its reactivity is often insufficient for effectively removing sulfur dioxide. Lime, a byproduct material, is an environmentally friendly option due to its abundance and low cost. Zeolites, microporous crystalline materials with thermal and chemical stability, catalytic properties, and a high specific surface area, are commonly used for gas separation and as catalysts.

The study aims to investigate a semi-dry system operating at low concentrations that is designed to address challenges in practical gas desulfurization. Porous materials, specifically slaked lime and a selected synthetic 13X zeolite are evaluated as adsorbents. The efficiency of the adsorbents is evaluated using microgas chromatography. A model calculation detailing gas mobility, X-ray powder diffraction, thermal analysis, and scanning electron microscopy are used in the integrated approach to elucidate the mechanisms governing gas desulfurization and propose an experimental prototype setup for the absorption of SO_2 in semi-dry and low concentrated systems.

Hydration processes of geomaterials for green and sustainable applications

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Keywords: lime hydration, double hydrated dolomitic limes, flue-gas desulphurization.

This work introduces and validates diverse hydration assessment methodologies utilizing a developed and tailored fully integrated planetary mixer engineered for Cimprogetti's Technological Laboratory. This specialized apparatus is engineered to consistently hydrate different calcined limes, encompassing high-calcium lime (quicklime), magnesium-rich lime (dololime), and magnesium oxide (periclase). The aim is to produce fully hydrated materials, even those exhibiting low reactivity, to yield final products with specific properties for different industrial applications such as construction and building materials and flue-gas desulphurization (FGD). Different hydration protocols were optimized to produce enhanced high calcium-hydrated lime, double-hydrated dololime, and magnesium hydroxide coming from calcination of pure limestones, pure dolostones, and pure magnesites of various Italian and foreign geological provenances. It is well-established that the calcination process is primarily affected by burning temperature and retention time, which significantly impact the reactivity of the burned compounds with water (Vola et al., 2019; Huang et al., 2020). Consequently, hydration can be a challenging process, depending on the degree of over-burning or sintering of Ca-Mg limes.. However, the complete conversion of periclase (MgO) into brucite ($Mg(OH)_2$) in dolomitic limes is often hardly achievable under ambient conditions (Lanas & Alvarez, 2004). Therefore, hydration kinetics have been increased using high temperature, and naturally generated steam pressure. Effectively, the new planetary mixer, insulated and pressurized to withstand up to 3 bars, is also equipped with a heating system capable of reaching up to 200°C. Furthermore, enhanced hydrated limes, presenting high BET surface area and pore volume (PV) for acid gas treatments, were synthesized with specific recipes employing high water-to-lime ratios coupled with TEA fluidizing additive. In this research, several types of lime products, previously calcinated in-lab to simulate different industrial kilns, were investigated before and after hydration tests. Additionally, the materials were characterized using the Whole Pattern Profile Fitting (WPPF) on X-ray powder diffraction (XRPD) data analyzed by the Rietveld method for microstructural and quantitative phase analyses. Porosimetric investigations were conducted using nitrogen gas adsorption, employing BET and BJH methods. These techniques facilitate the identification of the complete conversion of oxides into hydroxides, as well as the determination of crystallite size, BET-specific surface area, and BJH pore volume of hydrated products. The materials obtained are suitable for various industrial applications, including modified activated binders, flue gas desulphurization, flame retardant, neutralizer of water pollutants, and chemical sensors for ethanol.

Huang L. et al. (2020) - Influence of calcination temperature on the structure and hydration of MgO. Constr. Build. Mater., 262, 120776, https://doi.org/10.1016/j.conbuildmat.2020.120776.

Lanas J. & Alvarez J.I. (2004) - Dolomitic limes: Evolution of the slaking process under different conditions. Thermochim. Acta, 423, 1-12, https://doi.org/10.1016/j.tca.2004.04.016.

Vola G. et al. (2019) - Reactivity and overburning tendency of quicklime burnt at high temperature. ZKG Int.,10, 20-31.

Lime and higth zeolitic geomaterials content in mixtures: perspectives in hydraulicized eco-mortars production

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Keywords: pozzolans, lime reactivity, C-S-A-H.

This paper describes the pozzolanic reactivity with aerial lime of two volcanic materials with high zeolite content from Central and Northern Sardinia (Palomba et al., 2006; Naitza et al., 2006). The zeolites are represented by predominantly clinoptilolite and subordinate mordenite. These materials were preliminarily micronized, sieved low < 63 μm and then dry-mixed with aerial lime (CL90), followed by addition of water in a 0.5 (solid/liquid) by weight ratio in order to create a paste system without the use of aggregate. The volcanic materials and paste systems were analysed by SEM scanning electron microscopy, Differential Thermal Analysis (TG-DTA) and XRPD Diffraction at the different time: 1, 3, 7, 14, 28, 60, 90 days under two different curing conditions: limited CO_2 input from outside, and in air at ordinary temperature. In addition, for comparison, homologous systems were prepared with the same weight proportions, using silica fume as a pozzolanic additive. These last is considered a hyper-pozzolan agent because of its marked reactivity with lime. The results obtained for the systems matured with limited CO_2 input showed appreciable reactivity by both samples investigated. The hydration kinetics of these systems appears to be slower, compared with that of the homologous system containing silica fume. In the case of zeolitic systems cured under normal atmospheric conditions (in air), the reaction between the lime and the zeolitic additive is slower, compared with that of systems cured with limited CO_2 contribution and the reference system containing silica fume, because the effect of carbonation is prevalent. Therefore, the curing process is critically influential on the development of any hydraulic products (C-A-S-H). The results obtained as part of the research, provide a preliminary scientific basis for the possible use of zeolitic materials in the field of the production of hydraulic mortars, characterized by greater sustainability, as it excludes a treatment of geomaterials by thermal or chemical activation.

Palomba M. et al. (2006) - Industrial mineral occurrences associated with Cenozoic volcanic rocks of Sardinia (Italy): geological, mineralogical, geochemical features and genetic implications. Ore Geol. Rev., 29, 118-145.

Naitza S. et al. (2006) - The zeolite mineralization associated with the Miocene volcano-sedimentary successions of Sardinia (Italy). Geophys. Res. Abs., 8, 02022, E.G.U. Meeting, Vienna, April 2-7, 2006.

Tripoli Formation rocks as new resources in alkaline-activation technology: a feasibility study

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Keywords: geopolymers, alkali-activated materials, natural precursors.

Alkali-activated materials (AAMs) are inorganic compounds formed by dissolving solid aluminosilicate precursors in a strongly alkaline liquid medium. Well-designed, AAMs can be considered a valid alternative to substitute Ordinary Portland Cement (OPC) due to their notable energy efficiency and reduced environmental impact compared to traditional cements (Palomo et al., 2021). These binders reduce the CO_2 emission, primarily attributed to their production at room temperature, bypassing the necessity for high-temperature thermal treatments. Moreover, their production can exploit a diverse range of natural raw materials, including volcanic ash, rocks, and rock processing waste, thereby minimizing transportation costs related to the materials.

This study aims to utilize the diatomite of the Tripoli Formation, previously unexploited as a natural precursor for AAMs, particularly in niche applications such as cultural heritage restoration. In particular, this natural raw material has been selected both for its local availability and for its mineralogical composition, since it includes phases such as calcite, gypsum, silica, and clay minerals, which are important in alkali-activated materials technology and commonly used in cementitious materials. The investigation of Tripoli diatomite reactivity in an alkaline environment was conducted through selective chemical attack with an 8M sodium hydroxide (NaOH) solution, representing conditions closest to alkaline synthesis. This test aimed to dissolve amorphous phases and slightly affect crystalline ones. The total amounts of soluble phases were determined gravimetrically. Subsequently, feasibility studies involving the synthesis of alkaline-activated materials using Tripoli Formation rock alone or in binary mixture with metakaolin yielded promising results in terms of workability and mechanical properties. Samples were subjected to X-ray diffractometry, FT-IR spectroscopy, scanning electron microscopy and uniaxial compressive testing for a complete mineralogical, textural and physical-mechanical characterization to provide insights into their properties and potential applications.

The present contribution falls within the research activities of the PNRR project CHANGES - Spoke 6 - History, Conservation and Restoration of Cultural Heritage. The main focus of the spoke is to develop and apply integrated methodologies, strategies and approaches to support the processes of historical understanding, conservation, restoration, monitoring, sustainable and participatory planning in multi-layered contexts of cultural heritage.

Palomo A. et al. (2021) - Portland Versus Alkaline Cement: Continuity or Clean Break: "A Key Decision for Global Sustainability". Front. Chem., 9, https://doi.org/10.3389/fchem.2021.705475.

New method to quantify fluorite in geo-complex material: the case of Pianciano mine (Central Italy)

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Keywords: carbonatites, mine, complex geo-materials.

Geo-complex materials consist of mixtures of two or more different raw materials, requiring the definition of ad hoc beneficiation methods for their characterization. In this case, the products studied, marketed by So.Ri. Co.M. Srl - Società Ricerche Coltivazioni Minerarie, consist of two different mixtures from the Pianciano mine: carbonatite and clay fluoritite. The mine is located 3 km southwest of Lake Bracciano, near Castel Giuliano (Rome, Italy). The Pianciano-Castel Giuliano carbonatite-fluoritite sequence was first described by Mastrangelo (1976) as the main deposit in the Sabatini Mountains area, covering about 6-8 km^2 and characterized by the presence of four different mineral facies: white carbonate material; yellow carbonate material; white fluoritite material and grey fluoritite material. The latter represents the source of CaF_2. The deposit has since been extensively studied (Stoppa et al., 2016; 2019), and its facies have been interpreted by Stoppa et al. (2016) as carbothermal residual carbonatites.

The Pianciano's geo-complex materials are heterogeneous, with fluorite being mainly f < 200 µm, therefore their CaF_2 grading it's difficult to assess. The new proposed method relies on differentiation of granulometric spindles and their evaluation. After primary quartering, the material is homogenized using hydrogen peroxide (H_2O_2) at 120 vol. the solution obtained is sieved and dried (T < 80°C). Both 200 µm passing and retained is dried and quartered for quantitative analysis using X-Ray Powder Diffraction. SEM EDS Analysis control is performed on the qualitative characterization of this geo-complex material. Each spindle is represented by different proportions of contained minerals, with the < 200 µm fraction being as semi-pure materials with only fluorite, calcite, and barite. This griding procedure allows the efficient assess of the real mineralogical content the different mixing ready for marketing. Fluorspar is currently used in clinker production to reduce CO_2 emissions. Due to its importance, it is necessary to accurately assess the fluorspar content in geo-complex materials to use them as raw materials and limit industrial waste.

Stoppa F. et al. (2019) - Italian carbonatite system from matle to ore deposit. Ore Geol. Rev., 114,103041.

Stoppa F. et al. (2016) - State of the art: Italian carbonatites and their potential for critical-metal deposits. Gondwana Res., 37,152-171.

Mastrangelo F. (1976) - I Giacimenti. Rend. Soc. It. Min. Petr., 32, 29-46.

Comparative trace element concentrations in carbonate lithologies used for the production of lime and their washing muds

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Keywords: trace elements, Critical Raw Materials, lime.

Numerous raw materials are of increasingly high importance in many industrial fields, while at the same time presenting high risks in their supply chain. The European Union has, with the Regulation (EU) 2024/1252, also known as the Critical Raw Material Act, updated the list of these essential materials and laid out policies to increase production in European countries. This study in accordance with the new policies and in collaboration with UNICALCE S.p.A., a leader company in lime production and part of an international group, focuses on the characterization of washing muds produced during stone processing, while also comparing them with the original carbonate rocks (limestone and dolostone) from which they derive. Facies character, petrographic and diagenetic features and trace element concentrations were preliminarily analysed from two quarries, Vaiolo Alta (LC) and Costiolo-Forcella (BG), both of which extract material from the Lower Jurassic shallow-water, partially dolomitized, carbonates of the Albenza Formation. The two localities differ in the abundance of diagenetic dolomite both as subhedral dolosparite mosaics completely or partially replacing the original limestone or as hydrothermal dolomite cement in fractures, with Vaiolo Alta expressing more extensive and advanced dolomitization of the observed facies compared with Costiolo-Forcella. The methodologies adopted for this study were optical microscopy for the facies analysis, and ICP-MS for the trace elements. The results show low but varied concentrations, with relatively high contents of strontium (27-723 ppm) and uranium (0.10-0.84 ppm). As the lime industry involves in Europe hundreds of quarrying sites and produces millions of tons of fine-grained sub-products even relatively low amounts of metals and especially CRM metals, eventually identified as associated with specific facies, could be potentially of interest for recovery. The difference in trace element patterns between source rock and washing muds serves as an important starting point in the future considerations and potential recycling of these sub-products.

Recovered silt filled geopolymers for low-strength concrete applications in road construction

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Keywords: geopolymers, metakaolin, waste silt.

Geopolymers are inorganic polymeric materials derived from the reaction between a solid aluminosilicate and an alkaline activating solution. Geopolymers have shown remarkable qualities compared to Ca-based cements, such as excellent mechanical strength, durability, high thermal and chemical resistance to acidic and alkaline environments (Lyon et al., 1997), with the additional quality of requiring lower temperatures and contributing with 80% less CO_2 emission during their production. Among the wide variety of applications these products may be found in construction industry as they have been studying for their similarities with Ordinary Portland Cement (OPC) (Davidovits, 2008). A wide variety of raw materials are employed as precursors in the geopolymer synthesis to obtain materials for different applications. Moreover, significant research has been conducted on the effect of incorporating industrial by-products as additives in the geopolymeric matrix aiming at improving the properties of the composites, e.g., mechanical, fire-resistance and high durability (Solouki et al., 2021). In this study, a novel composition employing metakaolin (MK) as raw material coupled with a quarry derived by-product silt, as filler, is presented (Valdrè, 2023). The present research has both economic and environmental goals, potentially facing greener and low-cost sustainable concrete production, while preserving suitable mechanical properties in low-strength concrete applications. The mechanical properties of MK-based geopolymer with Si:Al ratio equal to 2, namely Na,K polysialate-siloxo binder, and its composite have been studied in depth. The geopolymer samples were synthetized varying the ratio of NaOH/KOH in the activating solution, but keeping fixed both the M^+O ratios and the water content (Davidovits, 2008). The binders were cured at different temperatures, i.e., 85°C for 2 hours, 60°C for 3 hours and 40°C for 4 hours. The mechanical properties, the structural, morphological and microchemical characterization of metakaolin, silt powder and the geopolymers were carried out by means of unconfined compression tests (UCT), X-ray diffraction and ESEM-EDS analysis. Results have underlined that the curing process at 40°C generally improves the mechanical performances of the mixed Na^+/K^+ geopolymers compared to higher curing temperatures products. The maximum fracture stress obtained was approximately 21 MPa at 40°C. The use of a filler resulted in composites with mechanical properties similar to those of the sole binder, meaning that the performance was not degraded by adding the waste silt. ESEM imaging showed the presence of some inhomogeneities (cracks and voids of few micrometers) in the products. The proposed material that safely uses a waste by-product (end-of-waste) and reduces the carbon footprint by geopolymerization could be suitable for low-strength concrete applications, such as in semi-rigid or rigid road pavements.

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Lyon R.E. et al. (1997) - Fire-resistant Aluminosilicate Composites. Fire Mater., 21, 67-73, https://doi.org/10.1002/(SICI)1099-1018(199703)21:2<67::AID-FAM596>3.0.CO;2-N.

Solouki A. et al. (2021) - Thermally treated waste silt as filler in geopolymer cement. Materials, 14(17), 5102. https://doi.org/10.3390/ma14175102.

Valdrè G. (2023) - PRIN 2022: Sediments Eco-recycling Exploitation, Development and Sustainability (SEEDS). Financed by the European Union – Next Generation EU through the Italian Ministry of University and Research under PNRR - Mission 4 Component C2, Investment 1.1 “Fondo per il Programma Nazionale di Ricerca e Progetti di Rilevante Interesse Nazionale (PRIN)”.

Multi-methodological analysis of orpiment As_2S_3 and related possible applications in bidimensional optoelectronics

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Keywords: orpiment As2S3, 2D minerals, optoelectronics.

Orpiment, whose chemical formula is As_2S_3 (space group $P2_1/n$), is a well-known mineral since ancient times because of its use as yellow and golden pigment, hence its Latin name after *auripigmentum* (Bonazzi & Bindi, 2008), which can be commonly found in veins and hot-spring deposits (Gaines et al., 1997). Besides its use in artwork and in the extraction of arsenic, As_2S_3 is a very important phase in materials science and optoelectronics for its semiconducting properties. Furthermore, from the crystallographic perspective, orpiment is made of layers of arsenic sulphide stacked along the [010] direction, thus the mineral presents a heterodesmic structure with strong covalent in-plane As–S bonds and weak van der Waals interactions between the As_2S_3 layers. It is worth noting that the cited layers are not atomic-flat like, for instance, as graphene or mica, but present a puckered surface.

Considering the growing interest in bidimensional, easily cleavable minerals and materials presenting peculiar electronic and optical properties, orpiment could be an important candidate for advanced use in optoelectronics and other related physical applications.

In the present work, we report a detailed experimental and theoretical characterization of the crystallographic, physical (electronic and optical) and vibrational properties of orpiment. On the experimental side, we performed X-ray powder diffraction (XRPD), environmental scanning electron microscopy (ESEM) with energy-dispersive microanalysis (EDS) and confocal Raman microspectrometry on a natural sample of orpiment provided by the "L. Bombicci" Mineralogy Museum (Bologna). This knowledge was corroborated by theoretical simulations carried out within the Density Functional Theory (DFT) with the CRYSTAL code (Dovesi et al., 2018) to provide further data at the atomic scale and help the interpretation of the results. We employed throughout the work all-electron Gaussian-type orbitals basis sets on As and S atoms and hybrid functionals (B3LYP and HSE06), including long-range interactions in the physical treatment via the DFT-D3 correction (Grimme et al., 2015). We also simulated the exfoliation of orpiment, considering different models with decreasing thickness (i.e., number of layers). The results show that the bulk mineral has a semiconducting behaviour, with band gap energy Eg = 2.44 eV, which increases up to 3.17 eV when it is exfoliated down to a single layer. The surface formation energy, which is directly related to the cleavage, is almost constant, meaning that the exfoliation of flakes with different thicknesses is not hindered by energy contributions. The phonon dispersion relations calculated for the bulk and layered mineral did not show any imaginary phonon band, hence all the structures are thermodynamically stable. All the measured and calculated properties provide further insight into orpiment as a suitable large-band semiconductor mineral for optoelectronics and other advanced technological applications.

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Valorisation of swing sludge from Cuasso al Monte (Italy) in alkali-activation process: feasibility study

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Keywords: alkali-activated materials, sawing sludge, circular economy.

In recent years, a growing awareness of environmental issues has risen, leading to the promotion of actions aimed at reducing the negative human impact of on our planet. These attempts have led to set ambitious goals to lower CO_2 emissions, with a view to a greener and more sustainable future (Ramón-Álvarez et al., 2023). In order to accomplish this target, a significant management of natural resources is necessary to protect the ecosystems and biodiversity. The stone industry, crucial for the development of the construction field, has to deal with different issues such as high production costs, energy and water consumption as well as its large amount of derived wastes, among them sawing sludge. This latter, constituting approximately 30% of the total sawn block volume, represents important environmental and health issues when improperly managed and disposed in landfills (Coppola et al., 2020). Within this context, Alkali Activated Materials (AAMs) offer a promising deal through the recycling of wastes to use as precursors for the synthesis of new materials in a sustainable process, which takes place at room temperature. Some attempts by other authors have already successfully explored and validate the feasibility of producing AAMs starting from different sawing sludges, including basalt and marble powders, to be applied in the fields of construction and restoration (Portale et al., 2023; Salihoglu & Salihoglu, 2018).

In this work, the potentiality of using Cuasso al Monte sawing sludge (FC), sourced from late-Hercynian granitic plutons renowned for their ornamental and structural properties, as a precursor for AAMs production was explored. Moreover, metakaolin was added to FC enhancing the reactivity of the system in turn activated using solutions made of sodium silicate (Na_2SiO_3) and 8M sodium hydroxide (NaOH). Cubic samples (2x2x2 cm) were cured at room temperature for 28 days. Mineralogical analysis was carried out by X-ray diffraction method (XRD) on both raw materials and synthesized binders, while uniaxial compressive strength (UCS) tests on consolidated binders. The XRD results showed the formation of an amorphous phase on the consolidated samples, testifying the occurrence of the polycondensation reaction.

Moreover, the AA-binders recorded an average compressive strength up to around 30 MPa, demonstrating the suitability of using FC as a precursor for the development of alternative materials for the construction field, in a perspective of eco-conscious construction practices.

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Portale S. et al. (2023) - Feasibility study about the use of basalt sawing sludge in building and restoration. Mater. Lett., 333, 133624, https://doi.org/10.1016/J.MATLET.2022.133624.

Ramón-Álvarez I. et al. (2023) - Mechanical performance after high-temperature exposure and Life Cycle Assessment (LCA) according to unit of stored energy of alternative mortars to Portland cement. Constr. Build. Mater., 365, 130082, https://doi.org/10.1016/J.CONBUILDMAT.2022.130082.

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Alkali-activated materials based on volcanic ash and waste glass: sustainable and alternative geomaterials from waste to resource

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Keywords: alkali-activated materials, recycle, waste materials.

In light of escalating ecological and climate challenges, there is a shift towards mitigating the environmental footprint of the construction sector. Therefore, the development of alternative materials is crucial. This study aims to explore the potential of utilizing waste materials such as nonrecyclable glass from Johns Manville company (*E*-fiber glass producer, Slovakia) and volcanic ash from Mt. Etna (Italy) in the process of alkaline activation. Waste glass, which amounts to an annual production of about 200 tons, poses a significant environmental challenge (Xiao et al., 2022). Similarly, volcanic ash from Mt. Etna is considered solid municipal waste and disposed of in landfills if not used in a safe and innovative and process. Previous research demonstrated the feasibility of using similar materials for AAMs production with interesting properties (Adesina et al., 2022; Scanferla et al., 2023). In particular, this work aims to realize AA-pastes using mixtures of volcanic ash and waste glass from glass fibers in borosilicate system as precursors, with two mix proportions (40-60 wt.% and 20-80 wt.% of waste glass and volcanic ash respectively) activated with 7M and 9M potassium hydroxide solution and cured at 60°C for 4 days. A multidisciplinary approach was performed, including: a feasibility study to assess if the final materials could withstand up to 3 hours in boiling water; XRD to investigate the differences in the crystalline phases between raw materials and the final samples obtained; FT-IR and SEM-EDX analysis to evaluate the gel formation and the surface morphology; Inductively coupled plasma mass spectrometry to investigate the potential for heavy metal release; compressive strength tests and helium pycnometer measures to quantify and evaluate the influence on the mechanical properties of the different reactants involved in each mix design related to the samples porosity. The results have shown that all formulations studied are feasible, with enhanced mechanical performance for the mixtures with lowest volcanic ash content, for both molarities of KOH, achieving values of approximately 20 MPa. Porosity decreased with the increase of alkali concentration, from approximately 25% for 7M to 21% for 9M. Carbonated and hydrated phases were identified from both XRD and FT-IR analysis, sign that the reaction among glass, ash, and alkali took place to form a stable gel. Grains of glass and ash are visibly embedded into an Al-Si-Ca matrix, as highlighted by SEM and EDX. These outcomes lay the groundwork for potential using of these mixtures in additive manufacturing process for the production of building elements made mainly of waste-based materials.

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Adesina A. et al. (2022) - Fresh and mechanical properties overview of alkali-activated materials made with glass powder as precursor. Cleaner Mater., 3, 100036, https://doi.org/10.1016/J.CLEMA.2021.100036.

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Xiao R. et al. (2022) - A state-of-the-art review of crushed urban waste glass used in OPC and AAMs (geopolymer): Progress and challenges. Cleaner Mater., 4, https://doi.org/10.1016/J.CLEMA.2022.100083.

S17.

Advanced minero-chemical characterization and processing of waste for a conscious reuse

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Application of mineralogy to waste reuse in ceramic materials

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Keywords: ceramics, waste reuse, XRD.

In the last years, United Nations are paying much attention to sustainability's theme, with several environmental targets to be reached. One of these targets is aimed at taking action for a responsible consumption and production, preserving as much as possible the extraction of natural raw materials as well as to limit the disposal of manufacturing subproducts and wastes (Zanelli et al., 2021).

In light of this, we have explored the possible reuse of fired ceramic scraps (FCS) into the ceramic production (at 12 and 21 wt.%), with particular focusing to the sanitary-ware cycle (Bernasconi et al., 2011), in partial substitution of natural raw materials such as quartz and feldspar. The results show that FCS reuse is feasible because the largest part of technological constraints are respected with the exception of the alpha linear thermal expansion of the fired body (αL, body), whose value tends to a progressive diminution as FCS content in the recipe is increased, with deleterious outputs if the ceramic body is glazed (Plesingerola & Kovalcikova, 2003).

Application of diffraction techniques (both RIR-Rietveld - Gualtieri, 2000 - and in-situ experiments) demonstrated that the body thermal expansion reduction is mainly addressed to phase fraction changes, with the largest effect due to the decrease in quartz content. Differences in the glass thermal expansion coefficient have been also highlighted as well as some residual stress at the quartz-glassy matrix interface.

These findings are important to figure out a possible slip composition that maintains the αL, body within tolerances also in presence of FCS, possibly with the introduction of other waste materials.

Bernasconi A. et al. (2011) - The role of firing temperature, firing time and quartz grain size on phase-formation, thermal dilatation and water absorption in sanitary-ware vitreous bodies. J. Eur. Ceram. Soc., 31, 1353-1360, https://doi.org/10.1016/j.jeurceramsoc.2011.02.006.

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Zanelli C. et al. (2021) - Wastw recycling in ceramic tiles: A technological outlook. Resour. Conserv. Recycl., 168, 105289, https://doi.org/10.1016/j.resconrec.2020.105289.

Bottom ashes from MSWI in ceramics: a higher value reuse of waste

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Keywords: MSWI, bottom ashes, tiles.

In Europe about 30 Mtons of bottom ashes (BA) from incineration plants are produced every year. Not more than half is reused, most after quality-upgrade treatments as a substitute for natural aggregates in road building or other construction related activities (Chen et al., 2023). Higher value applications are being sought, such as in the production of ceramic tiles, where careful processing and mixing are required to ensure compatibility with the ceramic matrix and to meet the necessary quality standards. However, research in this field is still in the preliminary stages (Namkane et al., 2016). The criticalities in the addition of BA in ceramics are: 1) the detrimental effect on the rheology of the paste from Cl and sulphates, 2) the behaviour under high temperature furnace heating, and the effect on technological properties 3) the release of potentially toxic elements in the manufactured product.

In this investigation, we explored the possible use of BA in sanitary ware ceramics. Sanitary ware is challenging due to strict technological and aesthetic constrains. BA were added to a standard industrial (SI) paste, used in sanitary ware production. We observed that the use of BA negatively affects rheological properties, likely for the dissolved salts. An improvement was observed if the BA were therefore sieved, and the coarser fraction was used (> 8 mm), after milling and repeated washing. Heating through a ceramic route produced the samples of interest. Each sample was analysed by XRD and XRF before and after each run; leaching tests were done, and ICP-MS were performed on the leachate.

Preliminary results show that addition of coarse and washed BA is not detrimental to rheological and technological properties of the paste and products. However, leaching tests on heated BA alone showed that increasing the heating temperature not all elements are efficiently immobilised. Elements such as Cr and V are strongly immobilized, Ti, Mn, Fe, Co, Zn and Pb increase their concentration in the leachate while for Ni, Cu, and Cd their behaviour is not clear. Leaching tests on sanitaryware ceramics with added BA are in progress. The reuse of BA in sanitary ware ceramics is a strong opportunity in circular economy, but upgrade treatment are required, as simply heating BA may not guarantee the immobilization of potentially toxic elements.

Chen B. et al. (2023) - A review on the utilization of municipal solid waste incineration (MSWI) bottom ash as a mineral resource for construction materials. J. Build. Eng., 71, 106386, https://doi.org/10.1016/j.jobe.2023.106386.

Namkane K. et al. (2016) - Utilization of coal bottom ash as raw material for production of ceramic floor tiles. Environ. Earth Sci., 75(24), 386, https://doi.org/10.1007/s12665-016-5279-0.

The CLEAN project: a sustainable methodology to reduce the environmental impact of MSWI fly ash and to recover strategic metals

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Keywords: MSWI FA, steam washing, heavy metals absorption.

Municipal solid waste fly ash (MSWI FA) is classified as hazardous waste due to its high metal and soluble salt content, giving rise to environmental risks upon its reuse. Multi-step washing proved highly effective, notably in chloride removal, yet often requires substantial water volumes (Ferraro et al., 2019). Therefore, water washing poses challenges including high water consumption, substantial wastewater generation, heavy metal enrichment, and potential secondary environmental contamination. The CLEAN project, funded by the Ministry of the Environment and Protection of Land and Sea, introduced the steam washing (SW) to reduce chloride and metal concentrations in FAs, exploiting the steam available in waste-to-energy plant, as a sustainable solution to decrease the volume of these residues and make them more suitable for stabilization, since the reduction of alkali chlorides (including KCl, NaCl) can improve fly ash mechanical and geotechnical properties as mechanical strength. While SW wastewater is rich in trace elements, investigations were conducted to recover heavy metals (Cr, Ni, Cu) for the raw-secondary materials market.

Detailed elemental characterizations of solid matrices (pre- and post-SW) and liquid matrices (leachates, wastewater) were carried out, by X-ray fluorescence (XRF), X-ray diffraction (XRD), and inductively coupled plasma mass spectrometry (ICP-MS). The results of leachates analyses of samples treated by SW show that steam washing was efficient in removing especially water-soluble chlorides including sodium chloride, potassium chloride (up to 80%) and sulfates (by 30%); while for heavy metals, like Cd, Zn, Pb, the removal was up to 80%, even at short time of treatment (15-30 minutes). It was noted a decrease of concentration all for trace elements, excluding Sb, (only 70% and higher than the legal limits), which still requires particular attention and study. Results about solid residues indicate metals like Cr (300 mg/kg), Ni (65 mg/kg), Cu (1500 mg/kg), and Sb (1800 mg/kg). After a 40% weight loss of FAs post-washing, there is a 80-90% surge in these elements per kg of ash. Residual washing water has high metal concentrations: 6000 mg/L Zn, 400 mg/L Pb, and 250 mg/L Cd, corresponding to approximately 15%, 10%, and 70% extraction from FAs (considering SW uses a 1.5-2.0 liquid-solid ratio).

Analyses for the elemental characterization of wastewater are underway after absorption and recovery of metals by minerals like zeolites. Three synthetic zeolites and a natural zeolite has already tested showing that Zn, Cd and Pb are successfully removed (reduction by about three orders of magnitude), using zeolites with low Si/Al (Si/Al~ 1.3; 1-2); whereas Cd is better adsorbed by more alkaline zeolite.

Ferraro A. et al. (2019) - Pre-treatments of MSWI fly-ashes: a comprehensive review to determine optimal conditions for their reuse and/or environmentally sustainable disposal. Rev. Environ. Sci. Biotechnol., 18, 453-471, https://doi.org/10.1007/s11157-019-09504-1.

Complexity of the system and plethora of crystal phases in fly ashes: a careful investigation of processes and products from cooling of the flue gas in the MSW waste-to-energy incinerators

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Keywords: fly ashes, melted drops, waste management.

The chemical-physical complexity of the material recovered from filters located along the path of the flue gases in the municipal-solid-waste incinerators (fly ashes - FA) is well known. FA are materials composed of a significant easily-soluble fraction, carrying highly volatile heavy metals, chlorides and sulfates, and classified as "hazardous" (Bernasconi et al., 2022). The samples investigated in this work were collected at the waste-to-energy plant of Turin (Orbassano - Iren Group Company). In this plant, the fly ashes deposited in the empty pass, in the boilers and in the electrostatic precipitators (EA, BOA and ESTA in Wolffer et al., 2021) are not differentiated, so that the samples under study are a mixture of them.

We have performed a preliminary characterization of the bulk original and washed ashes, using X-ray powder diffraction (XRPD) and transmission electron microscopy (TEM), with a focus on the detection and evaluation of the amorphous portion.

Then, we have attempted a new approach, which is to simplify the system by analyzing small portions of sample separately, and using XRD, SEM and EDS. More than 30 samples were selected on the base of optical features, glued to the tip of a capillary and analyzed by X-ray diffraction. Three main types of materials were classified:

I) isolated crystals SC of variable size (up to about 200 μm). Some of them show an idiomorphic habit and the morphological forms are well recognized. In most cases, the crystals are irregularly shaped and include impurities that make them opaque in transmitted light;

II) porous particles PP formed by aggregated of loosely cohesive crystalline phases (up to about 800 μm). The porous particles and the crystals forming them have variable size, color and aspect. Some of the crystals forming the aggregates exhibit an idiomorphic shape, presumably because of the inter-crystal voids that enable development of faces;

III) more compact spheroidal particles MD with smooth and shiny surface (up to about 500 μm). Specimens of such a type often show one or more spherical cavities within. The spheroidal shape, the smooth surface and the occurrence of "bubbles" point to them being products of a solidification from molten drops bearing dissolved gas. The MD can be viewed as a "closed" system (no exchange of matter) and their crystals can form an equilibrium paragenesis.

A noticeable number of crystals have been identified: quartz, cristobalite, anhydrite, feldspar, olivine, pyroxene, gypsum, hematite, gahnite, chromite, merwinite, monticellite, aluminum, corundum, periclase, perovskite, gehlenite-akermanite, calcite, ettringite, halite, sylvite, grossite, apatite, merrillite-whitlockite, Si-carbide, Ba-sulfide. This approach highlighted that FA is a very complex material, not only as a result of the many chemical species involved, but also because several crystallization processes take place, leading to different products, each one related to its conditions of formation.

Bernasconi D. et al. (2022) - Influence of speciation distribution and particle size on heavy metal leaching from MSWI fly ash. Waste Manag., 138, 318-327, https://doi.org/10.1016/j.wasman.2021.12.008.

Wolffers M. et al. (2021) - Characterization of MSWI fly ashes along the flue gas cooling path and implications on heavy metal recovery through acid leaching. Waste Manag., 134, 231-240, https://doi.org/10.1016/j.wasman.2021.08.022.

Innovative approaches for treating industrial byproducts: towards inertization and reutilization in advanced technological materials

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Keywords: inertization, industrial by-products, geopolymers.

In the framework of the circular economy, the recovery, processing, and reuse of industrial byproducts are topics that stakeholders support to achieve environmental targets such as resource management efficiency, industrial process optimization, and the reduction of environmental impact (including waste output, gas emissions, and sustainable use of raw materials).

A case study is represented by the secondary aluminum industry, which deals with special hazardous waste from screening, pyrolysis, and fusion processes. According to European Union regulations, such materials cannot be disposed of in normal landfills due to the high concentration of toxic substances and the potential development of hydrogen-enriched gases that can form explosive mixtures with air.

Experimental studies (Ercoli et al., 2021) were developed for a procedure that leads to a full chemical neutralization driven by the oxidation of metallic components in a stainless-steel batch mini reactor. Firstly, by controlling the process in an alkaline solution to study gas generation. Secondly, identifying correlations between the change in mineralogical phases and specific parameters such as loss on ignition (LOI) of the residues after the experiments.

Additionally, further procedures were planned to dilute and trap the pollutants within innovative inorganic materials called geopolymers to demonstrate the possibility of reusing them as foaming agents (Nguyen et al., 2022). The influence of foam generation on the density of geopolymers was deeply investigated, highlighting the physical properties, such as mechanical strength, thermal conductivity, specific heat, and thermal diffusivity (Ercoli et al., 2022). Leaching tests were performed to obtain preliminary results on the interaction and affinity of toxic elements with the structure of the geopolymer.

Processing these types of by-products represents a sustainable approach to waste management, thereby avoiding the risks associated with direct storage before chemical neutralization and the long-distance transportation to landfills for hazardous waste materials. Incorporating the industrial by-products into geopolymers provides a potential solution for their reutilization. It offers a promising alternative to Portland cement manufacturing, which demands large amounts of energy and emits approximately 80% more CO_2 (Krishna et al., 2020).

In conclusion, this experimental research aims to provide significant insights into waste management, offering economic and environmental benefits based on thorough mineralogical and physicochemical characterization of the products, exploiting advanced analytical techniques.

Ercoli R. et al. (2021) - Hydrogen-Rich Gas Produced by the Chemical Neutralization of Reactive By-Products from the Screening Processes of the Secondary Aluminum Industry. Sustainability, 13, 12261, https://doi.org/10.3390/su132112261.

Ercoli R. et al. (2022) - Mechanical and Thermal Properties of Geopolymer Foams (GFs) Doped with By-Products of the Secondary Aluminum Industry. Polymers, 14, 703, https://doi.org/10.3390/polym14040703.

Krishna R.S. et al. (2020) - A review on developments of environmentally friendly geopolymer technology. Materialia, 20, 101212, https://doi.org/10.1016/j.mtla.2021.101212.

Nguyen V.V. et al. (2022) - Low-Density Geopolymer Composites for the Construction Industry. Polymers, 14, 304, https://doi.org/10.3390/polym14020304.

Multi-methodical approach for a detailed characterization of cogeneration ashes and their valorisation in the fertilizer industry

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Keywords: by-products, ashes, fertilizer.

Various industries are paying growing attention to the importance of sustainability and environmental responsibility. This entails efforts to reduce waste, optimize resource usage, and minimize environmental impacts. Particularly, there is increasing interest in finding innovative ways to repurpose industrial by-products and waste materials, transforming them into valuable resources. This aligns with regulatory frameworks such as Directive 2008/98/EU, which promotes efficient waste management practices.

In the mineral fertilizer industry, there is a reliance on non-renewable mineral resources to produce fertilizers that support agricultural productivity. However, there is a growing recognition of the need to transition towards more sustainable practices by incorporating waste materials and implementing processes to transform them into valuable products.

One notable area of focus is the recovery and utilization of cogeneration ashes, which are generated from the incineration of biomass for electricity production. These ashes have been recognized for their potential as sources of essential plant nutrients, such as potassium, phosphorus, magnesium, and calcium. Additionally, due to the presence of basic cations in the form of oxides, hydroxides, and carbonates, these ashes can be an effective soil amendment (Freire et al., 2015; Maresca et al., 2017; Cruz et al., 2023).

From this perspective, this study aims to investigate the potential, from a mineralogical and chemical point of view, of cogeneration ashes in order to recover elements and minerals useful for plant growth and, at the same time, to reduce the landfills disposal in accordance with the principles of the Circular Economy.

In this study, eight samples of vegetal biomass ashes, comprising four fly ashes and four bottom ashes from different cogeneration plants, producing electricity through the combustion of agroforestry residues, were characterized using a multi- methodical approach. Various chemical, mineralogical, and microstructural analysis techniques, along with physical-chemical treatments, were applied to evaluate their content of phytoavailable components, occurrence of harmful substances, and viability as a sustainable resource for mineral fertilizer production.

Results reveal significant physical and chemical variability in fly and bottom ashes derived from various agroforestry residues. This variability is associated with factors such as the type of incinerator, combustion temperature, ash type and particle size of ashes. However, chemical analyses indicate the presence of substantial concentrations of K_2O, CaO, and MgO in all investigated samples, while leaching tests and mineralogical analysis reveal relevant water-soluble mineral phases that may be available to plants. Furthermore, investigations show the occurrence of basic cations in the form of oxides, hydroxides, and carbonates, which could be an excellent amendment to deal with soil acidity and compensate for the loss of nutrients.

Cruz N. et al. (2023) - Stabilization of biomass ash granules using accelerated carbonation to optimize the preparation of soil improvers. Waste Manage., 156, 297-306.

Freire M. et al. (2015) - Critical aspects of biomass ashes utilization in soils: Composition, leachability, PAH and PCDD/F. Waste Manage., 46, 304-315.

Maresca A. et al. (2017) - Recirculation of biomass ashes onto forest soils: ash composition, mineralogy and leaching properties. Waste Manage., 70, 127-138.

Radionuclides assessment in municipal solid waste incineration plants wastes: a comparative case study of pre- and post-pandemic periods

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Keywords: solid waste residues, characterization, pandemic, radionuclides, radiation hazard.

Municipal Solid Waste Incineration (MSWI) plants generate significant amounts of solid wastes such as Fly Ash (FA) and Bottom Ash (BA). These MSWI residues have received attention due to the presence of potentially toxic elements and significant isotopic fractionation (Funari et al., 2016). Knowledge and data coverage on activity of naturally occurring radionuclides such as polonium (^{210}Po), uranium (^{235}U, ^{238}U), radium (^{226}Ra), and potassium (^{40}K) in MSWI residues (e.g., Janković et al., 2011) is limited so far, even though such a kind of exploration is necessary to evaluate the potential of radiological hazard and environmental impact fully. Here, available types of BA and FA included samples from bag filters treated with soda additive (FAS) and lime additive (FAL), and quenched BA samples from grate-furnace MSWI plants, located in Northern Italy. Both BA and FA were sampled during pre- (2013) and post-pandemic period (2022). In this study, the main objectives were to determine and compare the radionuclides (^{210}Pb, ^{40}K, ^{226}Ra, ^{232}Th, ^{137}Cs, ^{241}Am, ^{131}I) concentration in MSWI samples to evaluate their abundance by Enrichment Factor (EF), and total radionuclide emissions with radiological impact. Gamma spectrometric analyses results showed that naturally occurring radionuclides (^{210}Pb, ^{40}K, ^{226}Ra, and ^{232}Th) were higher for FAL rather than FAS and BA, while the anthropogenic radionuclides (^{137}Cs, ^{241}Am, and ^{131}I) were comparatively low in all ashes for both periods. The EF showed that radionuclides were enriched in FA and BA with low to high enrichment level, as ^{40}K and ^{210}Pb being the most elevated nuclides. Activity Concentration Index (ACI) results of all radionuclides were found below the permissible limit (< 1), as recommended by the European Commission (1999), suggesting no potential radiological hazards in the external environment. The total emission factor of natural radionuclides based on regional estimation point to a potential risk of radiological hazard.

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Temperature treatments of bottom ash from municipal solid waste incinerator: new perspective and existing applications

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Keywords: MSWI-BA, environmental mineralogy, PTE.

The ever-increasing production of waste on a local and global scale is driving scientific research to investigate and deeply understand materials for their potential reuse in a circular economy. In this context, bottom ash (BA) from Waste-to-Energy (WtE) plants plays a paramount role, as it not only represents the majority (about 80% by weight) of the plant's output but can also be considered a valuable resource for new materials. Indeed, currently, BA has been used for various applications such as filler material in road construction and foundation material in noise barriers. However, in many regions, it is still mostly left unused and ends up in landfills (Gooi, 2020). Bottom ash is largely composed of silico-aluminates of Ca, Fe, Na, and K, both as amorphous and crystalline structures. The main problem associated with their use lies in the strong heterogeneity of the material, especially regarding the minor elements that these residues may contain and release into the environment over time during their utilization (Mantovani et al., 2023). The release mainly concerns heavy and potentially toxic elements (PTE), which are commonly leached even when BA is incorporated into other materials and subjected to heating processes (i.e., ceramic processes)(Ardit et al., 2022).

In this work, BA from the Parma WtE plant is treated at different temperatures (from 200 to 1250°C) and characterized using in-situ techniques (XRPD) and ex situ techniques (XRPD, SEM-EDS, Raman spectroscopy and XRF) to investigate the modifications of the material under different treatments. Additionally, leaching tests were conducted after each treatment to assess the release of elements. Preliminary results have shown that: a) the bottom ashes begin to melt at a temperature of 1150°C, releasing various gases and exhibiting a highly vesicular structure, b) despite the high-temperature firing process, all samples from 200 to 1150°C exhibit significant heterogeneity, especially at the microscopic level, c) the increase in temperature promotes the formation of wollastonite, melilites, pyroxenes, and feldspathoids together with amorphous materials, but small agglomerates of metal compounds are still present, d) leaching tests showed that the increase in heating temperature strongly immobilizes certain elements such as Cr and V, while Ti, Mn, Fe, Co, Zn, and Pb increase their concentration in the leachate. Other elements such as Ni, Cu, and Cd do not show a particular trend. The main outcome is an outlook about reuse of BA after treatments. The high temperature treatments of BA can be a way to reuse them as they are or combined with other materials, but it's necessary to assess in details the heterogeneity of the material, especially regarding the behaviour of the metallic phases and alloys.

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Gooi S. et al. (2020) - A critical review and gap analysis on the use of bottom ash as a substitute constituent in concrete. J. Clean. Prod., 268, 121752, https://doi.org/10.1016/j.jclepro.2020.121752.

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Sewage sludge ashes characterization and microwave thermochemical treatment for fertilizer production

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Keywords: phosphorus, fertilizer, microwave heating.

The majority of phosphorus (P) supply within the European Union originates from Morocco, while the demand for fertilizer continues to escalate. These dynamics raise significant concerns regarding supply stability and market volatility (Schoumans et al., 2015). This study aims to characterize sewage sludge ashes resulting from mono-combustion of municipal sewage sludge, identifying them as a potential resource for P recovery and fertilizer production, in line with circular economy principles. The ashes underwent comprehensive analysis, including chemical analysis via ICP-MS for total P and heavy metal (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn) composition, X-ray diffraction, and quantitative phase analysis (QPA) to examine phosphatic crystalline structures and to highlight the amorphous content. SEM-EDS analysis facilitated the identification of various P-compounds within the ash, enabling correlation between quantitative data from QPA and ICP-MS regarding crystalline and total P content. The as-collected ash samples contained P in various crystalline compounds such as whitlockite ($Ca_{9.5}Mg_{0.5}(PO_4)_7$), hydroxyapatite ($Ca_5(PO_4)_3(OH)$), monetite ($CaHPO_4$), and tetra-potassium pyrophosphate ($K_4P_2O_7$), with total crystalline P ranging between approximately 3-4 wt.%, while the total P content ranged between approximately 4-8 wt.%. However, the bioavailability of P in both crystalline and non-crystalline states was found to be low or absent, as typical of sewage sludge ashes (Kasina et al., 2023). Subsequently, the ashes underwent thermochemical treatment at various temperatures using an innovative approach utilizing microwaves (MWs) instead of conventional heating sources. The treatment involved mixing the ashes with two reagents - an additive and a reducing agent - in specific proportions. This treatment aims to enhance P bioavailability, following the AshDec® process mechanism, and to generate new crystalline P compounds, such as buchwaldite ($NaCaPO_4$) or $KCaPO_4$ orthophosphate, with higher bioavailability. Concurrently, the treatment led to a reduction in heavy metal content, volatilizing them due to their higher vapor pressure at the working temperatures (Xu et al., 2023). The treated ashes underwent a thorough characterization process, mirroring the earlier approach, ICP-MS, QPA, and SEM-EDS analysis. This comprehensive analysis aimed to evaluate the formation of new crystalline compounds and track the concentration trends of P and heavy metals following the treatment. Subsequently, several leaching tests were conducted to achieve the maximum solubility of P and the reduced solubility of the non-volatilized heavy metals. The results achieved through this new MW-technology are promising for the production of P-based fertilizers from sewage sludge ashes.

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Functional recovery of Provincial Road no. 2 and management of waste materials: from waste to by-products. Experiences of the Province of Southern Sardinia in the reuse and cold recycling of geomaterials

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Keywords: geomaterial reuse, recycling, cold recycling methods.

As part of the extraordinary maintenance and safety activities of the road heritage scheduled for the years 2022 and 2023 by the Road Service of the Province of Southern Sardinia, two functional lots of intervention were designed and carried out on Provincial Road no. 2, a four-way section travel lanes that connect the Municipality of Carbonia with the Municipality of Villamassargia.

The design parameters have been set in advance in order to optimize the "best practices" during the design phase, capable of reducing the production of intervention waste as much as possible in favor of the reuse of by-products of materials from milling and excavation. In this way, by reducing as much as possible the transfer of waste to landfill, it was possible to design an intervention capable of recovering the waste materials typical of traditional processes, in favor of less exploitation and supply of new natural resources.

The first design phases were set both through an in-depth analysis and overall study of the entire road axis, and with the recovery of previous prospecting and indirect investigations, carried out by the former Province of Carbonia Iglesias, which had carried out deflectometric and laser profiler tests on the entire road platform in previous interventions, starting from 2008.

These data were then compared with those acquired with the "Falling Weight Deflectometer" surveys carried out in May 2022. All the data concerning the elastic modules of the first layer (bituminous conglomerate), the second layer (granular or stabilized mix) and finally the background layer.

The parameters of the indirect investigations were compared with the stratigraphic ones acquired through a campaign of direct micro-cores carried out in May 2022, carried out within the first meter of depth, in order to calibrate the stratigraphic data present in situ with those of the indirect investigations. Subsequent processing concerned the verification of the load-bearing capacity of the stratigraphy of the pavements, as well as verification of the continuity and regularity of the seismic parameters developed for geotechnical purposes.

Compared to a "standard design" approach, by comparing various design hypotheses, the design hypothesis with cold recycling methods was chosen, then carried out with lime and cement treatment of the materials present in situ. This execution led to a decrease in excavation activities by 45%, a decrease in landfill disposal by 34%, the elimination (-100%) of the items regarding a new foundation layer, in addition to a 75% decrease in the bituminous conglomerate of basic.

The (less impactful) design approach carried forward, however, resulted in the obtaining of excellent functional results, verified with the execution of plate tests which highlighted exceptional results, thus being able to see how it is actually possible to match the functional needs of the project and reduction of the impacts of intervention on the environment.

Recycling of surgical masks into green products for the building sector

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Keywords: surgical masks, geopolymers, circular economy.

The MASKVERDE project aims to explore the feasibility of incorporating surgical masks into geopolymer-based matrices to produce building materials. Initiated by Fondazione TIM in response to the COVID-19 pandemic, the project addresses the need for a sustainable method to dispose of surgical masks, whether unused or expired, which would otherwise end up in landfills. This approach aims to fulfill various environmental, social, economic, and industrial needs.

Surgical masks, provided by a collaborating school, underwent shredding using a Retsch Knife Mill SM 100 to produce fractions characterized by different sizes (1 and 2 mm lengths) of the three polypropylene layers, including nose wires and elastic bands.

Geopolymer samples were created by mixing various precursors such as metakaolin with sodium and potassium-based alkaline solutions. Different amounts of mask fragments (ranging from 1 to 5% by weight) were added to the mixtures, incorporating varied fiber grain sizes. Examination of the samples using optical and scanning electron microscopes revealed excellent textural characteristics, particularly in samples containing smaller fibers.

Leveraging the exceptional chemical and physical properties of geopolymers allows for tailoring specific technical attributes to meet diverse application requirements. Comprehensive physical-mechanical testing, including compressive and flexural strengths, density and porosity measurements, and various durability tests, has showcased promising attributes for integrating these materials into a wide array of construction products. These applications span both external and internal uses, as well as specialized panel preparation. In this regard, Life Cycle Assessment (LCA) will be of interest to determine the environmental impact.

Preliminary data indicate the feasibility of implementing an upcycling process for surgical mask waste, thereby diverting it from landfills and transforming it into a green material. Advancing understanding of these materials and their potential applications can play a significant role in promoting circular economy principles and fostering synergies among local industries.

Sustainable binders for the stabilisation of subgrade layers of road pavement by recycling of biomass ash, municipal solid waste incineration ash and concrete demolition waste

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Keywords: supplementary cementing materials, subgrade layers stabilisation, composite cement.

Road subgrade layers have the important task of absorbing and redistributing external loads from the more superficial and bituminous layers of the pavement. Low load-bearing capacity and large void variations in the subgrade can cause cracking and deformation of the road structure. During road construction, it is sometimes not possible to avoid soils with low bearing capacity, such as inconsistent soils, which do not meet the conditions required by technical regulations. Nonetheless, quarry materials are becoming scarce, and they are not considered environmentally friendly since the expansion of quarries implies many environmental problems and quarries are often located far from construction sites, consequently increasing costs and environmental concerns. For these reasons, this kind of lands are often treated with cement able to improve their physical and mechanical characteristics. However, the production of this stabilising agent is very harmful to the environment as it generates a large amount of CO_2, which then has a negative impact on the Earth's climate processes. Thus, to avoid this, the utilization of supplementary cementitious materials (SCMs) for the partial or total substitution of cement could represent a pragmatic solution to mitigate the CO_2 emissions of its production (Habert et al., 2020). Thus, this work concerns a mineralogical study for the stabilisation of subgrade layers belonging to road pavements through a complete replacement of Portland cement (PC) by combinations of natural pozzolan (NP) or metakaolin (MK) in association with waste materials coming from Italy, including wood biomass ash (WBA), municipal solid waste incinerator bottom ash (MSWI), calcined concrete demolition waste (cCDW) and not calcined concrete demolition waste (CDW). In this way, binders with a much lower CO_2 footprint and higher recycled content were formulated. In a first step, this study investigated the binding potential of the selected waste materials based on their physical, chemical, and mineralogical properties, as well as their reactivity using the R3 testing (Avet et al., 2016). In a second step, the total substitution of PC by various combinations of MK-NP-SCMs was studied in terms of impact on the cement hydration kinetics and phase assemblage by using of X-ray diffraction, thermogravimetric and calorimetric analyses. Results of R3 testing show that WBA and MSWI in addition with portlandite, calcite and a potassium solution, present significant reactivity. However, the mineralogical and thermogravimetric results show that WBA, needs to presence of an aluminosilicate source to allow the growth of new cement hydration phases. Results about MK-NP-SCMs blends demonstrate that mixtures subjected at 90 days of maturation, containing WBA and cCDW, have a considerable reactivity and formation of new cement phases such as ettringite, hemicarbonates and monocarbonates. Finally, on the most promising mixtures, proctor and unconfined compressive strength test are underway to confirm the binder formulation results.

Avet F. et al. (2016) - Development of a new rapid, relevant and reliable (R3) test method to evaluate the pozzolanic reactivity of calcined kaolinitic clays. Cement Concrete Res., 85, 1-11, https://doi.org/10.1016/j.cemconres.2016.02.015.

Habert G. et al. (2020) - Environmental impacts and decarbonization strategies in the cement and concrete industries. Nat. Rev. Earth Environ., 1, 559-573, https://doi.org/10.1038/s43017-020-0093-3.

Wood biomass ash: a possible alternative to free lime and cement as stabilizing agent in clayey subgrade of road pavement

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Keywords: clayey soil stabilisation, mechanical analyses, supplementary cementing materials.

EU countries agreed upon increasing the use of renewable energy, which strongly stimulates the usage of biofuels for reducing CO_2 emissions. Following these goals, an increase in thermoelectric power plants powered by biomass is expected, which will cause an exponential increase in waste produced, thus making necessary their disposal. This work is aimed at researching and recycling wood biomass ashes (WBA) coming from the Umbria region (Italy), to be used as stabiliser for clayey soil belonging to the same area.

Based on the results of the initial lime consumption test (ICL), several samples were prepared by adding to the clay soil the amounts of lime and biomass ash that result in a pH value of 12.4. Furthermore, densification properties of studied mixtures were investigated carrying out standard Proctor compaction test. Data collected from these tests, performed on both the raw soil and the stabilized blends, made it possible to relate the Optimum Moisture Content to the dry density achieved in each mixture and to create mixes initially characterized by the same dry density and water content.

Such samples were then subjected to different curing time and analysed by mechanical tests such as UCT (unconfined compression test) and swelling tests to perform a comparative analysis among studied samples. At the same time the chemical-mineralogical evolutions of the different blends were monitored using X-ray powder diffraction (XRPD), thermogravimetric (TGA) and energy dispersive X-ray spectroscopy analyses coupled with scanning electron microscopy (EDS-SEM).

The results of ICL test showed that WBA provides a sufficiently alkaline environment, therefore two mixtures were prepared by adding two different WBA to a clayey soil, which needs stabilization as it is not suitable for any purpose construction in its natural state. The addition of ash causes a reduction in both soil plasticity and maximum dry density, an increase in optimal moisture content and a shift towards coarser size of grain distribution. Furthermore, the addition of ash to clay soil provides a positive impact on bearing capacity and swelling, as well as both short-term and long-term compression parameters. The chemical-mineralogical characterization of the treated soil, together with TGA, show the formation of new cementitious phases as the curing time increases. The results obtained indicate the possibility of reducing the use of traditional binders on road pavements (lime and cement) by incorporating WBA which are widespread and readily available in many geographical areas. This translates into a reduced environmental and economic impact as no extraction, processing or transport of raw materials is necessary.

Petrographic variation of CDW in an industrial plant: a case from Central Italy

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Keywords: CDW (construction and demolition waste), concrete, petrography.

Construction & demolition waste (CDW) accounts for over a third of the continental end of life (Eurostat, 2020). CDW are mainly made up of ceramic-like solids such as concretes, mortars, cementitious bindings (attached mortars or isolated cement pastes), bricks, perforated bricks, tiles, gypsum and rocks (CER-17.01). In addition, variable and relatively low levels (< 10/15 wt.% or vol.%) of ferrous and non-ferrous metals (CER-17.04) plus plastics, woods, and glasses (CER-17.02) can be present. Today, CER-17.01 waste is separated on-site or at the entrance of the plants from the other two categories CER-17.02 and CER-17.04; eventually, further treatment can liberate the CER-17.01 from these different materials (Serranti & Bonifazi, 2016). The ceramic-like CDW (CER-17.01) is then crushed into different grain size classes and resold for applications with low values and structural performance in the construction sector. The very low cost (a few euros per ton) of CDW is related to their extremely high petrographic and physical-mechanical variability, which determines downcycling reuses (embankments and fillings). Alternatively, a homogeneous stream of CDW with well-defined and stable physic-mechanical performance can be adopted even as aggregates for structural concretes. In this optic, several studies concerning the durability of recycled aggregate concrete (e.g. Silva et al., 2014) and also the Italian building regulation (NTC2018, DM 17/01/2018 Italy) fosters the reuse of certified recycled aggregates from concrete (RCA), provided that a conformity certification is provided (End of Waste, DM n. 278 15/7/2022 Italy). Moving from this appraisal, in this work, we monitor the petrographic variability of the products of a CDW processing plant sited in Martinsicuro town (Central Italy). For 6 months, the same aliquot of ~3 kg of representative CDW were sampled every 2/3 weeks; these crushed CDW are either from decommissioning a nearby building or from the leftovers from concrete pours. Thus, they are strictly RCA. Each of the 8 sampled aliquots was first examined according to its mesoscopic attributes; these specimens have good to excellent segregation of the most significant aggregate fragments (size commonly ≥ 2 mm) from the cement paste. A representative fraction per each of the 8 aliquots was selected and then finely milled for XRPD (X-ray powder diffraction) characterization. XRPD results unveil that CDW have low mineralogical variations through time since most of the crystalline part of the samples is made of calcite (≥ 60/70 wt.%), followed by moderate to abundant quartz (≥ 10 wt.%), plus a few of feldspars and sheet silicates. Other spectroscopic and micro-chemical facilities will investigate the poor to non-crystalline phases related to the cement pastes to quantify the possible enrichment and depletion of all these phases in defined gran-size ranges after the typical comminution and sorting by sieving processes.

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Recycling and reusing of construction and demolition waste from Umbria region: a second-generation binder

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Keywords: circular economy, construction and demolition waste, materials characterization.

Cement manufacturing contributes to 7% of global CO_2 emissions, mainly from clinker production due to, on the one hand, the combustion of carbon coke and/or pet coke in firing kilns at temperatures around 1450°C, and, on the other hand, the decarbonation process of the raw materials. The decarbonization of cement industry and the reduction of its huge carbon footprint is a priority for the cement industry, to align with the EU's "net zero" goal by 2050. The main objective of this work is to optimize the recycling of construction and demolition wastes (CDW) through a process of thermal reactivation. The materials used come from the 2016 Umbria-Marche earthquake and are managed by Valle Umbra Servizi (VUS) of Norcia (PG). The procedure here texted, aims to dehydrate, and partially decompose the hydration phases of cement in concretes, generating a material with binding properties and with the mineralogical phases present in clinker so that it can be used as a partial replacement for cement. The range of reactivation temperature used was from 600 to 700°C, with an attempt to limit CO_2 emissions. The CDW before and after the heat treatment were characterized by a multi-analytical approach, using techniques such as X-ray powder diffraction (XRPD), field emission scanning electron microscopy (FE-SEM), X-ray fluorescence (XRF), thermogravimetric analysis (TGA), and calcimetry. Starting from a complete mineralogical characterization of concrete wastes, where the most abundant phases were calcite, quartz, and some C-S-H and C-A-H phases, the analytical protocol was conceived to evaluate the amount of the transformations of C-S-H and C-A-H phases and verify the quantitative presence of typical clinker phases (alite-C3S, belite-C2S, celite-C3A, ferrite-C4AF) after thermal reactivation, as a function of time and temperature of the heat treatment. Results show the presence of clinker phases in the treated samples, particularly C2S and C3A, in addition to portlandite (CH) and lime (CaO) at 700°C. The effect of different proportion addition of reactivated CDW (20 wt.%, 30 wt.% and 40 wt.%), in place of traditional cement in a mortar, on the mechanical properties will be presented as obtained by flexural and compression tests, according to UNI EN 196-1. Optimizing the recycling of CDW would have a positive impact on the environment: far lower thermal reactivation temperatures than those used for clinker firing would be used and CO_2 emissions related to clinker production would be reduced. Their reuse would promote the recycling of waste materials that would otherwise end up in landfills, in line with the principle of a circular economy. Finally, the recovery of the waste materials would be optimized by producing a new second-generation binder for being used both in geotechnical applications and in the construction industry.

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Time-temperature-crystalline behavior of thermally treated MSW bottom ashes

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Keywords: bottom-ashes, thermal treatments, crystallinity.

The crystallization behavior of municipal solid waste (MSW) bottom ashes thermally treated at 1000°C and 1100°C for 1, 2,4, 8, 16 h has been investigated by powder X-ray Diffraction, Scanning Electron Microscopy (SEM) and Raman spectroscopy to distinguish between the crystalline and the amorphous phases.

The MSW bottom ashes considered for vitrification treatments fall within (~80-95 wt.%) the CaO- Al_2O_3-SiO_2 (CAS) system (Caurant, 2017; Karamanov, 2009), with relatively high CaO (17.20 wt.%), FeO_{tot} (16.31 wt.%) and Al_2O_3 (9.31 wt.%), and low SiO_2 (46.05 wt.%) and alkali content (ca. 5 wt.% Na_2O+K_2O). Minor elements composition (ppm) accounts for Cl (8730), Cu (6595), Ba (1458), Pb (1335), S (1000), Cr (915), Ni (277) (Stabile et al., 2019).

The main mineralogical phases present in the starting BA samples are quartz, gehlenite and calcite. The crystalline phases that usually form in the waste-based glass ceramics produced by thermal treatments are, therefore, silicates: typically, calcium-bearing silicates and aluminosilicates and sometimes spinel (including magnetite) (Isa, 2011). In fact, X-ray diffraction (XRD) analysis carried out on the treated samples revealed that the most abundant phases were high-T Ca-rich phases, like wollastonite ($CaSiO_3$), gehlenite ($Ca_2Al_2SiO_7$) and diopside ($MgCaSi_2O_7$). In particular, the crystalline phases were mainly identified as quartz and gehlenite and wollastonite in samples treated at 1000°C and diopside in samples annealed at 1100°C. XRD also indicated a variable degree of crystallinity (DOC) in the range of 30-50% in bottom ashes treated at 1000°C and 1100°C. Additional treatments at 1200°C for different durations (2, 4, 24 h) resulted in homogenous and completely glassy products as macro- appearance. SEM observations confirmed from completely to extensive vitrified areas of the products treated at the highest T. On the other hand, in the crystalline sample (in BAs treated at 1000 and 1100°C) the morphology of crystals has been investigated by SEM images; in particular, needle-shaped morphology of wollastonite and common tabular habit of gehlenite were observed in products obtained at 1000°C. The tendency of specific phases to crystallize, their distribution and crystallization rate is the focus of this study.

The comprehension of factors controlling the crystalline behavior of thermally treated bottom ashes is, in fact, important for the manufacturing of these glassy materials, whose physical properties can be of application in various fields, from the glass and ceramic industry to technological applications.

Vitrification processes can represent an important solution to avoid storage of this type of waste in landfills, also producing valuable glass or glass -ceramic materials, chemically stable, useful for the immobilization of potentially harmful heavy metals eventually present in them. In this regard, leaching tests, that can give useful insights, are in progress.

Caurant D. (2017) - Glass-ceramics for waste immobilization. In: Neuville D., Cormier L., Caurant D., Montagne L. (Eds), From Glass to Crystal - Nucleation, growth and phase separation: from research to applications, EDP Sciences, 492-525.

Isa H. (2011) - A review of glass-ceramics production from silicate wastes. Int. J. Phys. Sci., 6, 6781-6790.

Karamanov A. (2009) - Granite like materials from hazardous wastes obtained by sintercrystallisation of glass frits. Adv. Appl. Ceram., 108, 14-21.

Stabile P. et al. (2019) - Vitrification treatment of municipal solid waste bottom ash. Waste Manage., 95, 250-258.

A DSC-derived viscosity and Raman spectroscopy study on waste-based glasses in the CAS system

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Keywords: waste-based glasses, Raman spectroscopy, polymerization/viscosity.

Among different waste treatments, vitrification has been considered one of the most promising, producing a chemically stable material, which can immobilize toxic elements in its vitreous structure (Sanito et al., 2022).

Here, mixtures of different waste materials, e.g. ceramic and glass waste, incinerator bottom and fly ashes, added to construction and demolition waste (CDW), were subjected to vitrification experiments at 1200°C, ambient pressure and 8 h duration in a chamber furnace (Stabile et al., 2023).

The obtained products were mineralogically and chemically characterized by EMP, SEM-EDS and XRPD, exploring the distribution of the mineralogical phases as a function of the waste used at increasing amounts (from 30 to 70 wt.% of different waste materials added to a starting CDW fraction). The resulting vitrification products present a maximum amorphous content (i.e. 100 wt.%) in mixes made of CDW added with 70 wt.% ceramic waste materials (e.g., roof tile, ceramic powder). Referring to the CAS system, the best vitrification results were obtained when the waste mixture composition fell in the area close to the thermal minimum at 1170°C (Stabile et al., 2023).

The waste-based glasses or glass-like products were also characterized by micro-Raman spectroscopy to investigate the crystalline and the glassy content. By increasing the content of the waste added to CDW, the amorphization of the products emerged, exhibiting the typical Raman features of glass. On the other hand, in the products with higher content of CDW, crystalline phases were also detected, including mineral phases already present in the precursor materials (like calcite or gypsum) and newly formed high-T phases (like gehlenite, pseudowollastonite and minor amount of sulphates).

The distribution of Qn species (tetrahedrally coordinated cations with n bridging oxygens) was estimated from the Raman bands of glass features, by deconvoluting the stretching vibrations of the Qn units. Raman spectroscopy allowed us to describe the degree of polymerization of the different products. Some products, i.e. CP70, (containing 70 wt.% of ceramic added to CDW) showed higher content in Q3 and Q4 than Q1 and Q2, resulting in more polymerized glasses.

Further, a differential scanning calorimetry (DSC) approach has been adopted to retrieve the viscosity of these products (Di Genova et al., 2020; Stabile et al., 2021).

These results can be of relevant importance for the waste reuse in the glass industry, with particular attention to specific glass manufacturing processes (fining, molding, annealing) where viscosity plays a key role.

Di Genova D. et al. (2020) - Unravelling the effect of nano- heterogeneity on the viscosity of silicate melts: implications for glass manufacturing and volcanic eruptions. J. Non-Cryst. Solids, 545, 120248, https://doi.org/10.1016/j.jnoncrysol.2020.120248.

Sanito R.C. et al. (2022) - A review on vitrification technologies of hazardous waste. J. Environ. Manage., 316, 115243.

Stabile P. et al. (2021) - The effect of iron and alkali on the nanocrystal-free viscosity of volcanic melts: A combined Raman spectroscopy and DSC study. Chem. Geol., 559,119991.

Stabile P. et al. (2023) - Bulk Composition Effects on Vitrification of Mixed Fine Construction–Demolition and Inorganic Solid Waste. Minerals, 13, 1378, https://doi.org/10.3390/min13111378.

BIO-DUST: BIO-circular 3D printable prodUctS for cultural heriTage

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Keywords: circular economy, 3D printing, cultural heritage.

Every year in Italy, several thousand tonnes of eggshells, mollusc shells, fish bones and animal bones are stored as food waste (Food and Agriculture Organization of the United Nations, 2021), creating problems in their disposal. These biowastes are an important reserve of carbonate and phosphate that could be used as potential precursors in the production of useful biomaterials, limiting the exploitation of geological ones (De Angelis et al., 2017). In line with the Circular Economy Action Plan and the 12th goal of the 2030 Agenda, BIO-DUST project aims at producing a new green product starting from the recycle of food waste to be used in 3D printing. Indeed, carbonates and phosphates of geological origin are the most used fillers in the 3D printing technique called Fused Deposition Modelling (FDM) (Zárybnická et al., 2022). In a sustainable perspective, these inorganic fillers will be synthetized starting from food industry waste (Mignardi et al., 2020), consequently limiting the supply of natural resources. They will be mixed with algal-derived polysaccharides, to create safe, green, and nontoxic 3D printable biopolymers. The use of this product in the culture industry, not only as gifts in museum shops, but also for filling missing pieces of statues and to reproduce copy of artworks, will be fundamental for research, documentation, restoration and for educational purposes in an idea of wide accessibility and inclusive perspective. Reintegrating touch and other senses into the cultural experiences will have great benefits in accessibility, increasing the involvement in culture of persons with learning difficulties, children, elderly, blind or visually impaired visitors. Furthermore, a complete characterization of the new product, from the raw materials and during the whole production process, using both static and dynamic techniques as FT-IR, XRPD, SEM-EDS, TGA, NMR, will allow the evaluation of possible applications in other fields, such as engineering, medicine, food, and industries, further boosting the impact of the research. The first step of BIO-DUST project involved the collection of eggshells, mollusc shells and animal bones as raw materials from food waste. From these raw materials, inorganic additives (i.e., hydroxyapatite and biochar) were synthesized using different procedures, such as precipitation method by acid and by calcination and microwaves irradiation. Parameters such as calcination temperature and time, power and exposure time to microwaves, have been optimized in order to develop a sustainable production process. Both hydroxyapatite and biochar were characterized using the diagnostic techniques mentioned above.

De Angelis G. et al. (2017) - Recycling of eggshell waste into low-cost adsorbent for Ni removal from wastewater. J. Clean. Prod., 164,1497-1506, https://doi.org/10.1016/j.jclepro.2017.07.085.

Food and Agriculture Organization of the United Nations (2021) - World Food and Agriculture – Statistical Yearbook 2021. FAO, 368 pp., https://doi.org/10.1016/S0140-6736(59)91820-3.

Mignardi S. et al. (2020) - Valorization of Eggshell Biowaste for Sustainable Environmental Remediation. Sci. Rep., 10, 1-10, https://doi.org/10.1038/s41598-020-59324-5.

Zárybnická L. et al. (2022) - CaCO3 Polymorphs Used as Additives in Filament Production for 3D Printing. Polymers, 14, 199, https://doi.org/10.3390/polym14010199.

Thermodynamic modelling in the management of industrial waste streams

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Keywords: thermodynamic modelling, waste management, cement.

The current extraction rate of raw materials corresponds to over 100 billion tonnes (Gt) per year and, according to business-as-usual scenario estimates this will increase to over 170 Gt by 2050. About 35% of the overall stock of extracted resources is classified as unrecoverable waste upon processing, and only about 7% is obtained by recycling. These numbers demonstrate a broad scope for improving the circular approach to materials sourcing and waste management. Construction materials play a key role in this scenario, considering that they incorporate about 40% of the total extracted raw materials and the majority of extracted industrial minerals. On the other hand, cement-based materials can: a) safely incorporate different types of wastes, and b) be utilized for the stabilization of specific wastes.

This contribution will provide an overview of the role of thermodynamic modelling in devising appropriate strategies for waste management and reutilization in sustainable binders. Thermodynamic modelling can provide a tool to unravel the control of complex geochemical equilibria in aqueous solution in determining both the macroscopic properties of waste-based cement binders and the specific interactions between hazardous wastes and cement binders used for stabilization purposes. A series of specific examples from real applications will be illustrated.

Biotechnological potential of marine extremophiles in the treatment of valuable anthropogenic materials like spent car catalysts

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Keywords: waste management, PGE, biohydrometallurgy.

The metals supply market is facing a critical period because of the high demand for primary raw materials. In search of alternative sources of critical metals, spent automotive catalytic converters (SACC), an increasing waste category, represent a diversified source of supply of platinum group elements (PGE) and other elements of economic interest. Utilizing traditional methods from Solid Earth Sciences (ICP-MS, ESEM, XRD, etc.) in conjunction with marine biotechnology, we aim to develop a bio-hydrometallurgical process for treating SACC and recovering PGE. Marine sediments selected for bacterial isolation represent extreme environment for life survival and are from extreme marine environments such as offshore anthropogenic contamination (near river drainage), on volcanic/ophiolite rocks occurrence or the deep-sea (below 600 m isobaths).

Bacteria were isolated through a specific enrichment with SACC sample materials or its hydrochloric acid leachates for strains' targeted selection. Strains selected as best candidates for SACC bio-treatment are those best tolerant to extreme pHs, metal concentrations, including several potentially toxic elements and PGEs like Pt, and pulp densities. Some microorganisms such as *Pichia sp*. and *Rodococcus sp*. could tolerate impressive concentrations of 800 and 200 ppm of Pt and Pb, respectively. In the context of SACC bio-treatment experiments, *Pichia sp*. and *Microbacterium sp*. are best performing for Pt(II) bio-recovery.

A novel in-situ method to continuously monitor the aqueous carbonation degree of high calcium (chloro)(hydr-)oxide content-industrial alkaline waste through gas flow sensors

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Keywords: carbonation, monitoring, IAW.

Industrial Alkaline Waste (IAW) carbonation integrates Carbon Capture, Utilization, and Storage (CCUS) with waste management, addressing ecotoxicological challenges and carbon emissions. Despite its perceived scalability and commercialization examples, efficiently monitoring IAW carbonation remains a challenge. The most common method, thermal gravimetric analysis (TGA) (Martín et al., 2019), is widely applicable but has drawbacks. These include a lack of real-time data due to its ex-situ nature, complex interpretation and limited accuracy. An additional option was proposed by (Brück et al., 2018), but is limited to closed systems as it relies on pressure drop measurements. Alternative approaches were recently suggested by Mario et al. (2021) and Sorrentino et al. (2023).

The present study outlines a complementary methodological sequence to accurately monitor the carbonation degree of various IAW containing high Ca(chloro)(hydr-)oxide (CaClOH) content**.** Typical IAW concerned includes Air Pollution Control residues (APCr) from Municipal Solid Waste Incineration (MSWI), Cement Kiln Dusts (CKD), High-Calcium Coal Fly Ashes (HCFA), Waste Paper Fly Ashes (WPFA), and Calcium Carbide Residues (CCR).

In general, CaClOH species predominantly control CO_2 uptake and kinetics in direct accelerated aqueous carbonation of IAW, with limited contribution from Ca/Mg-bearing silicate dissolution. Utilizing gas flow sensors (GFS), this study shows how to compare CO_2 absorption vs. time patterns ($\eta(t)$) in the pure $Ca(OH)_2$ aqueous carbonation (CAC) with that of any IAW listed above, under similar operational conditions. The proposed monitoring method, successfully applied to multiple APCr and FA samples, can be summarized as follows:

Calibrating the CO_2 volume and mass uptakes through GFS measurements by using CAC as a standard. A preliminary study showed that in CAC, $\eta(t)$ displays four distinct rate-controlling mechanisms, denoted as step 1: maximum absorption; step 2: first downfall; step 3: secondary absorption; step 4: secondary downfall. Step 4 should be excluded as it corresponds to the CO_2 dissolution capacity of the water. $Ca(OH)_2$ reprecipitation in $CaCO_3$ at the completion of step 3 can be both observed and verified through sampling and X-ray Powder Diffraction. A calibration factor *k* is obtained. Performing carbonation experiments under consistent operational conditions with any of the aforementioned IAW samples and converting the CO_2 volume to mass uptake using the calibration factor *k*. This process will yield a comparable $\eta(t)$ pattern enabling the identification of the completion time for step 3. Finally, the total carbonation degree achieved (gCO_2/kg of IAW) can be determined.

Further research is necessary to adapt this method to Mg systems, given the diverse mineral phases encountered in MgO carbonation, which can influence the overall stoichiometry of the process.

Brück F. et al. (2018) - A fast and simple method to monitor carbonation of MSWI bottom ash under static and dynamic conditions. Waste Manage., 78, 588-594, https://doi.org/10.1016/j.wasman.2018.06.042.

Mario M. et al. (2021) - Portable quantitative confocal Raman spectroscopy: Non-destructive approach of the carbonation chemistry and kinetics. Cement Concrete Res., 139, 106280, https://doi.org/10.1016/j.cemconres.2020.106280.

Martín D. et al. (2019) - Proposed methodology to evaluate CO_2 capture using construction and demolition waste. Minerals, 9(10), 612, https://doi.org/10.3390/min9100612.

Sorrentino G.P. et al. (2023) - Accelerated and natural carbonation of a municipal solid waste incineration (MSWI) fly ash mixture: Basic strategies for higher carbon dioxide sequestration and reliable mass quantification. Environ. Res., 217, 114805, https://doi.org/10.1016/j.envres.2022.114805.

Carbonation performance of waste incinerator air pollution control residues (APCr) under wastewater reuse conditions - Towards a sustainable stabilization process

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Keywords: carbonation, waste, incineration.

Carbonation of alkaline feedstocks is considered as the most scalable strategy for CO_2 utilization and long-term storage in useful mineral byproducts (Baciocchi & Costa, 2021). This study explores the carbonation potential of Municipal Solid Waste Incineration (MSWI) Air Pollution Control residues (APCr) to divert them from landfilling, reduce carbon emissions, and mitigate rising landfill costs. APCr, classified as hazardous waste, are typically the only solid residue not extensively reused after MSWI, unlike bottom ashes for which solutions exist (Schnabel et al., 2021). An average MSWI plant generates approximately 3-4 wt.% of APCr from the MSW mass incinerated. When lime is utilized as additive for acid gas removal, APCr collected in baghouse filters typically contains elevated levels of calcium (chloro)hydroxide and Potentially Toxic Elements (PTEs) like Pb, Cr, Sb and V (Phua et al., 2019).

The novelty of the study lies in utilizing a high liquid-to-solid ratio (L/S) to simultaneously carbonate and wash the APCr, while regenerating the wastewater through distillation to reduce water consumption and separate the most soluble PTEs. Fresh APCr samples were collected in France to assess temporal and spatial variability in residue composition. Laboratory-scale tests using scrubbers from 1.5 to 5L coupled to a rotoevaporator successfully carbonated over 10 kg of APCr through 50 tests including 30 cycles at CO_2 flow rate of 0.4-2 L/min, L/S 10-50, T ranging between 283-363K, achieving carbonation degree exceeding 300 gCO_2/kg of APCr.

High-precision gas flow sensors generated CO_2 absorption rate vs. time patterns ($\eta(t)$). Solid-liquid phases characterization was conducted using XRPD with Rietveld refinement, SEM-EDS, ICP-MS, XRF and BET analysis. EN 12457-2 leaching tests were performed on both raw and carbonated waste residues.

Key findings include sustained high CO_2 absorption rates $\eta(t)$ under wastewater reuse conditions, with the accumulation of dissolved sodium, potassium, chloride, and calcium. Water recovery efficiency exceeded 90% during solution settling and supernatant separation. Pb, Cu and Zn were efficiently immobilized by carbonation, while chloride and the most soluble oxy-anions forming metals (Cr, Sb and V) were removed by carbonation washing and subsequent distillation during water regeneration. Optimal carbonation temperatures ranging from 323K to 343K were identified, with higher temperatures yielding a higher calcite/vaterite ratio. Process intensification experiments using a gas-liquid static mixer showed that $\eta(t)$ can exceed 90% during APCr aqueous carbonation. Calibration between $\eta(t)$ and pH enables continuous in-situ pH monitoring via gas flow sensors, minimizing heavy metal leaching.

By integrating the proposed process into the workflow of MSWI plants, APCr could achieve the necessary stabilization for incorporation into concrete blocks or the production of lightweight aggregates (Gunning et al., 2011).

Baciocchi R. & Costa G. (2021) - CO_2 utilization and long-term storage in useful mineral products by carbonation of alkaline feedstocks. Front. Energy Res., 9, 592600, https://doi.org/10.3389/fenrg.2021.592600.

Gunning P. et al. (2011) - Novel approaches to the valorisation of ashes using aggregation by carbonation. Proceedings of the 2nd International Slag Valorisation Symposium, Leuven, Belgium, 103-116.

Phua Z. et al. (2019) - Characteristics of incineration ash for sustainable treatment and reutilization. Environ. Sci. Pollut. R., 26, 16974-16997, https://doi.org/10.1007/s11356-019-05217-8.

Schnabel K. et al. (2021) - Full-scale accelerated carbonation of waste incinerator bottom ash under continuous-feed conditions. Waste Manage., 125, 40-48, https://doi.org/10.1016/j.wasman.2021.02.027.

S18.

Geosciences for the characterization, exploration and exploitation of primary and secondary mineral resources

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The Mo-LREE-(W) greisen and F-LREE-(Mo) hydrothermal mineralisation in the Oschiri - Alà dei Sardi area (N Sardinia)

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Keywords: CRMs, granitoid-related mineralisations, fluorite.

The Gallura region hosts widespread outcrops of metamorphites intruded by Variscan granite units. Granite-related ores were rarely exploited, but due to the interest in Critical and Strategic Raw Materials (C-SRMs) the potential of Sardinia as a prospect for W-Sn-Mo-Bi and F-REE granite-related deposits has been recently suggested.

We studied three granite-related ores in the Oschiri - Alà area: the Su Laccheddu (SLU) greisen, located about 3 km SW from the Giacone (GIA) granite- and greisen-hosted hydrothermal vein system, and the Monte S'Abbagana (MSA) greisen, spatially associated to pegmatites, located about 30 km eastward from the others.

The greisen facies include muscovite, sericite, quartz and relics of K-feldspar, plagioclase and biotite. Titanite and rutile are associated with altered biotite. The ore mineral assemblages are: a) molybdenite dry veins and disseminations, with interstitial Bi-Te phases and scattered hematitized pyrite; b) scheelite, with wolframite-columbite relics, at the grain boundaries of muscovite crystals. The MSA ore minerals include LREE phosphates and fluorocarbonates, such as xenotime-Y and synchysite-Ce, and Nb-Y-F phases like columbite and euxenite-Y. Zircon is common and associated with thorite/uraninite.

At GIA a fluorite-quartz veins system occurs within the granitoids striking NE-SW at low-angle, with multi-decimetre thickness and banded texture. Stockworks of fluorite veinlets depart from thicker veins, spreading in the host-rock. The veins are cut by a vertical fault breccia made of metamorphites and greisen clasts cemented by fluorite and subordinate quartz and molybdenite.

Brecciation is associated with a high-angle fault system revealed by fault mirrors on quartz veins, displaying sub-vertical slicklines and argillic alteration. It hosts fluorite veins, molybdenite spreadings, and greisen breccia blocks.

The three ores are seemingly part of an "F-rich open system" (Pirajno, 2009): greisening took place at deeper crustal levels and higher T (400-300°C), whereas hydrothermal fluids circulation occurred at lower T (< 300°C) along faulting at shallower levels. Fluids had a strong HF-rich signature and caused: a) pervasive alteration of biotite and feldspar; b) Ti-W-Nb and Ca-REE remobilisation; c) rutile, titanite, wolframite-scheelite, columbite, fluorite and REE fluorocarbonates precipitation. The high HF concentrations in the hydrothermal fluids caused extensive Y mobilisation and precipitation of xenotime-Y and euxenite-Y.

Hence, we propose that the SLU and MSA Mo-LREE-(W) greisen ores represent the roots of a unitary mineralising system that evolves towards the shallower GIA F-LREE-(Mo) hydrothermal veins. However, the Nb-Y-F signature of MSA (columbite, xenotime-Y, euxenite-Y, fluorite) suggests an affinity with NYF pegmatites. In conclusion, the area is of potential interest for further C-SRMs investigations and modelling that may serve as a guideline for other granite-related deposits of Sardinia.

Pirajno F. (2009) - Hydrothermal processes and mineral systems. Springer, 1250 pp.

Distinct magma evolution processes control the formation, endowments and metal ratios of porphyry Cu-Au deposits in thin and thick arcs

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Keywords: porphyry copper deposits, thick arcs, thin arcs.

Porphyry Cu-Au deposits (PCGDs) are the major global source of copper, an essential metal for the green transition, and a significant source of gold. They occur both in thick continental and thin oceanic arcs at depths of ~1-6 km above ~5-15 km deep parental magma chambers. Although metal precipitation processes for these deposits are similar in thin and thick arcs, it is not clear why porphyry deposits in these two environments display different Cu and Au endowments and different Au/Cu ratios, i.e., Au/Cu ~14 in thick arcs and ~80-120 in thin arcs. Using mass balance petrological modeling, I argue that PCGDs in thick and thin arcs form by two distinct magmatic evolution precursors (Chiaradia, 2022).

In thick arcs, PCGDs and their metal endowments and metal ratios can be explained by a two-stage process: (i) lower crustal accumulation of large volumes of hybrid magmas, fluids and metals during several Ma and (ii) subsequent transfer of these H_2O-undersaturated magmas to shallow levels where they exsolve aqueous fluids and metals. The decoupling between Cu and Au in thick arc deposits is due to the early magmatic sulfide saturation occurring at the deep crustal levels of a thick crust. Because Au is much more chalcophile than Cu, the loss of Au in the deep hybrid magma is nearly quantitative. In contrast, Cu remains in the magma in concentrations sufficient to form behemothian (> 31.16 Mt Cu) porphyry Cu deposits, because the Cu loss is compensated by the large magma volumes accumulated at deep crustal levels. Further decoupling may also occur due to different precipitation efficiency at variable shallow crustal levels.

In thin arcs, PCGDs form by little differentiated mantle-derived magmas that rise directly to shallow crustal levels where they exsolve fluids and metals. This process optimally exploits two advantages of the thin-intermediate arc environment to form giant to supergiant porphyry Cu deposits (> 5 and up to 30 Mt Cu) with the largest Au endowments (~500-2600 t Au) and highest Au/Cu ratios (~80-120) among all PCGDs known. The first advantage is the significantly higher Cu and Au contents of intermediate magmas in thin versus thick arcs, due to delayed magmatic sulfide saturation in thin arcs. The second one is the exsolution of fluids at an earlier stage of magma differentiation than in thick arcs before Cu and especially Au are removed by sulfides.

These two distinct magmatic pathways of PCGDs generation are ultimately controlled by the different arc thicknesses in the two environments, even though the processes of metal precipitation in the actual deposits of the shallow crust are similar. The model discussed here may stimulate the development of new tools for the exploration of porphyry deposits in the distinct environments of thick and thin arcs.

Chiaradia M. (2022) - Distinct magma evolution processes control the formation of porphyry Cu-Au deposits in thin and thick arcs. Earth Planet. Sci. Lett., 599, 117864.

Trace elements and REYs signature of ore and gangue minerals in the Zn-Pb(-Cu-Fe) mineralization of Longobucco and Fonte Argentila (Sila Massif, Calabria, southern Italy)

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Keywords: sphalerite, Zn-Pb(-Cu-Fe) mineralization, REYs and trace elements.

Here we illustrate key mineralogical and geochemical features of some Zn-Pb(-Cu-Fe) mineral deposits of the Sila Massif (Calabria, southern Italy) that were historically exploited (Fregola et al., 2023), unveiling their hidden genesis. We have collected and analysed samples from apparently vein-type mineralization associated with fault zones affecting the granodiorite of the Sila batholith at Longobucco (LGB) and Fonte Argentila (FAR). The mineral association comprises sphalerite (Sp) as primary ore mineral, along with galena (Gn), quartz (Qz) and calcite (Cal) in both areas. Samples from FAR site also contain chalcopyrite (Ccp), pyrite (Py) and fluorite (Flr). Mineral composition and microstructures were determined by petrographic observation, SEM, EPMA, and μ-Raman spectroscopy. Trace element distribution in sphalerite and chalcopyrite, as well as REY contents in calcite and fluorite, were also analysed through LA-ICP-MS. Sphalerite exhibits colour and chemical zonings mainly due to variations in Fe contents (up to 11.3 wt.%; 0.21 mol FeS). Trace elements identified in sphalerite include Mn, Co, Cu, Ga, Ge, Ag, Cd, In, Sn, Sb, Hg, Tl, Pb, and Bi. The reconstructed paragenetic sequence comprises five growth stages for both areas. Stages 1 and 2 register the main mineralization event, with the formation of Sp1, Sp2, and Qz1. In stage 3, following brittle deformation, massive precipitation of calcite (in LGB) and fluorite (in FAR) occurred. The REYs concentrations in Cal and Flr suggest mixing between two different fluids, one of likely igneous origin and the other diagenetic, also indicating a change from reducing to oxidizing conditions of the system. In LGB, calcite hosts synchysite with grain sizes in the range 20-60 μm, and LREE-Y contents from 2.40 to 42.6 wt.%. Furthermore, colourless Sp3 formed as a result of the recrystallization of Sp1 and Sp2 due to oxidizing conditions. A diffuse recrystallization of Qz2 occurred in stage 4 while, in stage 5, almost pure Gn formed along with Ccp and Py at the expense of previous minerals. Formation temperatures derived from Sp1 and Sp2 using the GGIMFis geothermometer (Frenzel et al., 2016) range between 170 and 220°C. This temperature range is in good agreement with that obtained from preliminary fluid inclusion analyses. In addition, the Zn/Cd (195-267), Ga/In (190-596), and In/Ge (0.24-1.20) average ratios in sphalerite, are indicative of a low-temperature ore-forming fluid. Our geochemical data indicate an MVT-SHMS ore formation, with no evidence of hydrothermal processes involved in the system, contrasting with the apparently vein-type character of the mineralization observed in the field. A genetic model connecting the paragenetic stages and geochemical data obtained from ore and gangue minerals for LGB and FAR Zn-Pb(-Cu-Fe) mineralization is presented here.

Fregola R.A. et al. (2023) - Review of polymetallic mineralization in the Sila and Serre Massifs (Calabria, southern Italy). Minerals, 13, 439, https://doi.org/org/10.3390/min13030439.

Frenzel M. et al. (2016) - Gallium, germanium, indium, and other trace and minor elements in sphalerite as a function of deposit type - A meta-analysis. Ore Geol. Rev., 76, 52-78, https://doi.org/org/10.1016/j.oregeorev.2015.12.017.

Hyperspectral analysis of vanadium-bearing ore deposits in the Mibladen district (Morocco) and the Otavi Mountainland (Namibia)

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Keywords: vanadium, hyperspectral remote sensing, PRISMA.

In recent years, the intensification of vanadium-dependent technologies has resulted in the growing economic importance of vanadium as a critical raw material. Economic concentrations of vanadium are most commonly found in specific types of ore deposits hosted either in mafic-ultramafic igneous systems or sedimentary or metamorphic rocks (Boni et al., 2023).

This contribution aims to study the applicability of spectral reflectance in the investigation of V-bearing mineral assemblages for the exploration of V-ores. Study areas include the Mibladen district in Morocco, consisting of stratabound karstic V-bearing Pb-Zn mineralizations hosted in Mesozoic carbonates, and the Otavi Mountainland in northern Namibia, hosting base metals sulfide and nonsulfide deposits in Neoproterozoic platform carbonates (Boni et al., 2007; Yaagoub et al., 2021). The surface-exposed areas were investigated through hyperspectral images acquired by the Italian satellite mission "PRecursore IperSpettrale della Missione Applicativa" (PRISMA). Additionally, the mineral assemblage in the samples was identified and mapped using Headwall Photonics hyperspectral cameras. Both the satellite and laboratory sensors cover the nominal 400-2500 nm range of the electromagnetic spectrum where absorption features of the target minerals exist (Laukamp et al., 2021). XRPD and SEM-EDS analysis were used to validate the results obtained.

The hyperspectral analysis allowed the identification of host rocks (dolomite and calcite), minor alteration minerals (phyllosilicates and Fe-oxy-hydroxides), and vanadates (vanadinite, descloizite-mottramite series). In addition, it was observed that changes in the chemical composition of vanadates and carbonates caused shifts in the absorption feature towards shorter or longer wavelengths. Specifically, vanadates had a variation in wavelength from 2397 nm (descloizite, ZnO > 18 wt.%) to 2426 nm (mottramite, ZnO < 2 wt.%). Similarly, dolomite shifts from 2311 nm to 2321 nm based on Ca content, while calcite shifts from 2330-2340 nm due to Mg content.

In conclusion, hyperspectral analysis can provide specific targeting information for follow-up in situ surveys and drilling campaigns for this type of ore deposits.

Boni M. et al. (2007) - Genesis of Vanadium Ores in the Otavi Mountainland, Namibia. Econ. Geol., 102, 441-469.

Boni M. et al. (2023) - Vanadium ore resources of the African continent: State of the Art. Ore Geol. Rev., 157, 105423, https://doi.org/10.1016/j.oregeorev.2023.105423.

Laukamp C. et al. (2021) - Mineral Physicochemistry Underlying Feature-Based Extraction of Mineral Abundance and Composition from Shortwave, Mid and Thermal Infrared Reflectance Spectra. Minerals, 11, 347, https://doi.org/10.3390/min11040347.

Yaagoub D. et al. (2021) - Analysis of tectonic fracturing in the Mibladen ore deposit (Upper Moulouya, Morocco) and its impact on the Pb-Ba mineralization emplacement. Rend. Fis. Acc. Lincei, 32, 325-342, https://doi.org/10.1007/s12210-021-00995-1.

Geology and mineralogy of the S'Aliderru bentonite deposit (Sardinia, Italy)

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Keywords: Sardinia, bentonite, montmorillonite.

Bentonites are a group of rocks formed essentially by smectites, mainly belonging to the montmorillonite-beidellite series. Bentonites derive from the alteration of volcanic and/or sedimentary rocks, with a prevalent siliceous-vitreous component, by aqueous fluids that operate at temperatures between 90°C and 120°C. During the alteration, chemical elements are remobilized and the composition and structure of the minerals are modified. The resulting mineral assemblage depends on the nature of the protolith and the composition of the altering fluids (Cuadros et al., 1999). Bentonites have a wide range of properties (CEC, thixotropy, swelling, viscosity, water absorption) which make them a very important industrial mineral, which are periodically tested also by the EU for the possible inclusion in the list of critical raw materials. S'Aliderru bentonite deposit is located in the northern Sardinia bentonite (Tertiary) basin (Italy). The deposit derives from the alteration of calcalkaline pyroclastic rocks of Oligo-Miocene age, which fill a structural depression occurring in the Mesozoic carbonate basement. The present work has the aim to define geological and mineralogical features of the S'Aliderru deposit and define its genesis. S'Aliderru deposit extends for 0.8 km N-S, 0.4 km E-W, with an average thickness of 50 m. The orebody consists of multiple bentonite lenses of variable colour, interbedded with moderately to strongly altered pyroclastic rocks, travertine bodies and sandy-to-conglomeratic lenses, and is locally dislocated by faults. The study was based mainly XRPD analysis of the samples, which were subjected to various processes (AD, EG, DMSO, heating) to identify the occurring mineralogical phases to understand the geological processes that led to the formation of the deposits and possible genetic differences at the basin scale. Petrography analyses and SEM analyses were also carried out. The XRPD analyses showed a classical mineralogical assemblage. In detail, the S'Aliderru bentonites are composed mainly of Ca-montmorillonite, with the accessory presence of kaolinite, chlorite, muscovite and biotite. Quartz, calcite, plagioclase and glass are also present. The petrographic analyses and SEM analyses have made it possible to state that the formation of smectite occurs at the expense of the glass and plagioclase present in the original tuffs and led to the identification of an unreworked marine fossil within the bentonite. The use of SEM also allowed the identification of hollandite and xenotime. The studies conducted confirm that the deposition of tuff flows and their subsequent alteration occurs in a transitional marine environment, but the presence of minerals such as kaolinite, chlorite, hollandite and xenotime suggest that one or more hydrothermal stages contributed to the development of the deposit.

Cuadros J. et al. (1999) - Analysis of Fe segregation in the octahedral sheet of bentonitic illite-smectite by means of FTIR, 27 Al MAS NMR and reverse Monte Carlo simulations. Am. J. Sci., 299, 289-308.

On the origin of spodumene-rich pegmatites in the Araçuaí Pegmatite District, Minas Gerais, Brazil: insights from mica and apatite mineral chemistry

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Keywords: lithium, pegmatite, geochemistry.

Spodumene rich pegmatites (SRP) represent a crucial source of lithium, a key critical raw material. In Brazil, the primary lithium deposits are represented by the SRPs in the Araçuaí Pegmatite District. These pegmatites have a high modal content (up to 30%) of coarse-grained spodumene crystals dispersed within a matrix of quartz, feldspars, and muscovite and form rather homogeneous ore bodies. In the Araçuaí Pegmatite District, SRPs have been interpreted as residual magmas derived from Cambrian two-mica granites associated with large barren pegmatitic bodies formed during the late tectonic stage of the Araçuaí Orogen. However, the relation between barren and mineralized pegmatites as well as the formation mechanism of SRPs in this region and elsewhere remains puzzling.

The analysed rock samples encompass the full range of inferred differentiation grades in the Araçuaí Pegmatite District, from two-mica granites to barren pegmatitic bodies, culminating in SRP. We present compositional data of muscovite and apatite, obtained with a combination of EMP and LA-ICP-MS analyses, to investigate the genetic relation among the different lithologies as well as the internal evolution of the SRP.

Except for minor biotite in the two-mica granite, all mica can be classified as muscovite. The muscovite from the SRP has higher Al and lower Fe contents than muscovite from other lithologies. In the spodumene zone of SRP muscovite exhibits the highest contents of incompatible elements Li, Cs, Mn, and Zn, negatively correlating with the K/Rb ratio. Li median contents varies from 783 μg/g in the border zone to 2619 μg/g in the spodumene zone of SRP, while median contents of 1204 and 1156 μg/g are measured in barren pegmatites and two-mica granite.

Apatite is a ubiquitous accessory phase in the samples, reaching up to 5-10% of modal content in the border zone of the SRP. Similarly to muscovite, apatite shows the highest contents of incompatible elements U, Th, Mn, and Zn in the spodumene zone of SRP, along with a drastic reduction in REE contents.

Both muscovite and apatite display an extreme evolution in composition within the SRP (one to two orders of magnitude for selected trace elements), suggesting the fundamental role of internal differentiation in the pegmatite to concentrate rare elements.

The presented data support the use of muscovite and apatite chemical compositions as indicators of the degree of differentiation and Li enrichment among various products of granitic magmatism. Even if the genetic relation between the different lithologies is still not defined, it is clear that they share the same fingerprinting enrichment in rare elements, supporting an origin from the same magmatic system. The association observed between muscovite and spodumene is recurrent worldwide in SRPs and highlights the system's relatively high alumina/low fluorine character, a crucial factor favouring spodumene as the primary Li bearing crystallizing phase over Li-F bearing mica.

Iron isotope systematics and ore forming processes: first results from the ophiolite-hosted, Tuscan Cu-Zn VMS deposits

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Keywords: iron isotopes, ore deposits, ophiolite-hosted VMS.

Ore forming processes still need to be improved, and new conceptual genetic models must be developed to help exploration of new ore deposits for the energy transition. Decarbonization and the switch to renewable energies will require increasingly large amount of Critical Raw Materials (CRMs) that must be provided by conventional and unconventional ore deposits.

The availability of copper, although considered as a common metal, will potentially limit the speed of the energy transition, because large amounts of this metal will be used in electric vehicles and power generation. For this reason, any implementation of genetic models regarding Porphyry-Cu and Volcanogenic Massive Sulphide (VMS) deposits is highly desirable. Ophiolite-hosted Cu-Zn VMS deposits from orogenic settings, with respect Porphyry-Cu deposits, represent a minor provider of copper, but their better understanding could shed new light on the mining potential at seafloor.

Stable isotopes of ore-forming metals, like Fe, can be used for the investigation of ore-forming processes, metal source(s), and water-rock interactions. The development of the High-Resolution Multi-Collector Inductively Coupled Plasma Mass Spectrometers (HR-MC-ICPMS), like that hosted in the Neptune-TIMS Laboratory (IGG-CNR, Pisa, Italy), given the opportunity to accurately measure Fe isotope ratios for ore deposit applications.

In the framework of the project "TEOREM - Deciphering Geological Processes using Terrestrial and Extraterrestrial ORE Minerals" (PRIN-MUR 2017AK8C32) and the project ITINERIS ISOTOPE VRE (IR0000032; PNRR; Next Generation EU), we developed the methodology for the Fe separation from different matrices, and the determination of Fe isotope ratios using HR-MC-ICPMS (Neptune Plus).

Determination of iron isotope composition was performed on samples of massive sulphide ore and gangue minerals from the ophiolite-hosted Cu-Zn VMS deposits of Tuscany (Italy). Samples of both primary chalcopyrite-pyrite-pyrrhotite stockworks and reworked nodular ores (bornite-chalcocite-chalcopyrite), were studied by SEM-EDS (Dini et al., 2024) and selected mineral separates were processed for Fe isotopic analyses.

First results show a significant variability of negative $\delta^{56}Fe$, consistent with the available data on copper sulphides from Mid-Atlantic slow-spreading ridge (Rouxel et al., 2004). The new data on Tuscan VMS deposits suggest that the nature of the oceanic crust hosting the ores (ultramafic vs. mafic) is likely to exert some control on the variation of $\delta^{56}Fe$.

Dini A. et al. (2024) - The Ophiolite-Hosted Cu-Zn VMS Deposits of Tuscany (Italy). Minerals, 14, 273, https://doi.org/10.3390/min14030273.

Rouxel O. et al. (2004) - Subsurface processes at the lucky strike hydrothermal field, Mid-Atlantic ridge: evidence from sulfur, selenium, and iron isotopes. Geochim. Cosmochim. Acta, 68, 2295-2311, https://doi.org/10.1016/j.gca.2003.11.029.

The supergiant epithermal Hg district of Mt. Amiata (Italy): metal source and genesis

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Keywords: mercury, black shales, Mt. Amiata volcano.

Mercury is an extremely rare element in Earth's litosphere but hydrothermal processes concentrated Hg in monometallic, high-grade deposits. More than half of the global Hg production (ca. 1 Mt of metal) came from three supergiant districts (Almaden, Spain; Idrja, Slovenia; Mt. Amiata, Italy) that exploited high-grade cinnabar ores (1-8 wt.% Hg). These grades imply an ore/source concentration factor of ca. 10^6, one to three orders of magnitude larger than any other supergiant metal ore deposit. Why these huge, high-grade Hg ores are almost monometallic and how such extreme concentration factors were attained?

Since the early, modern, scientific contributions on epithermal systems, the existence of Hg-rich hot springs and the formation of mercury deposits was attributed to metal mobilization from sedimentary sequences driven by hydrothermal fluids. The affinity of mercury for organic matter is responsible for the extreme Hg concentrations measured in peculiar sedimentary rocks like black shales (100-5000 ng/g). The role of black shales as the most suitable terrestrial source rock for Hg was later supported by many other authors. In this model, magmas involved in the formation of epithermal Hg ores provide heat and, possibly, part of the fluids. Conversely, other authors have argued for a magmatic/mantle source of the mercury involved in some of the world's largest deposits. A hypothesis that would seem to be supported by the substantial Hg flux measured in many volcanoes worldwide.

The Middle Pleistocene supergiant Hg district of Mt. Amiata volcano (Italy), with its preserved epithermal characters, is the best candidate to address these questions (Dini et al., 2017; Rimondi et al., 2015). Hg concentration profiles in rocks below the deposits, down into the contact aureole of the magma chamber at 5 km depth, indicate that the ca. 100000 t of mercury mined in the district were thermogenically released from Late Permian black shales, transferred upward as gaseous phase, and scrubbed by shallow paleo-aquifers (< 200 m depth). The upward isotherm propagation, ca. 300-150 ky ago, coupled with the extraordinary volatility of mercury, allowed a selective metal transfer & deposition, well before the inception of the present-day, liquid-dominated, geothermal system.

Results open many questions about the meaning of volcanic Hg fluxes worldwide, their inter- intra-arc variability, and the role of subsurface igneous activity on the geochemical cycle of mercury at global scale (Svensen et al., 2023).

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Svensen H.H. et al. (2023) - Release of mercury during contact metamorphism of shale: Implications for understanding the impacts of large igneous province volcanism. Earth Planet. Sci. Lett., 619, 118306, https://doi.org/10.1016/j.epsl.2023.118306.

The carbonate-hosted Sb(±Au) mineralization of Southern Tuscany: insights from stibnite and pyrite trace element composition and stable isotope geochemistry

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Keywords: Southern Tuscany, carbonate-hosted ore deposits, hydrothermal fluid evolution.

Antimony, a Critical Raw Material (European Commission, 2023) has been mined in Southern Tuscany until late ’80 of the last century from several carbonated-hosted Sb(±Au) mineralizations (Lattanzi, 1999). They are genetically linked to a widespread silicification of carbonate rocks (jasperoids) and have strong analogies with “Carlin-style” gold deposits (Sillitoe & Brogi, 2021). Even though these systems have been characterised through fluid inclusion and structural geology studies (Lattanzi, 1999; Brogi & Fulignati, 2012), there are still several open questions concerning sulfides geochemistry and the origin and evolution of the ore-forming fluids. The trace element composition of ore minerals is intricately connected to the redox state, pressure, temperature, and the source of mineralising fluids and thus can provide critical insights into ore-forming processes. Here we combine the trace element composition of sulfides (stibnite and pyrite) and stable isotope composition of quartz ($\delta^{18}O$) and calcite ($\delta^{18}O$, $\delta^{13}C$) associated with some of the main Sb(±Au) mineralisations of Southern Tuscany (Frassine, Cetine, Poggio Peloso, Campigliola, Micciano), to constrain the ore-forming process and concentration of precious metals in sulfides.

Brogi A. & Fulignati P. (2012) - Tectonic control on hydrothermal circulation and fluid evolution in the Pietratonda-Poggio Peloso (southern Tuscany, Italy) carbonate-hosted Sb-mineralization. Ore Geol. Rev., 44, 158-171.

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Lattanzi P. (1999) - Epithermal precious metal deposits of Italy-an overview. Mineral. Deposita, 34, 630-638.

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National databases, starting point for compliance with the Critical Raw Materials Act obligations

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Keywords: CRMA, mining, database.

The issue of security in the supply of mineral resources essential for industrial development is now placed at the top of the political-economic agendas of all advanced countries. To limit the dependence of supplies on the hyper-concentration of resources in politically unreliable countries, the European Commission has developed a new regulation for the safe and sustainable supply of raw materials considered critical or strategic (Critical Raw Materials Act - CRMA) published in the OJEU on May 3, 2024 (EC, 2024). The ISPRA - Geological Survey of Italy already has activities underway that are perfectly in line with the provisions of the new European regulation, in particular the art.19 and 27. Article 19 of the CRMA requires each member state to equip itself with a National Mining Exploration Plan by 24 May 2025. The starting point for the implementation of the plan is the recovery and review of previous data. With this in mind, all available mining data is being collected and harmonized. Included are data relating to all deposits cultivated in the past and the results of various national and local research campaigns, with a particular focus on critical raw materials (CRM). All the information collected is entered into the national GeMMA database (Geological, Mining, Museum, Environmental). The DB is created in total coherence with the European Mintell4EU database and represents the access point to a series of specific databases already created or in the process of being created (disused mining sites, current research concessions and permits, digitalization of 1927 and 1973 mining maps, Mining parks and museums, RIMIN project, geological maps, geochemistry, geophysics, etc.). The database is designed to be able to implement the data deriving from the acquisition of information available from Ministries, Universities, Research Institutions, Regions/PAs, European projects and new mineral research projects for the realization of which appropriate investments will be necessary for new surveys, sampling and analysis.

Previous mining activities have left approximately 150 million cubic meters of extractive waste which represents a serious environmental problem and is the subject of expensive interventions to reclaim the territories from heavy metals. The recovery of these metals, in addition to having an important economic value, would solve an environmental problem. For this reason, the CRMA provides in art. 27 that member states should have a specific database of extractive waste that will be a specific part of GeMMA. For this aspect, a line of activity has been included in PNRR-RePowerEU to map, characterize and computerize all extractive waste deposits nationwide in terms of presence and potential recovery of MPCs. The Geolgical Survey of Italy will be member of European Critical Raw Materials Board.

EC (2024) - Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020Text with EEA relevance. OJEU, L series, 2024/1252, https://eur-lex.europa.eu/eli/reg/2024/1252/oj.

Re-use of granite quarry waste for REEs-recovery along the industrial production chain: results from pre-concentration tests

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Keywords: Rare Earth Elements, circular economy, mineral processing.

Granite quarry waste from the "Serie dei Laghi" plutons in Piedmont (N-Italy) (Boriani et al., 1988) underwent several lab-scale beneficiation tests to enhance the recovery of Critical Raw Materials (CRMs) in the context of circular economy and sustainable mining, considering their pivotal role in the modern industry and the economic development strategies of the European Union (European Commission, 2023). Preliminary analyses by ICP-MS highlighted that the magnetic waste discarded during the industrial re-processing of granite for feldspar production is notably enriched in Rare Earth Elements (REEs), paving the way for simulating and refining a lab-scale treatment to optimise the concentration of REE-bearing minerals. SEM-EDS analyses allowed to identify monazite-(Ce) as the primary target mineral, predominantly locked within Fe-rich biotite (siderophyllite). The feed material was then milled to various grain sizes and subjected to multiple magnetic separation stages to determine the optimal conditions for REE mineral beneficiation. Results from recovery calculations indicate that approximately 90% of REEs are associated with the paramagnetic fractions at 75-150 µm and 150-250 µm grain sizes. According to ICP-MS, the 75-150 µm paramagnetic concentrate recovered at 1 A current intensity shows the highest enrichment to ~1800 ppm REEs + Y and Sc compared to ~200 ppm in the raw granite. However, significant REEs amounts remaining in the paramagnetic material at 0.4 A suggest possible incomplete liberation of monazite. Although grinding below 600 µm prior to magnetic separation favours the rejection of diamagnetic gangue minerals from the monazite-bearing siderophyllite, as confirmed by the quantitative phase analysis (QPA) on XRPD diffractograms, SEM-EDS observations and particle analysis by Automated Mineralogy reveal liberation issues for monazite particles above 100 µm due to their smaller size compared to siderophyllite. Further grinding below 100 µm was then applied to isolate monazite, but dry electromagnetic separation used on fine material demonstrated poor monazite recovery, possibly due to airflow influence, particle-particle adhesion, and particle-rotor adhesion (Park et al., 2021), indicating the need for alternative techniques for an effective recovery from the fine-grained pre-concentrate. Additional enrichment tests will consequently include wet magnetic separation and flotation, which is considered more suitable for materials with a grain size less than 100 µm (Jordens et al., 2013). This work underscores the potential of improving the beneficiation techniques to maximise the recovery of CRMs as by-products along the industrial production chain, advocating valorisation and sustainable management of mineral processing waste through its re-processing.

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European Commission (2023) - Study on the critical raw materials for the EU 2023 - Final report. Publications Office EU, https://data.europa.eu/doi/10.2873/725585.

Jordens A. et al. (2013) - A review of the beneficiation of rare earth element bearing minerals. Miner. Eng., 41, 97-114, https://doi.org/10.1016/j.mineng.2012.10.017.

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Preliminary evaluation of the antimony potential for different waste materials at abandoned mines of Villasalto and Ballao, Sardinia

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Keywords: mining and metallurgical wastes, CRMs, circular economy.

As the world's demand for raw materials increases with the growing global population and industrial applications, more raw materials are being listed as critical for Europe (critical raw materials - CRMs). Antimony is an important and not easily-replaceable metal that the EU Commission has classified as a CRM, as the EU supply is currently 100% reliant on import. The present study investigates the potential for Sb and other metals from the waste rock, tailings and slags dumped at the abandoned Villasalto and Ballao Sb mines in Gerrei region, SE Sardinia, aiming to their possible recovery. This region was for over one century the most important antimony-mining district in Italy. The Su Suergiu mine near Villasalto was mined for stibnite that occurred with some scheelite, pyrite and minor Pb-Zn-Cu sulfides in quartz-calcite veins within black shales and metalimestones. At the Corti Rosas mine in Ballao, 8 km to the north of Villasalto, the deposits take the form of veins and stockworks mainly hosted in metalimestones. The Sb ores from both mines were processed in the Corti Rosas plant; Sb concentrates underwent pyrometallurgy in the Su Suergiu smelter. Samples of mining waste, tailings and different types of slags were collected from Su Suergiu and Corti Rosas. The samples were analyzed for grain size, the mineralogical phases identified by XRD and the chemical composition analyzed by XRF and the ME-ICPORE method to obtain the concentrations of antimony in the different types of waste. Up to 33.2 wt.% Sb was found in slag samples, followed by tailings (up to 7.97 wt.% Sb), then waste samples (up to 0.64 wt.% Sb). In the slags, significant Zn (up to 1.9 wt.%) W (up to 0.38 wt.%) and Au (up to 53 ppm) contents are also reported. A positive correlation between Sb and Zn was found, especially evident in slag samples, which could mean a possibility of recovering zinc alongside antimony. Microdroplets of metallic Sb dominate in the glassy slags; other Sb-bearing minerals in studied materials were mopungite, melanostibite, schafarzikite, and valentinite, with quartz, calcite, and muscovite among the gangue minerals. Antimony contamination is high, as concentrations up to 1600 µg/L Sb were found in water samples for several km downstream of the mining areas. The metallurgical wastes of Su Suergiu are the most contaminating sources, also due to the presence of highly soluble Sb phases as mopungite. Overall, the study provides initial indications for the possible recovery of Sb (and other metals) from the materials studied, with the identification of the useful phases as well as the degree of liberation necessary for their valorization. Antimony recovery from the abandoned mine wastes of Gerrei region would provide a relevant secondary source for this critical metal and contribute to the solution for the problem of contamination in the area.

The antimony resource in Italy: evaluation of environmental impact and ore exploration of a Critical Raw Material under the MOLIERE project

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Keywords: critical raw materials, ore geology, environmental geochemistry and mineralogy.

Antimony (Sb) is widely used in strategic sectors and is listed as a "Critical Raw Material" (CRM) by e.g. Europe, Canada, USA, Japan, and Australia. To support the increasing demand of this metal for the green energy transition, new ore bodies need to be exploited, along with the development of Sb recycling. On the other hand, Sb is classified as one of the 13 priority metal pollutants and can be dispersed into the environment through natural and anthropogenic processes, such as oxidation of primary sulphides and mine wastes. In the current Europe scenario, a sustainable mining approach should optimize mineral extraction, minimizing the environmental impact.

Italy hosts potential Sb resources, although not numbered by worldwide statistics. Extraction up to the end of 1980s from Tuscany and Sardinia, left a legacy of mineral waste and tailings on these territories, which vehiculate potentially toxic elements (PTEs, e.g., As, Tl, Hg, W) to freshwaters and likely to the Mediterranean Sea. The Sb districts of Tuscany and Sardinia are therefore exceptional areas for studying ore-forming processes, for the evaluation of potential resources of Sb and associated metals inside the national borders, and to jointly evaluate the environmental impact of extraction, and the potential of cost-effective remediation solutions to reduce Sb and associated PTEs in the environment.

Herein, we present an overview of the MOLIERE project (*The antimony resource in Italy: evaluation of environmental impact and ore exploration of a critical raw material*) funded by PRIN 2022 PNRR, which combines different expertise to provide: i) a geological investigation of Sb ore resources with implications on ore-genesis and exploration, ii) an updated picture of the natural Sb dispersion in the environment and on the long-term environmental impact of past Sb mining, iii) low-cost solutions to limit Sb (and other PTEs mobility) in the mining areas.

To define the characteristics of the primary Sb ores and of the secondary Sb sources (weathered soils, mine wastes), a minero-chemical characterization of the Tafone Sb ore body (southern Tuscany) and of the associated hydrothermal fluids (fluid inclusion study), a geochemical distribution map of Sb and other PTEs in soils and a 3D reconstruction of the ore bodies will be produced. The long-term environmental impact of Sb exploitation will be assessed analyzing Sb and associated PTEs in stream sediments and waters from the Tafone Creek draining the mining area, and providing an assessment of the mass loads of Sb and other PTEs transported by the surficial draining networks to the Mediterranean Sea. As a final aim, the processes that might limit PTEs mobility, such as natural attenuation processes in the vegetation cover and possible cost-effective techniques for remediation at the plant-soil interface, will be investigated. Antimony sorption mechanisms of trap minerals such as LDHs as removal of Sb from freshwaters will also be studied.

Petrogenetic and metallogenic constraints from dark micas compositions of late-Variscan post-collisional granite suites from southern Sardinia (Italy)

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Keywords: granite petrology, dark micas trace elements, Sn-W-Mo ore deposits.

The Late-Variscan batolith of Sardinia displays numerous granitic intrusions emplaced at shallow crustal levels during post-collisional extension. In southern Sardinia they have been grouped in several rock-Units (AP, GS1, GS2, GS3, MM suites) resulting from partial melting of different crustal sources (Conte et al., 2017; Secchi et al., 2021). Granites show commonly a ferroan and F-bearing character and are either sub-aluminous (GS1) to peraluminous ilmenite, or metaluminous magnetite rock-series (GS2 and GS3). Remarkably, GS1 granites display a strong granophile metallogenic signature and are associated with numerous Sn-W-Mo mineral deposits. Dark micas are ubiquitous mafic minerals in all the studied rock-Units, thus representing suitable phases to constrain physicochemical conditions and metallogenic potential of granitic magmas. EPMA and LA-ICP-MS chemical analyses allowed identification of independent groups of primary dark micas corresponding to the each recognized granitic rock-Unit. Dark micas show low-Si contents (5.19 ÷ 5.77 a.p.f.u.) and range from Fe-biotite (MM) to siderophyllite (AP) and lepidomelane (GS2 and GS3). GS1 dark micas cluster at the boundary of lepidomelane and siderophyillite fields. In addition, except for the more sodic and alkaline GS3 rock-Unit, dark micas plot in the subalkaline up to calcalkaline field of the Mg/Al_{tot} diagram. Overall, dark micas exhibit low concentrations of Li, Rb, Sr, strongly variable amounts of Ba and very low values of Cs. Moreover, they show chondrite-normalized REE flat patterns and lower total REE average ppm contents compared to host rocks, in the range 0.2 (MM) ÷ 42.4 (GS1), with a peak value (79.3) in GS3 granite. The use of corrected F and Cl values [IVF/(IVF/Cl)] diagram confirms independent trends characterized by positive correlations with a marked F depletion in GS3 dark micas. In the Fe^{2+} - Fe^{3+} - Mg plot, dark micas from peraluminous rock-Units (i.e. AP and MM) show low oxygen fugacity conditions falling between the QFM and NNO *buffers*. More oxidized conditions are revealed by dark mica from GS3 granites which plot between the NNO and HM buffer. The oxygen fugacity can be also constrained from the calibrated curves in the $f(O_2)$-T space. Except for GS3, studied dark micas equilibrated at an oxygen fugacity between 10-15 and 10-17, which shows $f(O_2)$ conditions between NNO and QFM buffers for the temperatures of crystallization interval between 700°C and 750°C. The chemical characters of studied dark micas confirm the occurrence of independent magmas originated from different rock-sources and suggest low degrees of differentiation by crystal/liquid fractionation. The overall lack of correlation between physicochemical crystallization conditions of dark micas (i.e. temperature and reduced/oxidized conditions) and granophile Sn-W-Mo ore deposits confirm the prevalence of the nature of crustal sources in the metallogenic potential of Sardinian granitic magmas (Naitza et al., 2024).

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An old material for a new application: hydrous manganese dioxide from mining tailings as supercapacitor electrode

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Keywords: Amazon rainforest, mining tailings, supercapacitors.

The rapid development of global economy and the expanding industrialization have led to the depletion of fossil energy sources and to the extensive emission of carbon dioxide. In order to meet the demand for efficient energy storage systems, new electrochemical energy storage devices (EESDs) are currently under investigation. Supercapacitors (SCs), also known as electrochemical capacitors (ECs), have attracted wide attention as they are alternative to both conventional capacitors and secondary batteries. Indeed, SCs possess high-power density, long cyclic stability, good rate capability and fast charge/discharge. MnO_2 has been considered a staple of the research on SC electrodes, because of its low price, low toxicity, high theoretical capacity (1370 F g^{-1}) and good environmental compatibility, etc. Nonetheless the electronic conductivity and structural stability of MnO_2 are poor, limiting the performance and application of MnO_2-based electrode materials.

During mining, beneficiation, and transportation of high-grade Mn-bearing ores, up to 30% of the high-grade ore is turned into Mn tailings (i.e., equivalent to low-grade manganese ore) (Teng et al., 2019). Besides environmental issues, organized crime groups have been establishing (notably in South America) networks for theft, transport, and sale of tailings from legal or illegal exploitation sites. Therefore, directing mining tailings towards "recycling" should be the preferred choice, compared to storage in tailing ponds. Furthermore, reuse of mining waste may also be economically profitable. Indeed, materials science can allow mining tailings to be transformed into value added products: nanomaterials. Although millions of tons of manganese ore tailings are generated every year, mainly due to steel industry, studies concerning manganese recovery from low-grade ore/tailings and its application to electrochemical storage are still very scarce (Teng et al., 2019).

This contribute proposes the synthesis of a quasi-amorphous δ-MnO_2 (similarly to the commercially available "Permanox" (Euler & Helsa, 1979)) by exploiting mining tailings from a manganese (mainly cryptomelane) extraction site in the Brazilian Amazon rainforest. In particular, Mn recovery as potassium manganate (K_2MnO_4), and δ-MnO_2 synthesis were achieved through oxidative alkaline fusion with KOH and subsequent reduction using "low-end" reducing agents (H_2O_2 and ethanol) in solution. According to circular economy principles, highly alkaline liquor resulting from manganese oxide synthesis was recovered and used as electrolyte in supercapacitors. Conductivity and electrochemical properties of δ-MnO_2, electrolyte and supercapacitors were investigated.

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Teng F. et al. (2019) - Preparation of manganese dioxide from low-grade pyrolusite and its electrochemical performance for supercapacitors. Ceram. Int., 45(17), 21457-21466, https://doi.org/10.1016/j.ceramint.2019.07.136.

"Low cost/low end" birnessite-like MnO_2 recovered from Amazon mining tailings as conversion anode for Li-batteries

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Keywords: manganese, recovery, batteries.

Mining activities generate huge amounts of waste materials, often stored in tailings dams, posing serious environmental and social threats. In fact, extensive metal ore mining brings about land degradation, groundwater contamination, habitat destruction, and potential health hazards for nearby communities. Thus, sustainable mining solutions are called for.

Reconversion of mining tailings into harmless and value-added materials is regarded as one of the most promising options for "environmentally friendly" mining. In addition, tailings recovery allows the opportunity to turn waste materials into economically profitable products.

In this context, the present research focuses on the recovery of manganese (an E.U. critical raw material) from mining tailings sampled in an extraction site in the Brazilian Amazon rainforest (Carajás Mineral Province, Pará). The chosen mine represents a significant source of manganese-rich waste material.

Manganese typically occurs in minerals in association with iron as they have similar geochemical properties (Liu et al., 2019). Hence, this study takes advantage of alkaline (e.g. KOH) oxidative fusion to carry out manganese recovery from tailings (as potassium manganate, K_2MnO_4). By controlling fusion process parameters such as, temperature, duration, and tailings/KOH ratio, we aim to efficiently separate manganese from other elements, particularly iron.

Battery grade MnO_2 belonging to the birnessite (δ-MnO_2) family, was synthesized by directly reducing the manganate leachate recovered from Mn-tailings. Birnessite-like materials are well known for their unique properties such as layered structure, high specific surface area, and ion- exchange capabilities (Zhu et al., 2020). Reductant type (hydrogen peroxide, ethanol, manganese sulfate) effect on the morphology, crystallinity, and oxidation state of the manganese oxides was investigated. In addition, manganese oxides were incorporated as active materials into conversion anodes for lithium-ion (Li-ion) rechargeable batteries.

The efficiency of the recovery process is currently under evaluation, while batteries assembled with the recovered MnO_2 are being tested to assess their electrochemical properties, including specific capacity, cycling stability, and rate capability.

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Zhu S. et al. (2019) - Birnessite based nanostructures for supercapacitors: challenges, strategies and prospects. Nanoscale Adv., 2, 37-54, https://doi.org/10.1039/C9NA00547A.

Multi analytical approach to the study of Albanian phosphorite deposits in Jurassic and Cretaceous marine carbonate successions

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Keywords: phosphorite, Albania, carbonates.

The Mediterranean Phosphogenic Province includes numerous phosphorite deposits within sedimentary successions in North Africa, Southern Europe and the Middle East. (Notholt, 1985). This study investigates three uranium-bearing phosphorite deposits, occurring in the Jurassic to Cretaceous marine carbonate rock succession of Southern Albania, through petrographic, scanning electron microscope (SEM) and X-Ray powder Diffraction (XRD), and EMPA analyses. At Bogaz, uranium-rich phosphorites occur as authigenic fluorapatite cement in the interparticle space of hydraulic or tectonic breccia with clasts of Lower Jurassic (Sinemurian-Pliensbachian) shallow-water peritidal platform carbonates, containing *Siphovalvulina* foraminifers and *Palaeodasycladus mediterraneous* dasyclad algae. In Fushëbardha, the lower Toarcian (Lower Jurassic), carbonate facies rich in *Bositra*-like thin-shelled pelagic bivalves corresponding to the organic matter-rich "Posidonia" Shales of Austria and Germany, alternate with tabular phosphorite deposits. Gusmar deposit consists of pelagic calci-mudstone/wackestone with globotruncarid planktonic foraminifers indicative of Late Cretaceous (probably Coniacian) age, alternating with a few millimeters-thick layers of phosphates. SEM analysis was pivotal in identifying the euhedral morphology of calcium phosphate minerals with hexagonal basal section, often organized in radial spherulites and in confirming the presence of microbial organic remains, such as biofilm extracellular polymeric substances (EPS) and filaments.

The formation of phosphorite deposits within pelagic carbonates requires up-welling currents that contribute to increasing primary productivity, organic matter accumulation and expansion of the oxygen minimum zone. This allows the concentration of calcium phosphate associated with organic-rich sediments. Phosphorous and uranium migrate in the first few meters of sediments, from organic matter to pore fluids that precipitate apatite in suboxic conditions. The process described above is valid for the Toarcian Fushëbardha and the Coniacian Gusmar pelagic carbonate deposits both linked to global Oceanic Anoxic Event (OAE). As for the Bogaz fluorapatite in brecciated shallow, platform-interior carbonates, it was determined that a Toarcian or later hydraulic brecciation of the older and underlying Sinemurian-Pliensbachian carbonates was responsible for the formation of this secondary phosphorite deposit. Hydrothermal fluids percolating downwards into the carbonate sequence re-mobilized phosphates higher up in the stratigraphy and re-deposited them while brecciating the host carbonates.

This study is one of the first comprehensive investigations of primary sedimentary and secondary diagenetic phosphorites in Southern Albania.

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Punta Corna five-element vein system (Italy): Late-Alpine hydrothermal circulation and metallogenesis

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Keywords: cobalt, hydrothermal, alpine.

The Punta Corna Fe-Co-Ni-Ag-Bi deposit is located in the Lanzo Valleys, Piedmont (Italy). It consists of five-element mineralization exploited for Fe and Co until the 19th century and then abandoned. The global concern for strategic raw material supply, such as Co, has raised a renewed interest in old mining sites where economic potential was not fully investigated. Since 2018 the Junior Exploration Company AltaMin Ltd. owns the exploration license of the Punta Corna area for assessing the economic viability of the ore.

Mineralization consists of a complex vein system emplaced during the exhumation phases of the Alpine orogeny (Castelli et al., 2011). The veins are related to two sub-vertical faults systems, cutting all metamorphic structures since the Oligocene, in an extensional-transtensive regime (Perello et al., 2004). Various styles of brecciation, overgrowth and replacement indicate multiple hydrothermal pulses.

Hydrothermal activity started with silicification and sericitization of the host rock, followed by the precipitation of Fe-rich carbonates (siderite and ankerite), calcite, quartz and baryte. This first stage concludes with the deposition of base metal sulfides (pyrite, chalcopyrite, galena. The Fe-Co-Ni arsenides comprise nickeline, overgrown by safflorite, then euhedral skutterudite and final rammelsbergite in siderite and quartz gangue. Native Bi and As may be recognized in the core of skutterudite and safflorite (Moroni et al., 2019). The final hydrothermal stage is characterized by sulfides and sulfosalts such as tetrahedrite, chalcopyrite, sphalerite, galena, pyrite and bournonite. This stage, at the very end, also includes Bi-Sb sulfosalts such as the emplectite-chalcostibite solid solution, horobetsuite and wittichenite in siderite, quartz, ankerite and baryte.

Fluid inclusion studies employing microthermometry, cathodoluminescence, and micro-Raman spectroscopy revealed the presence of different fluid types, suggesting a mixing process as the cause of ore precipitation. These fluids exhibit distinct temperatures, salinities and composition, indicating diverse provenance sources. The evolution of fluids associated with Stage I mineralization and those linked to the arsenides align with existing models, stating that the transition from base metal sulfides to Fe-Co-Ni arsenides is triggered by a process of rapid reduction, caused by the oxidation of a reducing agent. The presence of Bi-Sb sulfosalts, appearing in the late stages of the mineralization, may represent a connection to the hydrothermal Au-Bi-Sb veins in the nearby Gran Paradiso Massif (Cevales et al., 1961).

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Cevales, G. (1961) - I giacimenti minerari del Gran Paradiso. Rend. Soc. Min. It., 42, 193-217.

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Ore variability in five-element (Ni-Co-As-Ag-Bi) vein systems: insights from the As/S vs. S binary plot

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Keywords: five-element veins, ore variability, arsenides curve.

Five-element (Ni-Co-As-Ag-Bi) veins (Kissin, 1992) are a class of hydrothermal deposits characterized by complex mineral assemblages such as native elements, Ni-Co arsenides and base-metal sulfides/sulfosalts in quartz and carbonate gangue, sometimes in association to barite and fluorite. Many theories have been proposed to explain the origin of fluids, the sources of metals and ore precipitation mechanisms (Scharrer et al., 2019 and references therein), which require a reducing agent usually represented by 1) methane (Markl et al., 2016), and/or 2) oxydation of Fe^{2+} to Fe^{3+} in siderite (Kreissl et al., 2018). Temperature of fluids varies greatly between localities (50-400°C) and appears not to play an essential role in ore-formation mechanism (Scharrer et al., 2019). Although conditions of ore precipitation can be very different, textural features and mineralogical associations display evident, worldwide-scale similarities. Another typical feature of this kind of deposits is represented by the extreme compositional and mineralogical variability of the ore inside the same vein system. A simple way to explain the observed variations is represented by a linear-log scale binary plot comparing S content in wt.% versus As/S ratio in the arsenides. Plotted in this diagram, the worldwide arsenide mineral compositions (Scharrer et al., 2019 and references therein), lie on a potential "Arsenides Curve" (equation: $y = 28.382x^{-1.085}$; $R^2 = 0.9968$). Fluctuations in Sb contents, especially for mono-arsenides/antimonides and sulfo-arsenides/antimonides solid solutions, result in a shift from the curve due to a lower As/S ratio. The plot shows a continuous trend from monoarsenides to sulfarsenides which reflects the general paragenetic successions observed in many deposits of this class. However, as reported in literature for numerous occurrences, this general trend does not exclude relevant variations and sequence inversions (e.g., diarsenides following triarsenides etc.). To interpret these different paths, the plot still offers useful keys, explaining these variations in terms of variability of As/S ratios. In fact, if reduction of arsenic immediately triggers precipitation of Ni-Co-Fe arsenides (Markl et al., 2016), their composition must also record the rapid evolution of physicochemical parameters of fluids during ore precipitation, especially their "reduced" As/S ratio and relative sulfur content. Arsenides precipitation may start everywhere in the curve and can move along the curve itself in directions that depend on fluctuations of As/S ratio and sulfur activity in the hydrothermal fluids. The result is a graphical visualization of the observed wide variations in arsenide mineral assemblages inside the same vein. Overall, these evidences may suggest a source from a rapidly evolving mineral system affected by local geological conditions, rather than derivation from separate pulses of compositionally different fluids.

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Critical raw materials (CRMs) in the Fluminèse-Arburèse districts (SW Sardinia): uidelines for regional-scale mineral exploration

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Keywords: mining exploration, mineral assemblages, metallogeny.

Sardinia was the most flourishing mining region of Italy with over 600 mining concessions and about 70 Mm^3 of mining dumps. The Fluminèse and Arburèse districts (SW Sardinia) are currently considered a target for Strategic and Critical Raw Materials (S-CRMs) due to the occurrence of F-Ba, Ni-Co-Bi, and LREE in mining dumps and underexplored hydrothermal vein systems and skarns.

One of the most relevant mine sites in the Fluminèse district is the Santa Lucia historical mine, exploited from 1868 to the 1980s. The mineralisation consists of a system of NW-SE, N-S and E-W veins (Filone Palazzo and Sa Mena E S'Oreri), hosted in Cambrian metalimestones and Ordovician metasiliciclastics. The ores include fluorite, baryte, base-metal sulfides, Pb-Zn sulfates and oxides in a quartz-calcite gangue.

The Santa Lucia veins occur in the vicinity of other unrelated and km-scale systems such as the five-element (Ni-Co-As-Bi-Ag±REE) veins and, at 15 km NW in the Arburèse district, the Montevecchio polymetallic vein deposit. The nearest is the Pala Su Sciusciu vein running E-W from the easternmost part of the Santa Lucia vein system. It consists of a quartz vein and hosts fluorite, baryte and, most notably, Sb-Ni-Co e LREE phases. Its geometry and mineral assemblage suggest a genetic link with the five-element system hosted in Ordovician-Silurian metasiliciclastics and black shales of the Arburèse district.

Here we report the first identification and preliminary SEM-EDS characterization of Santa Lucia primary LREE fluorocarbonates, such as euhedral hexagonal synchysite/bastnaesite associated with calcite, subhedral rutile and coronadite in quartz, and secondary anhedral Ni-oxides and phosphide associated with quartz.

The LREE and Ni-Ti assemblages suggest an affinity between the F-Ba-Zn-Pb Santa Lucia veins and the nearby Ni-Co-Sb-bearing Pala Su Sciusciu vein and Ni-Co-As-Bi-Ag±REE five-element veins. Ni-Co(-Sb)-arsenides, -sulfoarsenides and -sulfides are a trademark of the five-element veins (Scano, 2023) and have been reported to occur also in the surrounding Montevecchio veins. Moreover, REE-bearing mineral phases have been recently identified in the quartz-siderite gangue of both five-element and Montevecchio veins (Moroni et al., 2019; Deidda et al., 2021; Scano, 2023; Sedda et al., 2024). The variety of mineral assemblages (e.g. the relative abundance of fluorite and Ni-Co-Sb) may reflect factors such as the composition of host rocks, the extent of fluid circulation and processes of remobilization of elements from the surrounding F-rich Variscan granite-related ores (e.g. skarns and greisen).

In conclusion, this new set of results may serve as a hint for future investigations regarding CRM occurrences in the *Santa Lucia* area, and for a better understanding of the potential metallogenic relationships between apparently unrelated systems in the *Fluminèse* and *Arburèse* districts.

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Moroni M. et al. (2019) - The Pb-Zn-Ag Vein System at Montevecchio-Ingurtosu, Southwestern Sardinia, Italy: A Summary of Previous Knowledge and New Mineralogical, Fluid Inclusion, and Isotopic Data. Ore Geol. Rev., 115, 103194, https://doi.org/10.1016/j.oregeorev.2019.103194.

Scano I. (2023) - Vein intersection zones and host rock composition as controlling factors in polymetallic ore shoots genesis: insights from the Southern Arburèse five-element (Ni-Co-As-Bi-Ag) vein system (SW Sardinia). Rend. Online Soc. Geol. It., 61, 17-26, https://doi.org/10.3301/ROL.2023.42.

Sedda L. et al. (2024) - Unlocking Strategic and Critical Raw Materials: Assessment of Zinc and REEs Enrichment in Tailings and Zn-Carbonate in a Historical Mining Area (Montevecchio, SW Sardinia). Minerals, 14, 3, https://doi.org/10.3390/min14010003.

Alteration mineral mapping of Zn mineralization using EnMAP hyperspectral satellite data: a comparative study of the Skorpion-Rosh Pinah (Namibia) and Beltana (Australia) deposits

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Keywords: hyperspectral remote sensing, Zn mineralization, alteration mineral mapping.

Non-sulfide Zn mineralization has gained growing economic importance in recent years, becoming an attractive target for mineral exploration. Despite the occurrences of large alteration footprints associated with these deposit types, they remain underexplored through hyperspectral imaging methods. In this study, we investigate the alteration footprints of two distinct deposits comprising the supergene non-sulfide mineralization at Skorpion (Namibia) and the hypogene willemite-rich deposit at Beltana (Australia). The Skorpion mineralization occurs within a Neoproterozoic volcano-sedimentary succession, in the Gariep Belt, resulting from the oxidation of the massive sulfide by wall-rock replacement and in-situ oxidation (Arfe et al., 2017). The Beltana high-grade hypogene willemite mineralization is hosted in Lower Cambrian carbonate rocks, in the Arrowie basin. It is structurally controlled and associated with extensive hematite-rich hydrothermal zincian dolomitization (Groves et al., 2003).

This study aims to identify and characterize the district-scale hydrothermal and supergene surface alteration for both study areas by using hyperspectral imagery of EnMAP satellite instrument. The 30 m resolution EnMAP data are collected in the Visible Near-Infrared (VNIR) and Shortwave Infrared (SWIR) range, between 420 and 2450 nm in 224 contiguous bands, at a spectral resolution of 6.5 nm and 10 nm with a signal-to-noise ratio of ≥ 400:1 and ≥ 170:1 in the VNIR and SWIR, respectively (Kaufmann et al., 2006). A large suite of spectrally active minerals was detected over these deposits, including Fe oxy-hydroxides (hematite-goethite), carbonates (dolomite-calcite), and di- and tri-octahedral phyllosilicates (micas-kaolinite-smectite-chlorite). The spectral mineral maps representative of the abundance, composition, and crystallinity of these mineral phases were obtained by applying a multiple-feature extraction workflow based on polynomial fitting (Rodger et al., 2012). The results were validated using laboratory spectroscopy, analytical geochemistry (i.e., XRPD and FESEM-EDS) using thirty rock samples collected from both study areas.

This work demonstrates EnMAP capability in identifying distinct alteration footprints of various non-sulfide Zn deposits, supporting mineral exploration by providing district-scale vectors toward the mineralized centres, facilitating follow-up field works and drilling programs.

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Circular economy in the dimension stone industry: problems and challenges related to fine fractions generated during marble exploitation

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Keywords: marble sludge, sustainable mining, circular economy.

Marble and carbonate stones account for 58 percent of the world's dimension stone production and have been used as primary materials for construction and ornamental purposes since ancient times. However, according to recent studies (e.g., Mehta et al., 2020), the waste generation in the marble industry is estimated to be very high, with about 30-40% of production of fresh and high-quality blocks, while about 70% of the extracted material in the quarry is lost as waste. The fine fractions generated during marble exploitation and processing activities, which include microfine marble dust and sludge, represent a particularly difficult fraction to manage due to high cost for disposal and the lack of adequate protocols for recovery, other than landfills (Careddu & Dino, 2016).

According to data from recent studies (e.g. Tazzini et al., 2024), the fine particles generated from the exploitation of marble in the Carrara Marble Basin ("marmettola") have very promising characteristics, such as very fine and homogeneous grain sizes (silt), pure calcium carbonate composition (> 90%), and no relevant pollutants. This could indicate a potential for reuse in various industrial sectors that require high quality micronized $CaCO_3$ products (e.g. filler in paper production, paints, or chemical applications such as cosmetics and pharmaceuticals). Furthermore, it has potential applications in the construction industry as a mineral filler, substituting original materials like sand or aggregates in concrete or mortars (e.g. Marras et al., 2022).

Despite promising data, the marble industry, especially in the CMB, faces persistent issues and challenges. In quarry areas, there is often an accumulation of waste, especially the fine fractions ("marmettola"), which are often improperly stored and dumped in quarry yards. This not only causes economic losses for the companies, but also violates EU waste recycling principles and creates environmental problems (e.g. on rivers and springs).

This issue is exacerbated in quarries that use chemicals (like epoxy resins) to strengthen marble benches and blocks before transport, methods that are growing fast to optimize quarry production and reduce waste. However, in case of cutting of a fully resin-impregnated marble bench or block could result in a mixture of dust, water, and resin residues, demanding additional attention compared to the other (and more pure) fine particles. Targeted research, using further mineralogical and chemical analysis (e.g., XRF, ICP-MS, FTIR), is underway, with the aim of investigating both the potential environmental impacts of this materials and the possibility of its recycling, in a circular economy and sustainable mining perspective.

Positively reshaping the perception of these materials, particularly in the CMB, one of the world's most renowned marble districts, could turn them from being perceived negative into a valuable resource, generating a positive impact on both the environment and society.

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Tazzini A. et al. (2024) - Managing Marble Quarry Waste: Opportunities and Challenges for Circular Economy Implementation. Sustainability, 16, 3056, https://doi.org/10.3390/su16073056.

Age and evolution of the Raibl carbonate-hosted Zn-Pb deposit (NE Italy)

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Keywords: lead, zinc, carbonate-hosted deposits.

The Bleiberg-Kreuth, Mežica, Raibl and Salafossa ore deposits are the most representative Pb-Zn ore deposits in the eastern Southern Alps, and have produced more than 75% of the total Pb and Zn extracted from the Alps (Brigo et al., 1977). These four deposits, as well as most other Pb-Zn deposits that are hosted in Alpine Triassic sedimentary sequences, are located near the Periadriatic Line, an E-W striking fault of regional importance that divides the Austroalpine nappes in the north from the Southern Alps and Dinarides to the south.

The Raibl mine is located in the Julian Alps near the village of Cave del Predil (Friuli Venezia Giulia, Italy), close to the borders with Slovenia and Austria. The deposit is hosted by the Carnian Schlern Dolomite (locally also known as Dolomia Metallifera), which is locally interlayered with a basinal unit formed by carbonatic-tuffaceous sediments ('pseudo-Buchenstein' or Acquatona Formation; Brigo & Cerrato, 1994; Jadoul et al., 2002). The Raibl ore bodies are composed by different amounts of sphalerite, galena and iron sulphides, forming columns and veins and, rarely, stratiform bodies. Occasionally, mineralized breccias filling fissures and erosion cavities also occur. Colloform sphalerite (i.e. schalenblende) is the most common ore type, which is represented by yellow or red sphalerite bands hosting dendritic or crystallized galena. Depending on the sector of the deposit, pyrite and/or marcasite may also be present. Gangue minerals are dolomite, calcite and rarely barite.

Previous workers subdivided the Raibl deposit into three sectors based on the chemical features of sphalerite and geometry of the ore bodies, and suggested a relation between mineralization style, paleogeography and tectonic evolution (Omenetto et al., 1979; Brigo & Cerrato, 1994). In particular, the episodic (re)activation of Triassic syngenetic faults is considered to be one of the main driver of the mineralization processes, promoting the circulation of metallogenic fluids and a prolonged polyphase remobilization and re-concentration of original sulphide ores. However, the actual timing and duration of the main mineralization stage(s) has largely remained unconstrained.

We present a large set of new in situ U-Pb ages of petrographically well-characterized hydrothermal carbonates found in spatial association with the sulphides. The combination of petrographic observations with U-Pb geochronological data allow to distinguish several generations of carbonates (pre-, syn- and post-ore) crystallized between 234.3±5.7 Ma and 92±10 Ma. By combining the radiometric ages of the sulphide-associated hydrothermal carbonates with the chemical and isotopic composition of the ore minerals, it is possible to link the mineralizing events with the activation (or re-activation) of the Triassic faults during the Mesozoic. A comparative analysis with similar Alpine Zn-Pb ore districts will be crucial to build a comprehensive metallogenic model that encompasses all the coeval ore deposits occurring in the Alps.

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Brigo L. et al. (1977) - Comparative reflections on four Alpine Pb-Zn deposits. In: Klemm D.D., Schneider H.-J. (Eds), Time- and Strata-Bound Ore Deposits, Springer, 273-293.

Jadoul F. et al. (2002) - Ladinian stratigraphy and paleogeography of the Southern Val Canale (Pontebbano-Tarvisiano, Julian Alps, Italy). Mem. Soc. Geol. It., 57, 29-43.

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S19.

Environmental mineralogy and sustainable development

CONVENERS & CHAIRPERSONS

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Critical metals distribution in bauxite residues: a multivariate statistical analysis approach

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Keywords: red muds, compositional data analysis, critical metals.

Bauxite residues (RM), the byproduct of the Bayer process for aluminium extraction from bauxite ore, pose significant environmental challenges, while containing valuable critical metals (CMs). A preliminary analysis of red mud (RM) samples from the disposal sites in Portovesme, Sardinia, Italy was conducted to understand the geochemical and mineralogical features influencing the accumulation of CM in these matrices. The major elements-CM relationships were assessed by Compositional Data Analysis (CoDa).

The analytical characterization was performed through a combination of X-ray powder diffraction (XRPD) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). XRPD reveals that the main minerals are hematite, gibbsite, boehmite, anatase, cancrinite, sodalite, and quartz, consistent with what depicted in previous studies for RM from the same site (Castaldi et al., 2008; Mombelli et al., 2019). ICP-MS assessment includes the following major oxides composition (wt.%): SiO_2 (11.9-22.6), Al_2O_3 (17.4-24.9), Fe_2O_3 (22.2-30.3), MgO (0.7-4.7), CaO (2.6-5.9), Na_2O (3.5-11.5), K_2O (0.2-0.7). The average iron percentage is 25.8 wt.%, underscoring the considerable presence of iron in bauxite residues, whereas the average alumina percentage is 20.75 wt.%, consistent with the large amount of Al-hydroxides detected by XRPD. Among the LREE, the Ce is the most abundant (93-258 ppm).

CoDa was performed through Principal Component Analysis after a transformation of raw data into centred log ratio. Significant variability pertains to SiO_2, Al_2O_3, Fe_2O_3, followed by TiO_2 and MgO. Similarly, elements like Sc, V, As, Ni, Ga, Hf, and Sr exhibit variable concentration ranges, whereas Co, LREE, HREE, Ta, and W have substantially constant low concentrations within this dataset. The PC1 and PC2 association reveals that TiO_2 and Na_2O have a significant impact on the distribution of HREE, LREE, Sc, Nb, and Co, likely through mineral interactions and complex formation. MgO and Al_2O_3 play a role in controlling V, As, Ni, and Ga distribution.

This preliminary study highlights the potential of red muds as a geo-material for the recovery of critical metals, providing an environmentally friendly solution to the challenges posed by their disposal. Further research could facilitate the efficient utilization of this secondary byproduct, aligning with sustainability goals (Liu & Naidu, 2014).

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Liu Y. & Naidu R. (2014) - Hidden values in bauxite residue (red mud): Recovery of metals. Waste Manage., 34(12), 2662-2673.

Mombelli D. et al. (2019) - Iron Recovery from Bauxite Tailings Red Mud by Thermal Reduction with Blast Furnace Sludge. Appl. Sci., 9, 4902. https://doi.org/10.3390/app9224902.

Red mud treated with KOH: from disposal material to new resource

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Keywords: red mud, magnetic zeolite, arsenic removal.

Red mud (RM) is a waste material resulting from alumina production when bauxite ores are subjected to caustic leaching processes. Its mineralogical composition is characterized by the presence of hematite and goethite with minor amount of boehmite and, subordinately, calcium oxides, katoite, sodalite. RM has been used as alumina and iron source for the synthesis of zeolites thus promoting one useful method to reduce the amount of this waste to be deposed of in landfill. In detail, in our previous papers, this alkaline waste was used for the synthesis of LTA and X-type zeolite in combination with fly ash (Belviso et al., 2015), as alternative aluminium source for FAU and GIS types zeolite (Belviso et al., 2018) or as non-conventional Fe source for the synthesis of zeolite A with magnetic properties Belviso et al. (2020a). Red mud treated by sonication was also used to form zeolite-layered double hydroxide composite (LTA-LDH) (Belviso et al., 2020b). In all these experiments, the waste material was alkaline activated by sodium hydroxide. To the best our knowledge, zeolite synthesis from red mud by KOH alkaline activation has not been yet performed.

In this new work, the solid waste resulting from bauxite ore (red mud) was converted into useful products consisting in hydrogarnet together with zeolite. RM transformation from disposal material into new source was carried out using potassium hydroxide as activator and hydrothermal process (HY) or vapor phase crystallization (VPC) approach. The results indicate the formation of katoite and zeolite L (LTL topology) with both approaches. All the synthetic products display magnetic properties. In addition, a preliminary investigation on arsenic removal from drinking water (from 68 to 87%), makes the synthetic materials appealing for environmental applications. Finally, the synthesis of large amount of very useful newly-formed phases using vapour molecules confirms the efficiency of the innovative and green VPC process.

Belviso C. et al. (2015) - Synthesis of magnetic zeolite at low temperature using a waste material mixture: fly ash and red mud. Micropor. Mesopor. Mat., 202, 208-216.

Belviso C. et al. (2018) - Red mud as aluminium source for the synthesis of magnetic zeolite. Micropor. Mesopor. Mat., 270, 24-29.

Belviso C. et al. (2020a) - Effect of red mud added to zeolite LTA synthesis: Where is Fe in the newly-formed material? Micropor. Mesopor. Mat., 298, 1100583.

Belviso C. et al. (2020b) - Synthesis of composite zeolite-layered double hydroxides using ultrasonic neutralized red mud. Micropor. Mesopor. Mat., 299, 110108.

Evaluating mineralogical and geochemical characteristics for understanding groundwater quality and secondary asbestos exposure risks: the case of Calabria Region

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Keywords: hydrodispersed asbestos, fibers, groundwaters.

Recently, there has been a growing recognition of asbestos fibers in groundwaters, highlighting these as an unconventional source of exposure. Utilizing contaminated water for domestic, agricultural, and industrial purposes poses the risk of fibers migration from water to air, impacting residential, public, and occupational settings. Research suggests that polluted water sources can lead to airborne fiber concentrations exceeding regulatory limits due to processes like evaporation or mobilization (Avataneo et al., 2022). Water serves as a conduit for fibers, facilitating their dispersal and accumulation in distant locations. Consequently, hydrodispersed asbestos emerges as a novel environmental pollutant, with systematic assessment of its presence still lacking. Moreover, the risk of ingesting asbestos fibers via drinking water remains inadequately addressed, with conclusive evidence yet to be established. This study investigates asbestos pollution in groundwaters in ophiolite area of Calabria Region (Southern Italy). In detail, 22 water samples (including springs and river waters) were collected in the central part of Calabria region and thoroughly characterized. Tremolite emerges as the predominant asbestos mineral, followed by chrysotile, actinolite, and anthophyllite. Additionally, non-asbestos minerals such as Mg-hornblende, gedrite, edenite, and rutile were also detected. Geochemical analyses identified two main hydrochemical facies, Ca-HCO3 and Mg-HCO3, with variable heavy metal concentrations ranging from 0.23-17.13 ppb for Cr, 4.72-49.12 ppb for Fe, 1.12-30.36 ppb for Ni, and 5.37-30.24 ppb for Zn, respectively.

The analyses revealed the ubiquitous presence of asbestos fibers in investigated waters, with concentrations up to 330000 fibers/Liter. Morpho-dimensional examination indicated variability in fiber dimensions, with a significant proportion falling within pathogenic criteria. The highest concentration was observed in a Mg-HCO3 river water sample highlighting the issue of fiber transportation and accumulation in areas distant from the source. Consequently, distribution maps of fiber levels were generated. These findings show that groundwaters can be considered a potential pathway for asbestos contamination, emphasizing the necessity for comprehensive assessments and further research to mitigate health risks associated with asbestos exposure via water sources.

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Avataneo C. et al. (2022) - Chrysotile asbestos migration in air from contaminated water: An experimental simulation. J. Hazard. Mater., 424, 127528, https://doi.org/10.1016/j.jhazmat.2021.127528.

Mineralogical and petrographic assessment of asbestiform minerals in the Timpone Seluci metabasites (Pollino Massif, Southern Italy)

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Keywords: mineralogy, asbestiform minerals, Pollino Massif.

There is a wide interest about the toxicity and carcinogenicity of asbestos minerals occurring innatural rocks since the inhalation of asbestos could cause health problems such as malignant mesothelioma and lung cancers. In the Timpone Seluci metabasites the main constituent of the asbestos minerals is actinolite with the presence of further minerals such as glaucophane. In this work we performed a petrographic and mineralogical characterization of Timpone Seluci (PZ) metabasites which belong to the Frido Unit of the Liguride complex in the southern Apennines. The studied metabasites show a massive structure and with colours ranging from dark green to blue. Petrographic characterization was performed by using optical microscopy (OM) and scanning electron microscope (SEM) while bulk mineralogical composition was assessed by using X-ray powder diffraction analysis (XRPD). The main minerals found in the studied rocks are plagioclase, quartz, clinopyroxene, blue amphibole, green amphibole, lawsonite, epidote, pumpellyite while accessory and secondary minerals are apatite, opaque minerals, chlorite and sericite. Actinolite exhibits acicular and fibrous habitus. Mineralogy and petrographic features reveal that metabasites have undergone a metamorphic event with high-pressure conditions, as evidenced by the finding ofglaucophane and lawsonite, attributed to Alpine metamorphism. Subsequently, the metabasites were affected by a retrograde event under greenschist facies, testified by the presence of albite, chlorite and actinolite. The presence of some of the main mineralogical phases observed in the petrographic study was confirmed by X-ray powder diffraction and scanning electron microscope analysis.

Recycling detoxified asbestos cement in several commodities

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Keywords: asbestos, inertization, recycling.

The large amount of asbestos containing materials (ACM) still present in the built environment represents an environmental concern. The application of a sustainable detoxification process followed by recycling is recommended by the EU. With the A-FIRE project (Asbestos Fast Inertization & Recycling), we thermally treated asbestos-cement (Eternit®-like) slates commonly used for roofing at 1100-1150°C, obtaining the transformation of asbestos into non-toxic minerals, cement-like phases and glass (Vergani et al., 2022). We used this product as secondary raw material (SRM) for the production of sanitary ware (Bernasconi et al., 2022), as filler in epoxy resin for flooring applications (Campanale et al., 2023), in mortar for plaster applications (Capitani et al., 2024), in rock-wool production, as partial substitution of cement, in biopolymers and geopolymers. The recycling in sanitary ware is possible up to 5 wt.% of detoxified asbestos cement (DAC), provided that sulphates that adversely affect the workability of the slurry could be washed out and if the whiteness is not a prerequisite. Recycling DAC as filler in epoxy is possible up to 30 wt.%, where it can substitute for common inorganic filler such as barite and wollastonite, reducing the cost of the composite and increasing the durability of the flooring. Recycling DAC in mortar for plaster application as inert up to 7 wt.% does not alter the water demand and workability of the mixture and slightly increases the flexural and compressive strengths. Recycling DAC in the production of rock-wool mixed with diabase in the proportion 70:30 by weight is possible and leads to fibres with morphology, composition and biosolubility similar to those of commercial rock-wool. Tests as substitute of cement, as filler in biopolymers (polylactic acid) and as SRM in geopolymers are in progress; preliminary results are very promising. Finally, Life Cycle and Cost Benefit Analyses suggest that asbestos inertization and recycling represents a sustainable alternative to deep landfilling.

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Campanale F. et al. (2023) - Epoxy Resins for Flooring Applications, an Optimal Host for Recycling Deactivated Cement Asbestos. Polymers, 15, 1410, https://doi.org/10.3390/polym15061410.

Capitani G. et al. (2024) - Recycling thermally deactivated asbestos cement in mortar: a possible route towards a rapid conclusion of the "asbestos problem". J. Environ. Manage., 355, 120507, https://doi.org/10.1016/j.jenvman.2024.120507.

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Advancements in zeolite-based recovery of Rare Earth Elements: a step towards resource security and sustainability

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Keywords: zeolite, ree, circular economy.

Rare Earth Elements (REEs) represent a group of seventeen elements, including the Lanthanides along with scandium and yttrium, playing a pivotal role in modern technology. Their demand has been escalating due to their extensive use in various applications such as computer memory, DVDs, rechargeable batteries, catalytic converters, magnets, mobile phones, LED lighting, superconductors, glass additives, and medical imaging agents. An European study on Critical Raw Materials (Bobba et al., 2020) highlights REEs as crucial for the energy transition, projecting a significant surge in their utilization by 2050. However, the supply risk is heightened as China currently dominates the market, supplying 98% of the EU's REEs. Diversifying the supply sources is imperative to enhance resource security and reduce dependency on a single country. Various waste materials have been identified as potential sources of REEs, including phosphogypsum, red muds, mine tailings, and electronic wastes. Effective recovery methods such as selective precipitation, solvent extraction, adsorption, and ion exchange are exploited for REEs recycling. Among these methods, the use of zeolites, known for their cation exchange properties, hold promise for REE recovery (Confalonieri et al., 2022). However, their stability in acidic solutions and selectivity towards different REEs require further exploration. In this work (Colombo et al., 2024) the cation exchange capacity of a synthetic 13X zeolite, FAU type, against four REEs with concentrations mimicking those obtained from the leaching of spent fluorescent lamps (Eduafo et al., 2015) was evaluated. The aim was to assess the efficiency of zeolites in REE recovery and develop a methodology for selective separation. Despite acidic conditions during testing, zeolite cation exchange properties remained largely unaffected. NH4-13X zeolite exhibited good affinity for REEs, with Ce, La, and Y reaching maximum exchanged values of 23, 22, and 16 atoms per unit cell (p.u.c.), respectively. Eu concentrations were too low to saturate the zeolite across all liquid-to-solid ratios, hindering the evaluation. The optimal liquid-to-solid ratio for Ce and La was found to be 50/1, while Y saturated the zeolite even at a 10/1 ratio. Ce and La exhibited a higher affinity for the zeolite than NH4 and Na, while Y showed intermediate affinity. This selectivity may stem from Y's smaller ionic radius compared to Ce, La, and Na. REE recovery from exchanged zeolites showed minimal Ce and Eu recovery but nearly half of La and Y were recovered. Studies involving selectively releasing La over Ce and Y over Eu using NH4-13X zeolite in a multi-elemental solutions system are ongoing, as well as a deep structural characterization of the exchanged zeolites via high resolution XRPD and XAS.

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Eduafo P.M. et al. (2015) - Experimental Investigation of Recycling Rare Earth Metals from Waste Fluorescent Lamp Phosphors. In: Neelameggham N.R., Alam S., Oosterhof H., Jha A., Dreisinger D., Wang S. (Eds), Rare Metal Technology 2015, The Minerals, Metals & Materials Society, 253-259, https://doi.org/10.1002/9781119093244.ch29.

Synthesis and surface functionalization of geo-inspired nanotubes for Alzheimer's Disease treatment with increased tolerability

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Keywords: nanotubes, hydrothermal synthesis, surface functionalization.

Hydrated magnesium silicate $[Mg_3(Si_2O_5)(OH)_4]$ nanotubes (NTs), in their highly biocompatible stoichiometric form, are synthesized in aqueous solution with Mg and Si precursors, under hydrothermal conditions, and used as nanoscintillators.

The brucitic $[Mg(OH)_2]$ outer layer of NTs confers a basic behaviour to the surface which, in a mild acidic environment, tends to concentrate Mg^{2+} ions, promoting positive Z-potential and surface functionalization with anionic species. This property is exploited to give therapeutic effects to NTs by surface anchoring of Chlorin e6 (Ce6) and cyclic D,L-α-peptides (CP-2).

Ce6 is a water-soluble organic dye able to produce reactive oxygen species under visible light excitation in physiological environment, and CP-2 represent an alternative for the selective target of early toxic amyloid-β (Aβ) aggregates, the main responsible of the progression of the Alzheimer's Disease.

We propose the inhibition of Aβ oligomers formation by an X-ray activated photo-dynamic approach: biocompatible and blood-brain barrier-permeable NTs are injected into blood and selectively attached to Aβ aggregates. Irradiation by low doses of highly penetrating X-ray promotes scintillation and then visible light excitation of Ce6, generating singlet oxygen, which selectively destroy Aβ oligomers (Secchi et al., 2022; 2023).

Synthesized NTs, bare and functionalized with Ce6 and CP-2, are characterized with a multi-analytical approach to assess the performance of each step of photo-activation process.

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Secchi V. et al. (2023) - Energy Partitioning in Multicomponent Nanoscintillators for Enhanced Localized Radiotherapy. ACS Appl. Mater. Interfaces, 15, 24693-2470, https://doi.org/10.1021/acsami.3c00853.

Understanding the behaviour of fibrous antigorite in artificial lysosomal fluid: evidence for toxicity assessment

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Keywords: fibrous antigorite, toxicity, asbestos.

Antigorite, a serpentine polymorph, can occur in an asbestos-like morphology and may pose risks to human health. For example, in New Caledonia, exposure to fibrous antigorite has been identified as one of the contributing causes to the mesothelioma epidemic that affected its population (Baumann et al., 2011). However, the toxicity of antigorite has yet to be fully defined.

In the perspective of assessing the hazard of this mineral, a crucial step is to investigate its key toxicologically relevant physico-chemical properties and compare them with those of asbestos minerals. This work aimed to model biodurability, fibre surface modification, and chemical reactivity following interaction with an artificial lysosomal fluid (ALF) simulating the intracellular environment of phagocytic cells (Marques et al., 2011). Two antigorite samples from Calabria and Liguria (Italy) were investigated, along with three asbestos samples: UICC chrysotile, UICC crocidolite, and fibrous tremolite (Basilicata, Italy).

Biodurability was assessed by incubating the samples in the ALF at pH 4.5 for up to 28 days at T = 37±1°C. The leached cations were quantified by inductively coupled plasma optical emission spectrometry (ICP-OES). Surface modifications following dissolution were monitored by X-ray photoelectron spectroscopy (XPS). The focus of these analyses is on the chemical speciation of surface Fe, since Fe can catalyse, through the Fenton reaction, the generation of highly reactive hydroxyl radicals (•OH) (Andreozzi et al., 2017) capable of inducing lipid peroxidation and oxidative damage to DNA (Mossman, 2018). Chemical reactivity was evaluated by testing the release of •OH radicals in the presence of H_2O_2 for up to 15 days, on both pristine and incubated fibres, using the spin trapping technique coupled with electron paramagnetic resonance (EPR) spectroscopy.

Results show that the biodurability of the two antigorite samples is higher than that of UICC chrysotile but significantly lower than that of UICC crocidolite and fibrous tremolite. Dissolution causes changes in Fe speciation on the surface of the fibres, and the surface alteration, in turn, leads to changes in reactivity. The observed behaviour of fibrous antigorite seems to support the hypothesis of its potential toxicity, with consequent risk to human health.

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Mossman B.T. (2018). Mechanistic in vitro studies: What they have told us about carcinogenic properties of elongated mineral particles (EMPs). Toxicol. Appl. Pharm., 361, 62-67, https://doi.org/10.1016/j.taap.2018.07.018.

Approaching knowledge of naturally occurring asbestos in volcanic geological contexts of southern Italy

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Keywords: asbestos amphiboles, Mt. Etna, Sicily.

Naturally occurring asbestos (NOA) refers to the natural presence of asbestos minerals within geological formations such as rocks, sediments, or soils. Fibrous minerals, although not classified as asbestos, can also be hazardous to human health and have been reported in various rock formations. Human activities (e.g. quarrying, excavation for services, infrastructure, or agriculture) as well as natural phenomena (e.g. weathering, earthquakes and hurricanes), can disturb or expose these asbestos-containing fibres, releasing them into the environment and posing potential hazard to human health. In southern Italy, the volcanic products of Biancavilla (Etna, Sicily) mark the first known occurrence of amphibole asbestos in a volcanic environment (Burragato et al., 2005). Furthermore, mineralogical analysis of these minerals led to the identification of a new end-member of the calcic amphibole group of the edenite series, which was identified and approved as a fluoro-edenite by the CNMMN (IMA, code 2000-049) (Pinizzotto et al., 2018 and references therein). The site of Monte Calvario (Biancavilla, CT) was therefore declared a Geosite of Global Interest in 2015 due to its degree of scientific interest. The fluoro-edenite fibrous amphibole was reported to cause mesothelioma in the regional population of Biancavilla and its carcinogenic hazard to humans was definitively established by the International Agency for Research on Cancer Working Group (IARC, 2017) by means of well documented epidemiological, chemical, in vitro and in vivo studies.

The fluoroedenite crystals found in the altered benmoreal lavas of the Biancavilla area (Pinizzotto et al., 2018) are commonly associated with feldspars, quartz, clino- and orthopyroxene, F-Cl-apatite, ilmenite and hematite, and probably crystallised from high-temperature volcanic fluids (Burragato et al. 2005). These crystals can exhibit prismatic or acicular or fibrous habit (Burragato et al., 2005; Pinizzotto et al., 2018) and their mineralogical and crystallographic investigations show a general depletion of Ca and Mg content in the fibres compared to prismatic ones, and a similar F content in both occurrences, with high F and Na contents compared to those of tremolite and actinolite fibres (Burragato et al. 2005).

Therefore, a comprehensive petrographic, mineralogical, petrophysical, and geochemical characterisation of such minerals is essential not only to assess the environmental risks to the population living near the Biancavilla asbestos sites but also to establish the knowledge base for further research into the human health impacts of these minerals as well as for the development and implementation of remediation techniques.

With this aim, this contribution will report on a review of the state of the art of naturally occurring asbestos in the volcanic geological contexts of Etna and provide new insights into the fluoro-edenite of Biancavilla, showing the preliminary results of an extensive PhD research work.

Burragato F. et al. (2005) - Geo-volcanological, mineralogical and environmental aspects of quarry materials related to pleural neoplasm in the area of Biancavilla, Mount Etna (Eastern Sicily, Italy). Environ. Geol., 47, 855-868, https://doi.org/10.1007/s00254-004-1217-7.

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2017) - Some Nanomaterials and Some Fibres. 111, 215-242,

Pinizzotto M.R. et al. (2018) - Environmental monitoring of airborne fluoro-edenite fibrous amphibole in Biancavilla (Sicily, Italy): a nine-years survey. J. Mediterr. Earth Sci., 10, 89-95, https://doi.org/10.3304/JMES.2018.018.

Structural behaviour of graphene and silver functionalized graphene oxide loaded with perfluorinated compounds during thermal heating

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Keywords: GO, PFOA, PFOS.

Perfluorinated substances (PFAS) are environmental contaminants that are difficult to break down chemically, thermally, and biologically. Adsorption is the most effective and affordable way to remove PFAS from aquatic environments. Graphene oxide (GO) has gained popularity in water filtration because of its aqueous dispersibility, reactivity, high stability, flexibility, and low cost. Adsorption experiments, high performance liquid chromatography, in situ powder diffraction data, and thermal analysis were used in this study to evaluate PFAS removal and study the real-time evolution of graphene oxide (GO) before and after Ag functionalization, perfluorooctanoic acid (PFOA), and perfluorooctane sulfonate (PFOS) loading. Diffraction data revealed structural changes, and the interaction of PFOA and PFOS with GO interlayers caused a (001) peak shift to higher 2θ values, indicating their presence in the structure. At 150°C, functional groups were ejected, structural defects occurred, and the GO characteristic peak (001) shifted. At 350°C, the (001) reflection disappeared and the (002) peak intensity increased, suggesting that GO was converted to reduced graphene oxide (rGO). Silver loading in GO (AgGO) was confirmed by new reflections attributed to Ag nanoparticles and a decrease in d*hkl* values. The degradation of PFOA and PFOS molecules occurred between 375 and 400°C.

Thermogravimetric and High-Temperature X-ray Diffraction study on the desorption of humic monomers from Y zeolites

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Keywords: zeolite, HBA, HT-XRD.

The study examined the thermal behavior of p-hydroxybenzaldehyde (HBA) desorption from Y zeolites using both isothermal and non-isothermal methods, in order to obtain a detailed structural and kinetic interpretation of the process. Rietveld refinement of in situ powder XRD data and thermal analysis revealed that HBA thermal degradation occurred in the temperature range of about 250-480 °C. This process has a considerable impact on the framework's geometry, resulting in cooperative tilting of the tetrahedra and deformation of both the 6MRs and 12MR rings. For comparison, the HBA desorption experiment was also repeated in isothermal conditions at four different temperatures (200, 250, 350, and 400°C). There were no significant differences between isothermal and non-isothermal kinetic data. Overall, the results of both experimental conditions suggest that the cooperative tilting of tetrahedra and the deformation of rings play a crucial role in HBA desorption. The similar activation energies obtained from isothermal and non-isothermal kinetics further validate the accuracy of the experimental methods employed in this study. These findings provide valuable insights into the mechanisms involved in the desorption process of HBA.

Mobility of hazardous elements in ceramic bodies

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Keywords: porcelain stoneware, element mobility, immobilisation efficiency.

Waste recycling can potentially become a common practice for improving the environmental sustainability of the ceramic manufacturing process. However, the introduction of waste can considerably expand the compositional spectrum of raw materials with possible inclusion of hazardous components. Therefore, prior to the resorting of any secondary raw material, it is fundamental to assess the degree of inertization of hazardous elements (HEs) through the ceramization process. The aim of the present work is to quantitatively assess the mobility of various HEs (Ba, Co, Cr, Cu, Mo, Pb, Sb, Sn, Sr, V, Zn) introduced in silicate ceramics. For this purpose, four batches were formulated following the typical recipes to obtain: three largely vitrified ceramic products (i.e., two different porcelain stoneware bodies and a red stoneware) and a largely unreacted body (low fired brick). An artificial waste, with an aluminosilicate matrix containing all the HEs cited above, was added to all the batches in the amount of 10 wt.%. The eight batches were experimented at the laboratory scale, simulating the industrial tile-making process. After the characterization of the main technological properties of the fired products (water absorption and bulk density), they were subjected to leaching test (EN 12457-2:2002, to evaluate the HEs mobility), XRPD-Rietveld analyses for the quantitative phase composition, and SEM-EDS observation to determine the microstructure and the HEs diffusion. Obtained data indicated a different mobilization mechanism depending on both specific hazardous element and ceramic typology, with significant criticisms related to Mo, Cr and Sr, mostly in the largely unreacted body.

Mercury (Hg) pollution in riparian vegetation along the Paglia River in the Monte Amiata Hg mining district (Italy): implications for a sustainable environmental management and risks

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Keywords: mercury, riparian trees, biomass.

Riparian vegetation plays an important role in fluvial ecosystems. Catchment runoff in abandoned mine sites is often source of heavy metals in the environment through long distance transport of contaminated sediments, which are deposited in riverbanks. In those areas riparian vegetation limits the dispersion of sediments and associated contaminants through the stabilization of the riverbanks, and takes up contaminants from the soil, acting as a temporary storage of the metals.

In this study, the potential mercury (Hg) uptake from plants growing on soil anomalous in Hg was quantified to understand the risks associated to the use of riparian trees as biofuels or in case of fire. Riparian trees were sampled from the riverbanks along a section of the Paglia River (Tuscany, Italy), that drains the abandoned Monte Amiata Hg mining district, characterized by anomalous content of Hg (>1 mg/kg). The riparian vegetation is here occasionally cut during bank maintenance, and the resulting wood may end up into wood chips for solid biofuel.

Three cores of trunks were collected from each tree sampled in five sites along the Paglia River. Poplars (*Populus* spp.) are the most abundant specie naturally widespread along the Paglia riverbanks, together with *Robinia* spp. and *Quercus* spp. At each site, a soil sample was also collected.

In soils, Hg ranged from 3.5 to 52.8 mg/kg, above the limit for Italian soils (1 mg/kg; D. Lgs. 152/2006), consistent with previous studies defining the sampling area as a "Hg impacted corridor" (Fornasaro et al., 2022).

In trees, Hg ranged between 0.5 and 93 ng/g. Anomalous Hg concentrations (195-353 ng/g) in a few trees are probably associated to soil particles trapped in the tree barks. Most of trees presented Hg concentrations below 100 ng/g, which represent a recommended Hg limit for the quality of solid biofuels, according to the European EN ISO 17225 (2021). From a commercial point of view, Hg contents in trees should have little to moderate impact on the value of the locally harvested wood chips. On the other hand, in case of wildfires, Hg emission from burning trees in the studied area was estimated at about $1.4*10^{-3}$ kg Hg/ha, whereas from soils the emission reached 27 kg/ha, posing a risk to the surrounding environment (biota, human health and animals) and acting as a potential secondary source of Hg0 to the atmosphere.

Understanding the Hg content of the riparian vegetation allows to correctly evaluate its storage effectiveness, the mechanisms governing the Hg uptake by arboreal plants, as well as their potential as a secondary source of Hg to the atmosphere in case of fire, or upon anthropic utilization as biomass. In similar contaminated areas, investigation of metals fate and transport between soil and plants is important to assess the actual risks of emissions in case of fire or for providing remediation strategies for contaminated soils through phytoremediation strategies.

D. Lgs. n. 152 (2006) - Norme in materia ambientale. G.U. Serie Generale, 88(96), 13-424.

Fornasaro S. et al. (2022) - Total Mercury Mass Load from the Paglia-Tiber River System: The Contribution to Mediterranean Sea Hg Budget. Toxics, 10, 395, https://doi.org/10.3390/toxics10070395.

EN ISO 17225-1:2021 (2021) - Solid biofuels - Fuel specifications and classes - Part 1: General requirements.

Mineralogical and geochemical characterization of red muds from Portovesme (SW Sardinia, Italy)

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Keywords: red muds, XRD, TEM.

Red mud (RM) residues produced by Bayer process for alumina refining is a hazardous material which may be valorized as a source of secondary raw material with a potential for REE extraction (Pietrantonio et al., 2021). The mineralogic composition of RM depends on the mineral composition of the source material, i.e. bauxite and on the specific processing parameters of the Bayer cycle. In turn, bauxite is a complex ore that can contain up to one hundred mineral phases (Ostojić et al., 2014). In this study, ten RM samples supplied by the Eurallumina company (Portovesme, Sardinia, Italy) and randomly collected from three storage basins were investigated combining X-ray powder diffraction (XRPD), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Transmission Electron Microscopy (TEM).

XRPD results evidence that the common phases to all samples are hematite, gibbsite and boehmite, anatase, cancrinite, sodalite and quartz as also found in previous investigations (e.g. Snars & Gilkes, 2009; Castaldi et al., 2011 and references therein).

Oxide composition (wt.%) from ICP-MS analysis indicates significant amounts of Al_2O_3 (20.8) and Fe_2O_3 (25.8) as major components. Elements like Sc, V, As, Ni, Ga, Hf and Sr exhibit high variability whereas Co, light rare elements (LREE), heavy rare elements (HREE), Ta and W have low variability. Abundance of Ce (93 ÷ 258 ppm) is a notable feature of the analysed samples.

TEM investigation was carried out on the sample with the highest concentration of Ce. From a morphological viewpoint, the selected sample shows particles with variable morphology, with occurrence of lamellar or acicular crystals, mostly forming globular nano-aggregates. SAED patterns show peaks, corresponding to the main phases detected by XRD. Chemical mapping reveals an elemental distribution consistent with the main phases detected by XRD and SAED and suggests the occurrence of a second Ti-bearing (titanite) and a Ca-phosphate phase (apatite). At the present stage of investigation, there is no clear evidence of a Ce-bearing phase (i.e. Ce may be dispersed in small amount in several different minerals).

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Petrography, geochemistry and mineralogy of serpentinite rocks in the ophiolite units at the Calabria and Basilicata regions, Southern Apennine (Italy): state of the art and ongoing research

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Keywords: serpentinite, ophiolite, Southern Apennines.

This contribution summarizes results carried out over the last decade deriving from a multi-analytical and multidisciplinary study on serpentinites in the ophiolite units of Basilicata and Calabria regions, southern Italy, depicting the "state of the art" .

Indeed, due to their multifaceted importance, that spans from tectonic and petrological to economic and in terms sustainable development, there has been increasing interest in these serpentinites.

From the tectonic and petrological viewpoint, since serpentinite rocks testify the ocean-floor metamorphism that took place and transformed the original mineralogy and fabric of previous ultramafic rocks, their knowledge is a critical key-point for understanding the complex microplate tectonics of the central Mediterranean area.

From the economic point of view, it is worth noting that, due to their beauty and attractiveness, serpentinite rocks from southern Apennines have been exploited and marketed as heritage stones since prehistorical times worldwide. Therefore, their detailed knowledge may provide a useful tool to understand their behavior when they are employed as building materials, to predict their performances upon emplacement in monuments, and to plan correct restoration by considering the provenance of the lithotypes employed. Another important topic deals with environmental issues since it has been reported that serpentinites from Calabria and Basilicata may contain asbestiform and other fibrous minerals, as testified by the occurrence of chrysotile, tremolite, and actinolite asbestos located within the veins, which could lead to health problems due to asbestos fiber exposure. Finally, the contribution presents and discusses recent preliminary studies which highlighted as serpentinite may be considered as an important potential CO_2 sequestration sink and may thus influence global climate.

Sustainable development in traditional ceramic glazes: harnessing MMVF waste for environmental innovation

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Keywords: ceramic glaze, thermal inertization product of fibres, secondary raw material.

We have developed a ceramic glaze by utilizing the thermal inertization product of Man-Made Vitreous Fibres (MMVF) as a secondary raw material. The MMVF used in this project are derived from rock wool, primarily composed of silicon with varying amounts of alkalis, aluminum, and iron. Despite their widespread use in sectors such as construction due to their exceptional properties like high chemical and physical stability, MMVFs, being fibrous materials, pose potential carcinogenic risks.

Zetadi S.r.l. has patented a thermal inertization process for these fibres, subjecting them to a prolonged thermal cycle with a maximum temperature of 1350°C, resulting in the transformation of MMVFs into an inert product termed "ReWo" (Recycled Wool).

In recent years, the ceramic industry has increasingly emphasized resource optimization and waste recycling, aligning with the principles of a circular economy. Utilizing "extramuros" waste like "ReWo" has become essential. This waste, entirely amorphous, exhibits excellent fusibility at high temperatures, making it an ideal melting component in ceramic products.

We conducted experiments with various ceramic glaze formulations, incorporating 40% to 50% "ReWo" along with other secondary raw materials, such as boric glass from laboratory glassware. The most promising formulation comprises 44% "ReWo" and 10% hematite, resulting in a lustrous, burgundy ceramic glaze. Additionally, the glaze exhibits high resistance to acid/base attacks, and leaching tests indicate negligible release of hazardous elements. These findings underscore the suitability of "ReWo" as a valuable secondary raw material for traditional ceramic glaze manufacturing.

S20.

High-resolution chemical and textural imaging techniques as analytical tools in Earth Sciences

CONVENERS & CHAIRPERSONS

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From Earth's mantle to Cosmo: case studies by imaging techniques

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Keywords: volumetric information, spatial distribution, genetic implications.

In recent years, the investigation of minerals by imaging methods provides an accurate and high-resolution textural representations and distributions of chemical elements (chemical zoning), presence and distribution of point defects as impurities and OH and extended defects as domains, twins, inclusions etc…. These methods often can be used in non-destructive way on samples, offering a possibility to map minerals with no loss of precious material and its valuable information and guaranteeing the reproducibility of analyses.

Comparisons among maps obtained with different techniques can be particularly valuable to fully characterize rare and precious minerals, very important to obtain important genetic implications. As an example, information about the ambient mantle have been acquired applying different imaging techniques to diamonds and their inclusions. X-ray topographic images, obtained by a diffractometric technique sensitive of deformation field associated to extended structural defects, were combined with μ-FTIR maps and optical images to study plastic deformation on super deep diamonds from Juina (Brazil) (Agrosì et al., 2017). The combined use of these methods shows a good fit between the mapping of spatial distribution of extended defects observed on the topographic images and the μ-FTIR maps corresponding to the concentration of N and H point defects. A further example of the validity of this methodological approach regards a study of multiphase inclusions entrapped within a diamond from Juina (Brazil), using a combination of imaging non-destructive methods: μ-CT was used to investigate the size, shape, distribution and X-ray absorption of inclusions, mapping by μ-XRF, μ-Raman Spectroscopy and μ-FTIR were used to determine the chemical and mineralogical composition of the inclusions. This study allowed the first finding of maohokite and huntite in diamond and provided evidence of formation of ferropericlase–magnesiowüstite and diamond in a carbonate-rich environment at depths corresponding to the Mantle Transition Zone (Agrosì et al., 2019).

The powerful role of imaging techniques has been also successively applied to the study of meteorites. Investigations carried out using a 3D reconstruction obtained by μ-CT supported by chemo-mineralogical characterization obtained by SEM-EDS, allowed to obtain volumetric information about spatial distribution of different mineralogical phases, internal structures, grain features, volume percentage and shape of voids, adding new elements about the origin of porosity in Al Haggounia 001 meteorite (Manzari et al., 2023). Lastly, preliminary non-destructive analyses by μ-CT and SEM-EDS of micro-spherule FB-A1 from Monte Gariglione (Italy), revealed the presence and volumetric distribution of exotic Al-Cu alloys disseminated in a porous matrix of silicate glass containing olivine, Fe-Ni droplets and oxides, allowing the second finding of natural quasicrystals (Agrosì et al., 2024).

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Heterogeneity of N distribution into diamond single crystal: a closer look into the role of inclusions in the distribution of N aggregation state

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Keywords: diamond, FTIR, nitrogen.

Mineral inclusions in natural diamonds represent entrapped portions of the Earth's mantle acting as witness of its composition and geochemistry. This makes diamonds a unique window on the processes in the Earth's mantle through time. It is well known that N represents the most common impurity in diamonds and its distribution into crystal defects is strongly controlled by temperature conditions (Taylor et al., 1990; Speich & Kohn, 2020). Upon increasing temperature, single nitrogen (C centers) progressively tends to aggregate into clusters of atoms and vacancies (A and B centers) (Goss et al., 2004). Fourier Transform InfraRed (FTIR) spectroscopy is the most valuable method to estimate the aggregation state of N and retrieve the temperature conditions in which the diamonds grew. This study aims to assess the possible involvement of diamonds mineral inclusions in the growth of the defects due to the N incorporation. For this purpose, four lithospheric octahedrally-shaped diamonds from the Siberian craton having silicate and sulfide inclusions of eclogitic origin have been investigated. The diamonds have been studied through high resolution FTIR mapping (2-4 cm^{-1}) at Diamond Light Source-Beamline B22 (UK). Preliminary analyses show the predominance of B centers as the main N defect, which leads to classify diamonds as 'Iab' type. Maps collected at the diamond-inclusions interface reveal a preferential N concentration near the inclusion with a marked abundance of A centers close to the interface. This scenario opens the possibility of a determining role by silicate and sulfide inclusions during the diamond growth stage because of their direct involvement in the distribution of N defects inside the crystal structure. Further single-crystal X-ray diffraction analysis together with Raman spectroscopy, could help to better determine the nature of inclusion (syngenetic-protogenetic-epigenetic) and contextualize the N defect distribution found around our suite of inclusions.

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Micro-Raman mapping of the oxidation state of Mn in deep-ocean polymetallic deposits

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Keywords: Raman Spectroscopy, manganese, marine polymetallic deposits.

Marine ferromanganese deposits (crusts and nodules) are important strategic reservoirs for rare and critical elements (e.g., Co, Mn, Li, Pt, Zr, Nb, Te, Ni, V, Bi, Mo, W, and REY) that are essential to high-technology and green-energy applications (Hein et al., 2013). Their occurrence, mineralogy, and chemical composition reflect the processes of formation and the genetic depositional environment (e.g., water redox chemistry and biological activity). In these deposits, Mn may occur under different oxidation states (Mn^{2+}, Mn^{3+}, and Mn^{4+}) depending on the (bio)geochemical conditions existing during mineral growth. Marine ferromanganese crusts and nodules are thus precious archives of regional and global oceanic and climatic conditions. However, these deposits occur typically as cryptocrystalline and fine–grained mixtures of different Fe-Mn oxides and their characterization is extremely challenging by standard X-ray diffraction.

Raman spectroscopy provides a valuable tool for characterizing Fe-Mn oxide mixtures (Bernardini et al., 2019), being sensitive to short-range cation-anion arrangements. Moreover, the laser spot on the sample can be reduced to ~1 μm^2 allowing for high spatial resolution chemical analysis (Bernardini et al., 2021; 2023). Beside the identification of the mineral, Raman spectroscopy provides a quick and reliable determination of the oxidation state of Mn down to the microscale (Bernardini et al., 2021), which is unachievable in a fine scale by other techniques (e.g., XANES and XPS).

Here we show that the intensity ratio between some peculiar bands in the Raman spectrum can be used to map the microscale spatial distribution of the oxidation state of Mn in deep-ocean ferromanganese deposits. Thanks to its imaging capabilities, Raman spectroscopy may be used as an innovative tool opening a new way for the use of these widespread geomaterials for environmental (redox) reconstructions of past marine environments.

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Bernardini et al. (2021) - A reliable method for determining the oxidation state of manganese at the microscale in Mn oxides via Raman spectroscopy. Geostand. Geoanal. Res., 45, 223-244, https://doi.org/10.1111/ggr.12361.

Bernardini et al. (2023) - Micro-Raman mapping of critical metals (Li, Co, Ni) in a rhythmically laminated deep-ocean ferromanganese deposit. Geochemistry, 126014, https://doi.org/10.1016/j.chemer.2023.126014.

Hein et al. (2013) - Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: comparison with land-based resources. Ore Geol. Rev., 51, 1-14, https://doi.org/10.1016/j.oregeorev.2012.12.001.

Transmission electron microscopy in Earth Sciences: conventional and advanced applications

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Keywords: Conventional TEM, high resolution TEM, time-resolved TEM.

Transmission electron microscopy (TEM) is the reference technique for investigations of solid materials below the micrometre scale. It is widely used in Material Sciences, Life Sciences and Earth Sciences. The success of TEM relay on the fact that with a single instrument, during the same session, one can get information of the morphology, crystallography end chemical composition of the sample with a nanometre resolution. With modern, properly equipped instruments, a sub-angstrom resolution can be achieved, crystal structures can be determined, and temporary state of the matter photographed. In this presentation, common TEM operation modes, such as diffraction contrast imaging (bright field and dark field), high resolution imaging (HREM), selected area diffraction (SAED) and will be briefly describes, as well as recently developed techniques, such as electron diffraction tomography (EDT) and time-resolved TEM (Fast-TEM).

2D image analysis of mortars: amount of cement paste and texture of the aggregates

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Keywords: texture, image analysis, mortar.

The texture of phases in rocks has been quantified by image analysis on polished mesoscopic slabs and/or thin sections to visualise phases, voids and particles. 2D sections are digitalised at variable magnifications using a high-resolution scanner (HRS), transmission optical microscopy (TOM) and scanning electron microscopy (SEM) (Higgins, 2006). However, similar investigations are rare for construction materials (Abbas et al., 2009; Han et al., 2016). In fact, measurements of the abundance of different fractions (cementitious paste vs. aggregates or pores) and the types and textures of the aggregate clasts are lacking. Here, the authors explore the quantification of textural attributes on 16×4×4 cm^3 standard mortars, prepared with 1:2:4 weight fractions of water:cement:aggregate, respectively. As determined by XRPD (X-ray powder diffraction), these aggregates are mainly composed of quartz (qz), plus minor amounts of alkali-feldspar (af) and sheet silicates (ss); their sieved grain-size distribution (ϕ vs. wt.%) is 0.2, 10, 33.3, 29.5, 19 and 8 wt.% for ≤ 0.125, 0.125-0.25, 0.25-0.5, 0.5-1, 1-2 and 2-4 mm (Fuller curve), respectively (Galderisi et al., 2023). A 4×4 cm^2 polished thin section was prepared and imaged with three methods at variable magnifications: i) 1:1 by HRS, ii) 25:1 by TOM (plane polarised light) and iii) 100:1 by SEM (back-scattered mode). The unique HRS image of 14 cm^2 was directly analysed, whereas 18 for TOM and 208 for SEM adjacent (partly overlapped) microphotographs were used to prepare two stitched images. Qz is 32.6 area%, manually separated pores are 0.2 area% and cement+af+ss is 67.3 area% via HRS; instead, cement, pores (manually separated) and qz+af+ss (aggregate) are 54.3, 1.0 and 44.7 area% via TOM. The SEM image quantifies cement, pores, qz and af+ss as 41.8, 1.7, 45.1 and 11.4 area%, respectively. The SEM outcomes corroborate the XRPD measurements, while the HRS result is unable to, and the TOM outcome only roughly evaluates the actual cement and aggregate fractions. The 2D measurements of aggregate clasts by TOM and SEM were used to construct 2D Fuller curves using the sieving thresholds (Fuller curve). Several 2D size distributions were built considering the long, mean and short dimensions of the axis of equal-area ellipse, object diameters, bounding box sides, object sizes, Feret diameters and diameter of equal-area circle per aggregate clast. Several of these 2D curves for TOM and SEM will approximate the 3D Fuller curve obtained by sieving. Overall, HRS is rapid, but its measurements are mainly qualitative and only for particular transparent objects (here for qz and voids). Compared to SEM, TOM overestimates cement (41.8 vs. 54.3 area%) and underestimates aggregates (45.1+11.4 vs. 44.7 area%), but pores are similar (1.7 vs. 1.0 area%). Hence, SEM shows the best discrimination capacity of the types and textures of aggregates, besides the cement: aggregate ratio, but it is time-consuming.

Abbas A. et al. (2009) - Quantification of the residual mortar content in recycled concrete aggregates by image analysis. Mater. Charact., 60(7), 716-728, https://doi.org/10.1016/j.matchar.2009.01.010.

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Han J. et al. (2016) - 2D image analysis method for evaluating coarse aggregate characteristic and distribution in concrete. Constr. Build. Materi., 127, 30-42, https://doi.org/10.1016/J.CONBUILDMAT.2016.09.120.

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Micro-chemical and micro-structural studies of minerals and clues on the associated geological processes

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Keywords: transmission electron microscopy, scanning electron microscopy, energy dispersive spectrometry.

In recent years advancements in imaging and analytical techniques have enabled the acquisition of chemical and structural information from geo-relevant materials with an extraordinary space resolution. This has facilitated new interpretation and the gathering of information that, just a few decades ago, would have been unattainable. In this work we demonstrate the application of chemical and imaging techniques, utilizing scanning (SEM) and transmission (TEM) electron microscopy coupled with energy dispersive spectrometry (EDS), for the characterization of various minerals and their associated geological processes. Specifically, we investigate peridotite and its alteration, as well as polysomatic and polytypic disorder in CaREE-fluorcarbonates.

A serpentinized peridotite from the Monteferrato ophiolitic body has been studied using SEM- and TEM-EDS. Chemical analysis, conducted with the Aztec AutoPhaseMap and QuantMap software (Oxford Instruments), revealed that the serpentinization was a complex hydration process that converted the original mantle peridotite into a polyphase serpentinite. Indeed, geometric relationships among different serpentine domains indicate at least eight serpentinization events, each characterized by lizardites with varying Al and Fe contents. These different generations of lizardite are likely correlated with tectonic events, particularly in the more massive portions of the serpentinized ultramafics where brittle rheological behavior facilitated the ingress of aqueous fluids through fractures, subsequently filled and healed by new generations of lizardite.

The characterization of species and crystal-structural modularity in mixed-layer minerals, such as CaREE-fluorcarbonates, and the significance of short-range stacking disorder and long-range polysomes, offer valuable insights for interpreting the genesis of these minerals. High-resolution electron microscopy (HRTEM) is essential for elucidating the polysomatic and polytypic disorder comprehensively, since the contrast is sensitive to the different stacking of CO_3 layers that appears with different slants in HR, revealing the actual crystal system symmetry and any polytypic disorder (Capitani, 2019). Understanding polysomatism and polytypism is critical, as intergrowths of different polysomes may indicate changes in crystallization conditions or fluid composition (Gysi & Williams-Jones, 2015), and chemical transport involved in polysomatic reactions may govern reaction kinetics (Veblen, 1991). This becomes particularly important when the investigated minerals are primary ores for critical elements such as CaREE-fluorcarbonates.

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Veblen D.R. (1991) - Polysomatism and polysomatic series: A review and applications. Am. Mineral., 76, 801-826.

Imaging techniques as analytical tools in Earth Sciences

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Keywords: imaging techniques, spectroscopy, microscopy.

Improving the visualization of objects and their characteristics has always been a topic of interest in all scientific disciplines, particularly in Geology where the description of morphological, as well as chemical, mineralogical and physical features of samples is mandatory. For this reason, the study of minerals and rocks as a Science probably starts with the advent of the polarizing microscope (attributed to David Brewster in 1815), while a second major step coincides with the development of scanning electron microscopy (SEM, a technique fully developed in the second half of the XX century) and later of transmission electron microscopy (TEM). It is during the last 15-20 years, however, that imaging tools, mostly based on spectroscopic techniques have significantly accelerated our possibility to access with an unprecedented resolution and completeness of information all types of (solid) geological samples: rocks, minerals and fossils. The availability of fast computational procedures nowadays allows creating any kind of 2D and 3D images from arrays of analytical points thus providing in short time accurate and high-resolution distributions of chemical elements spanning the whole periodic table (including light elements), trace to ultra-trace constituents, isotopes, oxidation states, porosities etc. Very recently, the laboratory availability of 3D techniques like X-ray tomography, traditionally restricted to large-scale facilities (synchrotrons) has provided a significant impetus to the spatial analysis of rocks for applications ranging from structural Geology to ore Mineralogy, Cultural Heritage, Biomineralogy, etc..

In this opening short communication for this session we will discuss the evolution of the imaging methods, particularly during the last century, from the development of methods based on optics, to those based on the use of X-rays to those based on spectroscopies using lower-energy beams. The different talks presented during this session will show how these techniques may help in solving issues at different scale in Earth Sciences.

Color changes in topaz treated via irradiation and heat

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Keywords: gems, topaz Irradiation, treatment.

Natural topaz is commonly colorless, therefore various treatments (via irradiation and/or heat) are used to enhance its hue and/or clarity, from colorless to blue, the latter being the much-appreciated in jewelry. In this research we carried out a complete spectroscopic characterization of the effects induced by irradiation and subsequent heat treatment on a series of topaz crystals. The studied samples come from primary deposits of Hematita and Ouro Preto (Brazil), from the pegmatites of Alto Ligonha (Mozambique) and from secondary deposits of Tunduru (Tanzania) and Ilakaka (Madagascar). The original color of the crystals was different: some of them were colorless, some showed a natural blue color and one a brownish orange coloration.

The crystals were treated by using two different techniques: accelerated electrons and an innovative X-ray irradiation technique. All samples were characterized before and after the treatments by using spectroscopic techniques including UV-VIS, μ-RAMAN, EPR and FTIR. The samples were also chemically analyzed by SEM-EDS and μLIBS spectroscopy to evaluate the contribution of possible chemical variations to the color changes while modification in the OH vs O2- contents were studied via IR and Raman spectroscopies. In particular, the UV-VIS techniques were used to monitor the changes occurred during the treatment and address the mechanisms that trigger the new color in the crystals. All treated samples displayed a similar broad absorption centered at 620 nm, indicating the onset of the blue color during treatment. Another extremely interesting feature is the red-shift of the UV absorption thresholds in the treated samples that can be related to the changes from OH to O-; this feature was detected via analysis of UV-VIS spectra through variations of the FWHM of peaks in the UV range, by comparing the spectra collected on natural blue and treated blue samples. UV-VIS spectroscopy thus proved to be an extremely useful technique to ascertain whether samples have undergone irradiation treatment. The other spectroscopic techniques used, RAMAN, FTIR and EPR were found to be useful for establishing which defects are caused by the irradiation treatment and which trigger the blue color in topaz samples. The results of our work finally provide the minimum dose (3.6x107 Gy) to use by a LINAC (5 MeV) and the minimum temperature (230°C for 30 min) to induce the color changes in topaz.

SPM of layer silicates and interaction with single biomolecules at the nano-atomic scale

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Keywords: layer silicates, mineral - single biomolecule interaction, scanning probe microscopy.

Physical and chemical properties of minerals and materials surfaces can be effectively studied and even modified at the nano-atomic scale by using Scanning Probe Microscopy (SPM) methodologies. In fact, nowadays, advancements of SPM have made available a wide range of surface investigations at the nanoscale, such as for instance Atomic Force, Electric Force Microscopy, Kelvin Probe Force Microscopy, Magnetic Force Microscopy and very recently nanospectroscopic methodologies (Kurouski et al., 2020). SPM surface investigations include morphological, rheological, mechanical, electrical and magnetic properties of the surface, and the interaction with biomolecules at the single - molecule level (Moro et al., 2016). In the present work, we employed SPM to simultaneously investigate both the surface nanotopography and surface potential of important layer silicates, and in particular cleaved clinochlore samples. The same surfaces where also studied after interaction with fundamental biomolecules, such as nucleotides, DNA, RNA, amino acids, oligopeptides, red blood cells. The findings of this research allowed us to design and create mineral surfaces with specific physico-chemical properties controlled at the nanoscale, that were also used to drive the condensation, deposition and alignment of biomolecules, and stretching of DNA chains. The SPM observations were conducted at RT (~20°C), atmospheric pressure and relative humidity of about 40%. Clinochlore surface presents atomic flat terraces (~0.2 Å rms), extended from several micrometers to few nanometers, with a typical in-depth separation of ~4 Å (the thickness of the brucite-like interlayer sheet). The electrostatic surface potential difference varies between 100 mV and 500 mV, depending on the local crystal chemistry and environmental conditions. The surface is able to condense, organize, and agglomerate biomolecules at the nanoscale onto specific regions, with possible important catalytic repercussion mediated by surface charge and crystal-chemistry. The mineral - amino acids interaction process was also investigated by quantum mechanics simulations at the DFT/B3LYP level of theory, providing the conformation of the molecule on the surface, the intermolecular bonding scheme and the Brønsted-Lowry basic/acid strength related to Al^{3+}/Mg^{2+} substitutions in the brucite-like sheet and to Al^{3+}/Si^{4+} in the TOT (Moro et al., 2019; 2020). These methodological approaches and results give a contribute to the advancement of knowledge on layer silicates surface properties at the nano - atomic scale, and biomolecules - minerals interaction at a single - molecule level. They are of interest in a wide variety of basic and applied research fields, including mineralogy, environment, biology, medicine and nanotechnology.

Kurouski D. et al. (2020) - Infrared and Raman chemical imaging and spectroscopy at the nanoscale. Chem. Soc. Rev., 49, 3315-3347, https://doi.org/10.1039/C8CS00916C.

Moro D. et al. (2016) - Nanoscale cross-correlated AFM, Kelvin probe, elastic modulus and quantum mechanics investigation of clay mineral surfaces: the case of chlorite. Appl. Clay Sci., 131, 175-181, http://dx.doi.org/10.1016/j.clay.2015.11.023.

Moro D. et al. (2019) - Amino acids-clay interaction at the nano-atomic scale: The L -alanine-chlorite system. Appl. Clay Sci., 172, 28-39, https://doi.org/10.1016/j.clay.2019.02.013.

Moro D. et al. (2020) - Nanoscale oligopeptide adsorption behaviour on chlorite as revealed by scanning probe microscopy and density functional simulations. Appl. Clay Sci., 197, 105777, https://doi.org/10.1016/j.clay.2020.105777.

Atomic force, Kelvin probe, electric force microscopy and nanolithography of clinochlore

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Keywords: clinochlore, AFM, KPFM.

Spatially resolved techniques are of paramount importance to characterize the local topographical, chemical and physical properties of mineral surfaces, which in turn can determine their overall reactivity to the surrounding environment. In this regard, scanning probe microscopy (SPM) comprises a family of advanced techniques that allows the 3D measurements of surface topography and properties at the nano-atomic scale, such as electrical, magnetic, rheological, thermal and electrochemical ones. Furthermore, SPM-based nanolithography employs SPM tip-to-sample interactions for nano-atomic scale surface modifications (Bian et al., 2021).

In this work, we present atomic force, Kelvin probe, electric force microscopy and nanolithography of clinochlore surface. Kelvin probe force microscopy and electric force microscopy (EFM) techniques have been used for detailed 3D surface nano-characterization of the electrical properties. Furthermore, natural and synthetic 3D meso-nanostructures of clinochlore were investigated and produced by scanning probe microscopy related nanolithography methods (Moro et al., 2016; 2019).

The measurement were conducted at RT (~22°C), atmospheric pressure and relative humidity of about 40%. A Nanonis (SPECS Zurich, Switzerland) SPM Controller with two oscillators connected to a MultiMode head (Digital Instruments, Santa Barbara, California) was used. In static-mode EFM, specifically FIB-machined Si3N4 gold-coated tips (k ~0.06 N/m) were used and the probe-deflection vs. tip-surface voltage difference was calibrated by using a cleaved graphite standard. In dynamic-mode, NCHPt NanoWorId (Switzerland) Pt/Ir-coated silicon tips (k ~2.8 N/m, working frequency ~70 kHz) were employed. After cleavage, SPM revealed a meso-nanostructured heterogeneous clinochlore surface in terms of morphology, hydrophilic/phobic character and surface potential, related to the mixed sub-nm thick layer stacking structure of the mineral. Successful removal of sub-nm thick structural layers at the nanometric scale was also achieved.

Bian K. et al. (2021) - Scanning Probe Microscopy. Nat. Rev. Methods Primers, 1, 36, https://doi.org/10.1038/s43586-021-00033-2.

Moro D. et al. (2016) - Nanoscale cross-correlated AFM, Kelvin probe, elastic modulus and quantum mechanics investigation of clay mineral surfaces: the case of chlorite. Appl. Clay Sci., 131, 175-181, http://dx.doi.org/10.1016/j.clay.2015.11.023.

Moro D. et al. (2019) - 3D meso-nanostructures in cleaved and nanolithographed Mg-Al-hydroxysilicate (clinochlore): Topology, crystal-chemistry, and surface properties. Appl. Clay Sci., 169, 74-80, https://doi.org/10.1016/j.clay.2018.12.020.

Unveiling the acoustic-morphological features of fish otolith structures by multiscale imaging investigations

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Keywords: biomineralogy, imaging techniques, fish otolith.

Biomineralization serves as a crucial link between soft organic tissues, reflective of atmospheric and oceanic compositions, and the solid materials of the Earth, highlighting the intricate interplay between biology and the environment (Palazzo, 2022). In this framework, fish otolith structures, acting as invaluable repositories of information, offer insights into fish adaptation, behaviour, and relationship to environmental conditions (Popper et al., 2019; Hüssy et al., 2021).

The present multidisciplinary and multiscale approach deepens the previous research on *Merluccius merluccius* otolith structures as "information recorders". By employing scanning electron microscopy and high-resolution micro-CT techniques, we delve into the 3D morphology and ultra-morphology of otoliths, elucidating their differences during ontogenesis and between genders (Palazzo et al., 2022). Specifically, we characterize the "sulcus acusticus" and its sub-regions in undifferentiated, female, and male *Merluccius merluccius* otoliths, uncovering new and characteristic features with potential adaptive and functional roles in sound perception.

Our research aims to explore the acoustical implications of otolith variability and establish shape-structure-function relationships during fish ontogenesis and between genders. The present research contributes to the understanding of the otolith features related to fish hearing capabilities and behaviour, improving the state-of-the-art knowledge in this field.

Hüssy K. et al. (2021) - Trace Element Patterns in Otoliths: The Role of Biomineralization. Rev. Fish. Sci. Aquac., 29, 445-477, https://doi.org/10.1080/23308249.2020.1760204.

Palazzo Q. (2022) - Multiscale comparative analysis of marine biominerals and their ecological implications. [Dissertation thesis], Alma Mater Studiorum Università di Bologna. Dottorato di ricerca in Tecnologie innovative e uso sostenibile delle risorse di pesca e biologiche del mediterraneo (fishmed-phd), http://amsdottorato.unibo.it/id/eprint/10416.

Palazzo Q. et al. (2022) - Multi-scale analysis on otolith shape reveals differences in ontogenesis and sex in the European hake *Merluccius merluccius* in the western Adriatic Sea. R. Soc. Open Sci., 9211943, http://doi.org/10.1098/rsos.211943.

Popper A.N. et al. (2019) - Examining the hearing abilities of fishes. J. Acoust. Soc. Am., 146, 948-955, https://doi.org/10.1121/1.5120185.

Micro and macro mapping and imaging analyses for the identification of mineral pigments on paintings by using Fourier-transform infrared (FTIR) and energy dispersive X-ray spectroscopies

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Keywords: mineral pigments, micro mapping and imaging analyses, macro mapping and imaging analyses.

The study of the materials used in paintings requires micro-invasive or non-invasive approaches to reduce the damage and to conserve the integrity of the artwork. Since the mineralogical composition of pigments used in paintings are complex and not homogeneous, mapping and imaging techniques are preferred for their capability to map the elemental and molecular distributions.

One of the most useful micro-invasive approaches involves the study of stratigraphic sections using micro-Fourier-Transform InfrarRed (FTIR) spectroscopic imaging and mapping combined with scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) mapping. These two techniques can identify the molecular and elemental compositions of materials, respectively, including mineral pigments (Pronti et al., 2020), and well recognize the structure and mixtures of pictorial layers but small fragments (less than 1 mm) must be taken from the artworks.

The development of portable devices has allowed us to analyze paintings directly in situ, in a non-invasive way, with the advantage of not moving the artworks and avoiding any sampling.

A macro-FTIR scanner, in reflection mode (MA-rFTIR), permits to acquire distribution maps of minerals obtaining the chemical images of the investigated surfaces (Legrand et al., 2014; Pronti et al., 2024), particularly on wall paintings and not-varnished paintings. Through the combination with macro-X-ray fluorescence (MA-XRF), elemental maps are integrated into the molecular ones enabling a more comprehensive identification of the mineralogical composition of paintings.

In this presentation, the analyses of the mineral pigments used in Roman wall paintings and in ancient and modern easel paintings will be discussed using both micro and macro mapping and imaging approaches.

Legrand S. et al. (2014) - Macroscopic Fourier Transform Infrared Scanning in Reflection Mode (MA-RFTIR), a New Tool for Chemical Imaging of Cultural Heritage Artefacts in the Mid-Infrared Range. Analyst, 139(10), 2489-2498.

Pronti L. et al. (2020) - Advanced Methods for the Analysis of Roman Wall Paintings: Elemental and Molecular Detection by Means of Synchrotron FT-IR and SEM Micro-Imaging Spectroscopy. Rend. Lincei. Scienze Fis. Nat., 31, 485-493, https://link.springer.com/article/10.1007/s12210-020-00888-9.

Pronti L. et al. (2024) - Using MA-RFTIR Mapping as a Tool to Assess the Efficacy of Cleaning Treatments and to Aid in the Restoration Activities of Paintings. Coatings, 14(4), 511, https://www.mdpi.com/2079-6412/14/4/511/htm.

Theoretical and experimental study of structural, vibrational, and electronic properties of dolomite

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Keywords: dolomite, crystal chemistry and physics, DFT.

Dolomite $CaMg(CO_3)_2$ is an important mineral in a geological and environmental perspective. It has been thoroughly studying for its ubiquitous presence in sedimentary rocks as being part of the Earth's carbon cycle therefore, making it an important object of study to understand climate change (Liu et al., 2024). In this work we used novel multimethodology approaches, mainly theoretical, but also some experimental, to strengthen the knowledge of the minero-physical properties of dolomite. As mentioned, the study aims mainly to theoretically simulate the structural, vibrational and electronic properties of dolomite, and compare them to experimental data. The experimental knowledge was obtained from both existing updated literature and instrumental measurements performed in our laboratory on natural samples of dolomite taken from Traversella, Turin (Italy). The identification of dolomite in the samples and assessment of possible contaminations or presence of other minerals was performed by X-ray diffraction analysis (XRD), Environmental scanning electron microscopy coupled with energy dispersive spectroscopy (ESEM-EDS) at low vacuum, without requiring sample metallization, and vibrational analysis through FTIR (Fourier transformed infrared) and Raman spectroscopies. Ab initio simulations within the density functional theory (DFT) framework were performed with the CRYSTAL17 code. The effect of the Hamiltonian, chosen among 11 different functionals of the Jacob's ladder (Local density approximation - LDA, generalized gradient approximation - GGA, meta-GGA, global and range-separated hybrids) was assessed. In addition, D3 dispersive correction factor was applied when conceivable. Structure, vibrational and electronic properties of dolomite were investigated at 0K, typical settings of ab initio simulations (Valenzano et al., 2007). Vibrational frequencies were computed at the Γ point in the first Brillouin zone, and the LO-TO splitting was calculated. Overall, the cross-correlation between the experimental and theoretical data showed consistent results from the micro- and nano-scale down to atomic scale. The crystal structure of the mineral calculated using the different DFT functionals was in line with that obtained by XRD analysis. All the simulated IR and Raman spectra exhibited blue shifted bands, with the tendency of more blue-shifted bands in LDA whereas red-shifted in GGA. Finally, the calculated electronic properties, i.e. band structures and density of states (DOS), showed a band gap of ~5.0 eV, in good agreement with previously reported data (Hossain et al., 2011; Wang et al., 2021).

Hossain F.M. et al. (2011) - First-principles study of the electronic, optical and bonding properties in dolomite. Comp. Mater. Sci., 50, 1037-1042. https://doi.org/10.1016/j.commatsci.2010.10.044.

Liu D. et al. (2024) - Microbially-mediated formation of Ca-Fe carbonates during dissimilatory ferrihydrite reduction: Implications for the origin of sedimentary ankerite. Sci. China Earth Sci., 67, 208-221, https://doi.org/10.1007/s11430-022-1164-2.

Valenzano L. et al. (2007) - Ab initio vibrational spectra and dielectric properties of carbonates: Magnesite, calcite and dolomite. Z. Phys. Chem., 220, 893-912, https://doi.org/10.1524/zpch.2006.220.7.893.

Wang J. et al. (2021) - The electronic and optical properties of Au decorated($10\bar{1}4$) dolomite surface: A first principles calculations. Results Phys., 21, 103827, https://doi.org/10.1016/j.rinp.2021.103827.

Study of color zoning in tourmalines from different localities before and after treatments using chemical analysis and high-resolution images

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Keywords: tourmaline, chemical zoning, treatments.

Tourmalines are complex borosilicate belonging to the cyclosilicates class characterized by high chemical and structural complexity that making them a fascinating subject for mineralogical and petrogenetic studies. Tourmalines complexity contributes to its diverse physical properties and remarkable chromatic diversity, ranging from colorless to various shades of red, pink, blue, black, yellow, and green or multicolored zonation (Pezzotta & Laurs, 2011; Rizzo et al., 2023). Thermal treatment and irradiation are frequently applied in the market to improve their optical clarity and/or intensify the original color. This study examines five tourmaline samples from different pegmatite provinces, employing a comprehensive analytical method to investigate the causes of color change before and after electron beam irradiation and consequently thermal treatment. The preliminary chemical composition of tourmalines for the identification of main chromophores was obtained performing analysis point using scanning electron microscopy (SEM-EDS) and after detailed traverses across the samples with electron microprobe analysis (EMPA). These data were integrated also processing high-resolution images using SEM- back scattered electron (SEM-BSE) and variable pressure scanning electron microscopy (VPSEM) to obtain cathodoluminescence effects to study in detail the zoned samples. The samples were subsequently irradiated with doses equivalent to $5.1x10^4$ Gray and heated with values ranging from 450°C to 600°C producing a significant color change, respectively an intensification of color following irradiation and brighter colors after thermal treatment. Post treatments SEM-BSE and VPSEM images acquired on the zoned areas previously analyzed, showing no differences comparing to the image of the pristine samples. This indicated that no solid-state diffusion occurred as a result of the treatments.

Pezzotta F. & Laurs B.M. (2011) - Tourmaline: The kaleidoscopic gemstone. Elements, 7(5), 333-338, https://doi.org/10.2113/gselements.7.5.333.

Rizzo F. et al. (2023) - Compositional Variation and Crystal-Chemical Characterization of a Watermelon Variety of Tourmaline from Anjanabonoina, Central Madagascar. Crystals, 13(8), 1290, https://doi.org/10.3390/cryst13081290.

SINBAD-IR beamline at DAFNE-Light: application and developments of FT-IR spectroscopy in the field of Earth Sciences

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Keywords: FT-IR spectroscopy, chemical imaging, material science.

The SINBAD-IR is the Synchrotron Radiation beamline based on Fourier transform infrared spectroscopy at DAFNE-Light laboratory of INFN-National Laboratories of Frascati (Balerna, 2021). The beamline is specialized into micro imaging and spectroscopy in different research fields, including material science, earth science, biology/radiobiology, cultural heritage, and geophysics. In the field of geology, mineralogy and astrophysics, FT-IR spectroscopy is a widely used technique providing detailed information on the chemical composition and crystalline structure of the materials constituting rocks, minerals, crystal, and planetary bodies. Both inorganic and organic compounds, along with fluid/volatile substances contained within the crystalline lattice, can be detected (Conte et al., 2022; Della Ventura et al., 2024). By using an IR microscope coupled with an imaging detector it is possible to obtain 2D and 3D high-resolution chemical images delineating the presence and the distribution of crystalline phases and inclusions. Moreover, the possibility of using synchrotron radiation allows the analysis of grains sized between 5^{-10} microns, allowing the acquisition of spectra with a high lateral spatial resolution and a high and signal-to-noise ratio. The fusion of FT-IR analyses with other complementary ones such as SEM-EDX, micro-Raman, and micro-UV analyses enables a comprehensive characterization of analyzed samples by correlating morphological, molecular, and elemental data. In this work, some of the applications on geological, mineralogical and astrophysics materials, carried out at the Synchrotron Radiation laboratory, are presented, highlighting the advantages of the technique and future developments.

Balerna A. (2021) - DAFNE-Light INFN. Synchrotron Radiat. News, 34, 9, https://doi.org/10.1080/08940886.2021.1902711.

Conte A. et al. (2022) - Hydrothermal genesis and growth of the banded agates from the Allumiere-Tolfa volcanic district (Latium, Italy). Phys. Chem. Miner., 49(10), 39, https://doi.org/10.1007/s00269-022-01214-5.

Della Ventura G. et al. (2024) - Tracking the Ti^{4+} substitution in phlogopite by spectroscopic imaging: A tool for unravelling the growth micas at HP-HT conditions. Geosci. Front., 101777, https://doi.org/10.1016/j.gsf.2024.101777.

Unraveling symplectite development during granulite/amphibolite facies retrogression through X-ray quantitative image analyses

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Keywords: quantitative petrology, Calabria-Peloritani Orogen, image analysis.

Understanding the metamorphic journey of a rock becomes accessible through meticulous examination of its microstructures. These microstructures, which are the final product of the metamorphic evolution experienced by crystalline basements, can be the result of complex chemical reactions and often also deformation events, providing insights into the pressure-temperature trajectory followed by the rocks. Symplectites represent one of the most peculiar microstructures that can be observed in metamorphic rocks, displaying worm-like structures constituted by mineral intergrowths that develop simultaneously in a solid-state reaction (Vernon, 2004).

Optical and electron microscopy are commonly employed to quickly obtain qualitative insights into rock microstructures and identify their constituents, while image analysis techniques can be used to extrapolate more quantitative data. The increasing use of image processing methods in geological and petrological studies has proven to be a valuable tool across various fields of geosciences (Lanari et al., 2019; Ortolano et al., 2018; Visalli et al., 2021). Primarily, these methods rely on multivariate statistical analysis of EDS/WDS X-ray multispectral images that record the elemental distribution within rocks and minerals (e.g., Lanari et al., 2019 and reference therein). The large use of this technique has also prompted the development of innovative GIS-based semi-automatized tools facilitating the identification and classification of mineral phases, as well as the quantification of modal parameters from selected thin section micro-domains (Ortolano et al., 2018; Visalli et al., 2021).

In this study, high-resolution thin-section scans and X-ray elemental maps were processed by using the GIS-based Micro-Fabric Analyzer (Visalli et al., 2021) and Quantitative X-ray Map Analyzer software (Ortolano et al., 2018), obtaining grain-size distribution, mineral modal abundancies, and chemical compositions.

This is to define the effective equilibrium reactant volumes useful to compute reliable isochemical sections unraveling the P-T conditions that triggered the development of the symplectitic microstructures, occurring as Pl-Hbl-Cpx coronitic intergrowths around relict eo- or pre-Variscan garnets in a late Variscan amphibolite sample from the Aspromonte Unit (NE Sicily).

Lanari P. et al. (2019) - Quantitative compositional mapping of mineral phases by electron probe microanalyser. Geol. Soc. London, Sp. Publ., 478, 39-63, https://doi.org/10.1144/SP478.4.

Ortolano G. et al. (2018) - Quantitative X-ray Map Analyser (Q-XRMA): A new GIS-based statistical approach to Mineral Image Analysis. Comput. Geosci., 115, 56-65, https://doi.org/10.1016/j.cageo.2018.03.001.

Vernon R.H. (2004) - A practical guide to Rock Microstructure. Cambridge University Press, New Ed., 606 pp., https://doi.org/10.1017/CBO9780511807206.

Visalli R. (2021) - Micro-Fabric Analyzer (MFA): A New Semiautomated ArcGIS-Based Edge Detector for Quantitative Microstructural Analysis of Rock Thin-Sections. ISPRS Int. J. Geo. Inf., 10, 51, https://doi.org/10.3390/ijgi10020051.

A preliminary petrological study of refractory inclusions in NWA12800 meteorite

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Keywords: meteoritics, refractory inclusions, petrology.

Carbonaceous chondrites offer a glimpse into the early solar system's birth and evolution. These types of rocks represent the best specimens for studying refractory inclusions, the very first minerals forming in the solar system (Connelly et al., 2012). We have conducted initial studies on the carbonaceous chondrite NWA 128000. In particular, we focus our study on some of these mineral aggregates, known as Ca-Al-rich inclusions (CAIs). We aim to delve into the events that occurred within the protoplanetary disk. Analyses were performed by backscattered electron (BSE) imaging, X-ray elemental mapping and electron microprobe analysis with a Zeiss Sigma 300 Field-emission scanning electron microscope (FE-SEM) equipped with a high-resolution backscattered electron detector and a QUANTAX 60x60 mm^2 detector for energy dispersive X-ray spectrometry (EDS). One of the studied irregular shape CAIs show a core-mantle structure that may represent a sequence of two distinct nebular condensations caused by transport in a different protoplanetary disk environment. A second CAI type shows multiple sets of mono-mineralic rims interpreted as a record of recurring partial melting episodes during high-temperature events. These high-temperature events in the solar nebula, have probably been generated by "flash heating" (Wark & Boynton, 2001). Finally, the rounded CAI texture testifies to a complete melting event. The coexistence of various CAIs within a single thin section hints at a dynamic protoplanetary disk environment. Targeted investigations will aim to refine our petrological understanding of their formation scenarios.

Connelly J.N. et al. (2012) - The absolute chronology and thermal processing of solids in the solar protoplanetary disk. Science, 338, 651-655, https://doi.org/10.1126/science.1226919.

Wark B. & Boynton W.V. (2001) - The formation of rims on calcium-aluminum-rich inclusions: Step I - Flash heating. Meteorit. Planet. Sci., 36, 1135-1166, https://doi.org/10.1111/j.1945-5100.2001.tb01949.x

A preliminary petrological study of chondrules in NWA12800 meteorite

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Keywords: meteoritics, chondrules, petrology.

Chondrules, abundant in chondrite meteorites, are small, rounded silicate grains whose formation mechanisms still elude us (Russell et al., 2018). Describing their various textures proves invaluable in unravelling the crystallization history of these miniature worlds. This study aims to characterise chondrules founded in NWA12800, in order to produce datasets useful for upcoming petrological experiments. Analyses were performed by backscattered electron (BSE) imaging, X-ray elemental mapping and electron microprobe analysis with a Zeiss Sigma 300 Field-emission scanning electron microscope (FE-SEM) equipped with a high-resolution backscattered electron detector and a QUANTAX 60x60 mm^2 detector for energy dispersive X-ray spectrometry (EDS). Chondrules display diverse textural types, including barred olivine, porphyritic olivine pyroxene, and radial pyroxene (RP). These textures reflect variations in their crystallization conditions within the protoplanetary disk. Angular fragments of chondrules suggest impact processes, indicating episodes of fragmentation under sub-solidus conditions. Chondrules often exhibit dust-accretionary rims, composed of compacted material from the surrounding matrix, suggesting a history of free-floating in space and subsequent accretion of fine-grained material onto their surfaces. The presence of igneous rims on certain chondrules points to heating events that partially melt pre-existing dust-accretionary rims, highlighting episodes of thermal alteration and metamorphism in the early solar system. The acquired data are useful for design experiments aimed at understanding the petrological history of chondrules and improving existing models.

Russell S. et al. (2018) - Chondrules: Records of Protoplanetary Disk Processes, Cambridge Planetary Science, 11-56, https://doi.org/10.1017/9781108284073.

S21.

Mineralogy behind Earth processes: insights from the atomic to the macroscopic scale

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"Carbonato-apatite" is not a fake: the first reliable SCXRD proof of the incorporation of $[CO_3]$ groups within the apatite framework

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Keywords: apatite supergroup, crystal structure, "carbonato-apatite".

The existence of a "carbonato-apatite" has been hypothesized since the 19th Century (e.g., Henry, 1850). The name carbonato-apatite itself points to something in which $(CO_3)^{2-}$ ions play a significant role. Actually, in the literature the name carbonato-apatite often refers to minerals in which the wt.% CO_2 is very low. And when the crystal-chemical role of $(CO_3)^{2-}$ ions is considered, odd and unlikely proofs are sometimes produced, e.g., carbon is supposed to substitute for Ca in large, nine-coordinated sites, or $[CO_3]$ planar triangles are supposed to substitute for $[PO_4]$ tetrahedra.

At the best of our knowledge no reliable crystallographic data which demonstrate how $(CO_3)^{2-}$ can be accommodated within the apatite framework have been published so far.

Recently an apatite-like mineral has been sampled at Kobylianka ore occurrence near Hýľov, Košice Region, Slovakia. Symmetry and unit-cell parameters match those of apatites; preliminary EPMA data gave, in wt.%, SO_3 0.27, As_2O_5 22.76, PbO 74.94, Cl 0.20. Those data, in the lack of direct determination of wt.% H_2O, could lead to the empirical formula $Pb_{4.99}(As_{2.94}S_{0.05})O_{12.01}[(OH)_{0.92}Cl_{0.08}]$, with (OH) calculated assuming 12 O + 1 [(OH),Cl] per formula unit. The resulting ideal formula, $Pb_5(AsO_4)_3(OH)$, would correspond to "hydroxylmimetite", a potential new mineral species.

A single-crystal X-ray diffraction study was carried out on that sample. Quite unexpectedly, some maxima were found along the channels of the structure which were interpreted as due to carbonate ions, based on both the electron densities and the geometry of bond distances and angles which match those of a $[CO_3]$ planar triangle. Moreover the three oxygens of the carbonate ion form reliable bond distances with the Pb2 atoms. Preliminary Raman spectra confirmed the occurrence of carbonate groups in that sample. Therefore the low amount of monovalent anions – $(OH)^-$, F^-, Cl^- – is balanced by a significant amount of $(CO_3)^{2-}$.

Based on the SCXRD information it may be argued that the apatite-like mineral from Kobylianka is an intermediate member between the two compositions $Pb_5(AsO_4)_3(OH,Cl)$ and $Pb_5(AsO_4)_3(CO_3)_{0.5}$. The empirical formula resulting from the structural refinement is $Pb_5(As_{2.93}S_{0.07})_{\Sigma=3}O_{12}[(OH)_{0.35}Cl_{0.10}]_{\Sigma=0.45}(CO_3)_{0.31}$; it is close to the 50% boundary, however it lies on the carbonate-dominant side. Accordingly it could represent a potential new mineral species, not "hydroxylmimetite", yet the first example of an apatite supergroup mineral having (CO_3) as a species-forming constituent.

Additional data must to be collected on that sample before it can be submitted for its official recognition as a new mineral, in particular quantitative data on the wt.% H_2O and CO_2 – both key constituents – are mandatory. However, the crystallographic data already represent a strong and unequivocal proof that $(CO_3)^{2-}$ ions can be incorporated within the apatite framework.

Henry T.H. (1850) - XVII. On francolite, a supposed new mineral. Phil. Mag. Ser. 3, 36, 134-135.

The strange case of a mineral with pyroxene chemistry and HP-olivine structure

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Keywords: Earh's mantle, new mineral, Mg-silicates, shocked meteorites.

High-pressure minerals found in shocked meteorites can provide valuable insights into the deep interior of our planet Earth. They can give clues about the extreme pressure and temperature conditions that exist deep within the Earth's mantle, and, by studying their stability fields, we can infer the physical and chemical environments at great depths. Most of the models for our deep Earth are based on well-known and common minerals. We here demonstrate that the scenario could be much more complex than thought. During a mineralogical investigation of the Suizhou meteorite, a L6 shocked chondrite having shock melt veins less than three hundred micrometers in thickness, we discovered a new mineral that seems identical to wadsleyite (M^{2+}:Si = 2:1) when looked at the scanning electron microscope or with an electron microprobe (same albedo), but it has the pyroxene stoichiometry (M^{2+}:Si = 1:1) and retains the wadsleyite structure. In detail, electron microprobe analyses pointed to the following empirical formula (based on 8 oxygen atoms pfu) $[(Mg_{2.73}Fe^{2+}_{0.14}Na_{0.03}Al_{0.03}Ca_{0.02}Si_{0.05})\Sigma_{3.00}(Si_{0.49}[]_{0.51})\Sigma_{1.00}]Si_2O_8$, ideally $Mg_3(Si_{0.5}[]_{0.5})Si_2O_8$ (the symbol [] stands for structural vacancy). Single-crystal X-ray studies showed the mineral to be orthorhombic, space group *Imma*, with the following unit-cell parameters: $a = 5.5820(10)$, $b = 11.418(3)$, $c = 7.708(2)$ Å, $V = 491.3(2)$ Å^3 and $Z = 4$.

This new mineral could be very common. Indeed, by means of routinely identification methods (e.g. EBSD), it can be misidentified as wadsleyite and, if one uses only the chemical composition it can be misidentified as one of the $MgSiO_3$ polymorphs (enstatite, akimotoite, majorite or bridgmanite). The present discovery underlines how complex can be the family of Mg(Fe)-silicates and how many secrets are still to be discovered.

Atomic dynamics of chalcedony under non ambient conditions: a Raman spectroscopy study

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Keywords: chalcedony, moganite, Raman spectroscopy.

Chalcedony (an ensemble of quartz crystals with a size < 1 micron) is widespread in near-surface rocks, and it has proved to be an important marker in many geological environments (Heany, 1993 and reference therein). Chalcedony also represents one of the main natural hosts containing the silica polymorph moganite. The moganite structure consists of alternative stacking slabs of left-handed and right-handed a-quartz, forming a framework containing 4-membered rings of corner-sharing SiO_4 tetrahedra, in contrast to the other low-pressure silica polymorphs whose structure is built up of 6-membered SiO_4-rings (e.g. Kingma & Hemley, 1994). Moganite is the second most widespread SiO_2 polymorph in nature after quartz (Heany & Post, 1992). However, it has been recognized as a mineral species only in 1999 (The New IMA List of Minerals) because it commonly intergrows with granular and or fibrous micro-crystalline quartz varieties. Consequently, moganite is not as well characterized as quartz, neither the effect of moganite presence on the high-pressure/temperature behaviour of microcrystalline quartz varieties has been thoroughly studied. In this work we analysed samples of moganite-bearing chalcedony using in situ Raman spectroscopy up to 7 GPa at ambient temperature as well as up to 1200K at ambient pressure. Our results provide insights on the effect of pressure and temperature applied on multiphase micro-crystalline material affected by metastability and or phase transition. We finally test the possibility of using hard-mode Raman spectroscopy (Bismayer, 2000) as a tool to characterize the character of phase transitions (e.g. first vs. second order transitions) and how it is affected by coexistence of different phases.

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New thermo-elastic and crystal-chemical insights on 11.5 Å phase: a major water carrier to the mantle transition zone

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Keywords: DHMS, 11.5Å phase, Earth's mantle.

In the past three decades, experimental studies have demonstrated the stability of new hydrous silicates in the MgO-Al_2O_3-SiO_2-H_2O (MASH) system, known as "Dense Hydrous Magnesium Silicates" (DHMS). These phases, like the DHMS in the simpler MgO-SiO_2-H_2O (MSH) system (e.g., phase A), can form after the destabilization of layer hydrous minerals (serpentine, chlorite). Recent research has studied their stability under mantle pressures and temperatures, highlighting their role in the deep-water cycle and their impact on the mantle's water budget (Hermann & Lakey, 2021).

Among these phases, the 11.5 Å phase, with chemical formula $Mg_6Al(SiO_4)_2(OH)_7$, has been identified as stable in the region between 7-11 GPa and 500-1000°C, and plays a potential role in storing and transporting water to the mantle transition zone (Cai & Inoue, 2019; Hermann & Lakey, 2021). In subduction contexts, the 11.5 Å phase has been associated with the destabilization of chlorite in Al-rich systems and can store up to 13 wt.% of water, a notably high content compared to other DHMS under similar conditions. Its crystal structure was determined by Gemmi et al. (2016) using standard precession-assisted electron diffraction tomography (PEDT), revealing a layered structure consisting of TOT groups and double di-octahedral layers of face-sharing octahedra (O-O), with unit cell parameters a = 9.012(1) Å, b = 5.201(1) Å, c = 23.202(5) Å, β = 97.8(1)° and space group $C2/c$.

We performed multi-anvil syntheses under different mantle P-T conditions (6-10 GPa and 700-900°C) to assess the effect of iron and chromium on the crystal-chemistry and stability of the 11.5 Å phase, starting from natural Fe-bearing chlorite sample and synthetic Cr-bearing systems. The results reveal that solid solutions from pure Mg-Al term can form with Fe-Al and Mg-Cr end-members.

The synthesis performed at the highest pressures crystallized single crystals up to 50x50x50 μm^3. Single crystal diffraction allowed ab-initio structure determinations and refinements, confirming the structural description reported by Gemmi et al. (2016).

In addition, we report the determination of PV and VT equations of state, which allow the density estimation for the 11.5 Å phase at mantle conditions. We observed also an interesting single crystal to single crystal phase transition at high temperature, at 400°C, upon partial dehydration, with noticeable 5% volume expansion and a partial unpacking of the double Mg-octahedral layers.

Cai N. & Inoue T. (2019) - High-pressure and high-temperature stability of chlorite and 23-Åphase in the natural chlorite and synthetic MASH system. CR Geoscience, 351, 104-112, https://doi.org/10.1016/j.crte.2018.09.010.

Gemmi M. et al. (2016) - Electron diffraction determination of 11.5Å and HySo structures: Candidate water carriers to the Upper Mantle. Am. Mineral., 101(12), 2645-2654, https://doi.org/10.2138/am-2016-5722.

Hermann J. & Lakey S. (2021) - Water transfer to the deep mantle through hydrous, Al-rich silicates in subduction zones. Geology, 49(8), 911-915, https://doi.org/10.1130/G48658.1.

Micro- and nano-scale investigation of (Ca-REE) fluorcarbonates: clues for REE partitioning and mobility

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Keywords: Rare Earth Elements, REE-fluorcarbonates, Transmission Electron Microscopy.

Micro- and nano-scale studies of ore minerals holds significant potential to enhance prospecting methods, metallurgical processes, and recycling strategies. Indeed, nanoscale processes revealed to be key factors for the control of large-scale ore deposits, since nanoparticles and nanominerals, apparently, play a significant role as agents of elemental transport, including heavy metals and radionuclides, particularly within hydrothermal systems (Reich et al., 2011). In this context, CaREE-fluorcarbonates, which are primary ore for Rare Earth Elements (REE), are the perfect example of how the micro- and nano-studies on geo-relevant minerals holds potentialities for understanding the crystallization pathway and elements partitioning in hydrothermal systems. Indeed, recent mineralogical and crystallographic studies on this class of minerals shed light on their nature and genesis. Particularly, the study of polysomatism may reveal important for the understanding of the crystallization conditions and fluid composition (Gysi & Williams-Jones, 2015; Conconi et al., 2023).

The CaREE-fluorcarbonates studied were found within the miarolitic cavities of a granophyre in the Western Southern Alps (Italy). Different mineral species with different morphologies and compositions were observed: (i) synchysite-(Ce) forming hexagonal prisms and rosette-like aggregates, (ii) bastnäsite-(Ce) forming blocky aggregates and (iii) bastnäsite-(Nd) forming more complex micro and nanostructures. Regarding the latter, transmission electron microscopy studies revealed a nanostructure consisting of an intergrowth of bastnäsite-(Nd) nanocrystals with hematite nanocrystals and phyllosilicates. A potential scenario regarding their formation has been proposed, suggesting that different CaREE-fluorcarbonates followed a crystallization sequence influenced by temperature and fluid fractionation. Initially, synchysite-(Ce) was formed, succeeded by bastnäsite-(Ce), and finally bastnäsite-(Nd). The varied morphologies observed were not only attributed to the prevalent REE in the fluid but also to fluctuating temperatures and cooling rates. Our research underscores nature's ability to effectively segregate REE from each other, such as Y from La, Ce, and Nd; Ce from Nd and La; additionally, Th, a radioactive and toxic element, appears to incorporate into the structure of CaREE-fluorcarbonates during the concluding stages of crystallization.

Conconi R. et al. (2023) - A multi-methodological study of the bastnäsite-synchysite polysomatic series: Tips and tricks of polysome identification and the origin of syntactic intergrowths. Am. Mineral., 108, 1658-1668, https://doi.org/10.2138/am-2022-8678.

Gysi A.P. & Williams-Jones A.E. (2015) - The thermodynamic properties of bastnäsite-(Ce) and parisite-(Ce). Chem. Geol., 392, 87-101, https://doi.org/10.1016/j.chemgeo.2014.11.001.

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A new synthetic strategy to produce hollandite-type nanocrystals, useful for environmental application

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Keywords: nanomaterials, tetragonal symmetry, temperature treatment.

Hollandite-type crystals attract attention thanks to their unique and interesting chemical-physical features. Herein, an innovative synthetic strategy was developed for the production of novel nano-sized hollandite-type single-crystalline potassium ferrotitanate (KFTO). The synthesis consists of a simple hydrothermal method using as a starting material an electrostatically stabilized nano-assembly of TiO_2 nanotubes (TiNTs) (Zennaro et al., 2013) and Surface active maghemite nanoparticle (SAMNs) as starting materials (Magro et al., 2020). The evolution of the TiNTs-SAMNs conjugate, took place at the unprecedented temperature of 800°C, which is remarkably low in comparison to other hydrothermally generated KFTO materials (Gorshkov et al., 2021). The as-obtained nanomaterial was extensively characterized through X-ray powder diffraction, transmission electron microscope, scanning electron microscope, Fourier transform infrared spectroscopy, dynamic light scattering, and Raman spectroscopy. The refinement performed using the Rietveld data analysis reveals that the synthetized hollandite belongs to the hollandite supergroup, which is characterized by tetragonal symmetry with lattice parameters $a = b = 10.1502$ Å, $c = 2.9716$ Å, similar to the natural priderite (Post et al., 1982).

In particular, the nano-particulate gives rise to stable colloidal suspensions, displaying a zeta potential of -40 mV, that is a suitable feature for environmental applications. Besides enriching the chemistry TiO_2 derived nanomaterials, can stimulate further research on alternative synthetic strategies based on nano-sized reagents and environmental applications.

Gorshkov N.V. et al. (2021) - Electrochemical properties of hollandite $K_{1.5}Fe_{1.5}Ti_{6.5}O_{16}$ with carbon coating. Russ. J. Inorg. Chem., 66, 1121-1127, https://doi.org/10.1134/S0036023621080076.

Magro M. et al. (2020) - Colloidal maghemite nanoparticles with oxyhydroxide-like interface and chiroptical properties. Appl. Surf. Sci., 534, 147567.

Post J.E. et al. (1982) - Symmetry and cation displacements in hollandites: structure refinements of hollandite, cryptomelane, and priderite. Acta Crystallogr., B38, 1056-1065.

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Sphalerite from Longobucco and Fonte Argentila mineralization (Sila Massif, Calabria, southern Italy): crystal chemistry and genetic implications

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Keywords: sphalerite, crystal chemistry, Longobucco and Fonte Argentila mineralization.

Sphalerite is the main ore-mineral of the vein-type mineralization of Longobucco (LGB) and Fonte Argentila (FAR), outcropping within granodiorite of the Sila Batholith (Calabria, southern Italy). Such mineralization are of historical importance, but not deeply investigated yet (Fregola et al., 2023). We have examined the crystal chemistry of sphalerite through a combination of optical microscopy (OM), scanning electron microscopy (SEM), electron probe microanalyses (EPMA), μ-Raman spectroscopy (μ-RS), single crystal X-ray diffraction (SCXRD), and X-ray powder diffraction (XRPD).

Textural and paragenetic observations using optical microscopy allowed us to discriminate three distinct generations of sphalerite from LGB and FAR, corresponding to different mineralization episodes of the ore deposit. Sp-1 is light coloured (from light-yellow to brown), Sp-2 is dark coloured (from reddish-brown to dark brown), whilst Sp-3 is colourless. Colour variation is mainly due to different Fe-content, with the darker Sp-2 being the Fe-richest one (up to 11.3 wt.%; 0.21 mol% FeS). Sphalerite contains also minor amounts of Cd (up to 0.7 wt.%).

The phase composition of sphalerite samples has been confirmed by XRPD.

Data from μ-Raman spectroscopy, collected from sphalerite Sp-1, Sp-2 and Sp-3, have been correlated to the corresponding Fe concentrations. The colourless Fe-poorest Sp-3 shows the typical spectrum of almost pure ZnS sphalerite, with the main band at about 350 cm^{-1} (h3, A3; Raman band due to Zn-S bond vibrations). Raman spectra of Sp-1 and Sp-2 show a further band at about 300 cm^{-1} (h1, A1; Raman band due to Fe-S bond vibrations) becoming gradually dominant with increasing Fe-content, with respect to the Zn-S band. By plotting the obtained ratios of band intensities (h1/h3) and areas (A1/A3) against the corresponding FeS mole fractions, our results are in good agreement with the calibrated curves reported by the literature (e.g., Osadchii & Gorbaty, 2010).

The refined unit cell parameters, measured by SCXRD on Sp-1 and Sp-2 sphalerite of different colours (from pale yellow to reddish-brown), range between 5.4158 Å and 5.4230 Å. Using these cell parameters and the corresponding mol% FeS values in the equation by Chareev et al. (2017), we have estimated sphalerite formation temperatures in the range 117-141°C for the light Sp-1, and up to 192°C for the dark Sp-2. Such values are in good agreement with those obtained from our preliminary fluid inclusion analyses performed on quartz, as well as from our geochemical analyses of sphalerite trace element composition (Ciccolella et al., 2024).

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Ciccolella A. et al. (2024) - The Zn-Pb(-Cu-Fe) mineralization in the northern Sila Massif (Calabria, southern Italy): Genetic constrains from trace element concentrations in sphalerite. EGU General Assembly 2024, Vienna, Austria, 14-19 Apr 2024, EGU24-3657, https://doi.org/10.5194/egusphere-egu24-3657.

Fregola R.A. et al. (2023) - Review of polymetallic mineralization in the Sila and Serre Massifs (Calabria, southern Italy). Minerals, 13, 439, https://doi.org/10.3390/min13030439.

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Dellen crater impact melt rock: pyroxenes as a proxy for melt thermal history and water content

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Keywords: impact crater, pyroxene, water content.

The Dellen impact structure is located in a ca. 20 km wide basin filled by two lakes in the east central Sweden. This complex structure is covered by a thick moraine deposit, and most impact melted material can be found as loose blocks and boulders scattered throughout the moraine. Geophysical measurements show the presence of a coherent impact melt body about 9 km in diameter and 200 to 500 m thick for which impact ages range between 90, 110, to 140 Ma.

Here we describe the petrography and mineral chemistry of an impact melt glass (commonly referred to as dellenite) consisting of phenocrysts of subhedral orthopyroxene (average $Wo_4En_{63}Fs_{33}$), skeletal plagioclase (average $An_{59}Ab_{38}Or_3$), and euhedral magnetite within a glassy matrix of rhyolitic composition. Moreover we aimed to use the pyroxene crystals as a petrological tool to define the host rock cooling rate and the water content dissolved in their parental melt during pyroxene growth.

MicroFTIR measurements performed both in the glass matrix and in the euhedral glass blebs within the skeletal plagioclase show the presence of 1.4 wt.% H_2O in the rhyolitic glass. Comparing the water content of the glass with the water solubility of a silicate melt with the same composition as determined by the model by Papale (1999) suggests that the studied sample vitrified at a pressure of about 200-300 bar.

Dellenite orthopyroxene, studied by polarized FTIR spectroscopy, Mössbauer spectroscopy, single crystal X-ray diffraction and EMPA, are iron rich enstatite (Wo_4 En_{63} Fs_{33}) with a Fe^{3+}/Fe_{tot} ratio of 1.6%. Opx have very weak to absent OH vibrational IR bands, corresponding to H_2O contents ranging from 0 to 39 ppm H_2O. The variable contents seem to indicate H loss during post-formation processes, which may occur via $Fe^{2+} + OH^- = Fe^{3+} + O^{2-} + ½H_2$ redox reaction. In volcanic pyroxenes H loss may be a common process, however since H incorporation is associated to point defects with slow diffusion rates, by reversing the redox reaction the original H content of pyroxene can thus be recovered by thermal annealing experiments under reducing conditions (Weis et al., 2016; Nazzareni et al., 2020).

In order to restore H that was possibly lost, dellenite pyroxenes were thermally annealed under hydrogen atmosphere (at 1 Atm) in a horizontal glass-tube furnace. FTIR spectra were recorded after each heating step showing an increase in H content to a final average water content of 45 ppm.

Cations partition as derived by the SC-XRD and EMPA were used to calculate the orthopyroxene closure temperature (Tc) point to a Tc value of 833°C due to a quite fast host-rock cooling rate.

A tentative model for the evolution of the rhyolitic portion of the Dellen impact melt is under development merging geophysical data with our experimental data on water content of pyroxene and glass, and pyroxene geospeedometry.

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Spectroscopic study of the interaction mechanism of heavy metals and clay and organo-clays as sorbents in wastewater treatment

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Keywords: spectroscopy, heavy metals, montmorillonite.

Clays and organo-clays are largely proposed in the literature to reduce heavy metals (HMs) contamination in wastewater, via solid/liquid adsorption from many productive sectors (Mao & Gao, 2021). HMs, if spread in the environment, can have harmful effects to humans and to natural organisms. Among others, animal breeding represents one of the sources of HMs, being HMs, namely zinc oxide and copper salts, added to feed to improve animal health (Hejna et al., 2019). In this respect, the knowledge of the interactions HMs-sorbents is fundamental to understand sorbents behaviour in order to develop them for use in the field. In this work, both pristine STx-1b, a Ca-montmorillonite (STx, hereafter) and STx-modified with collagen hydrolysate (supplied by Ilsa group), are studied as sorbent for Cu^{2+} and Zn^{2+}. The capture of Cu^{2+} and Zn^{2+} has been performed with solid/liquid adsorption process, and inductively coupled plasma-optical emission spectroscopy (ICP-OES) has been applied to determine captured Cu^{2+} and Zn^{2+}. Specific Cu^{2+} and Zn^{2+} contents have experienced, namely 2 mmolCu/gcarrier and 1.04 mmolZn/gcarrier. Pristine STx is able to capture up to 0.55 mmolCu/gcarrier of Cu^{2+} and up to 0.45 mmolZn/gcarrier, of Zn^{2+}; while organoclay 0.47 mmolZn/gcarrier and 0.52 mmolcu/gcarrier, when applying an initial content of 2 mmolCu/gcarrier and 1.04 mmolZn/gcarrier for copper and zinc respectively. To gain insight into the different sorbent solids capability they have been fully characterized by XRPD, SEM-EDX, EPR, XPS and FT-IR, before and after metal capture. The results are discussed in terms of the nature and strength of the bonds.

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Twinning and superstructure in janchevite, $Pb_9VO_{10.25}\square_{0.75}Cl_{2.5}$

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Keywords: janchevite, oxychloride, crystal-structure.

Janchevite, the V-dominant analogue of parkinsonite, is a rare mineral belonging to the layered lead oxychlorides group. As in the case of parkinsonite, janchevite has been previously described (Chukanov et al., 2018) in the *I*4/*mmm* substructure but a full structural determination has not been reported to date. Here we present the results of an investigation on a sample of janchevite from the type locality (Kombat mine, Namibia), which was studied through single crystal X-ray diffraction, electron probe micro-analysis and X-ray absorption spectroscopy.

The superstructure of janchevite (R = 5.2%) was determined using intensity data gathered from a two-domains non-merohedral twinned crystal. Despite the pronounced tetragonal subcell reflections, the structure exhibits triclinic symmetry (space group *P*-1), with lattice parameters $a = 8.8382(7)$, $b = 8.8567(7)$, $c = 11.7103(17)$ Å, $\alpha = 103.385(10)$, $\beta = 94.192(10)$, $\gamma = 90.294(6)°$, $V = 889.13(16)$ Å^3 and $Z = 2$. Chemical analyses revealed the presence of Mo, As, Si, in addition to Pb, Cl, O, and V. The structural framework comprises alternating layers of PbO litharge and Cl- anions in a 2:1 ratio. High-charge cations (V^{5+}, Mo^{6+}, As^{5+}, Si^{4+}) are incorporated into the litharge sheet, creating square cavities hosting MoO_5 square pyramids and $(Si,As,V)O_4$ tetrahedra.

Through chemical, structural, and spectroscopic investigations, the crystal chemical formula was revised to $Pb_9VO_{10.25}\square_{0.75}Cl_{2.5}$ ($Z = 2$), analogously to what previously suggested for parkinsonite (Welch et al., 1996; Lepore & Welch, 2010). This implies the presence of additional apical oxygen atoms between adjacent Pb layers, which influence the interlayer thickness. In particular, a linear correlation between the interlayer oxygen content and the nature of structural defects has been observed.

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Lepore G.O. & Welch M.D. (2010) - The crystal structure of parkinsonite, nominally $Pb_7MoO_9Cl_2$: a naturally occurring Aurivillius phase. Mineral. Mag., 74, 269-275, https://doi.org/10.1180/minmag.2010.074.2.269.

Welch M.D. et al. (1996) - Cation ordering in lead-molybdenum-vanadium oxychlorides. Am. Mineral., 81, 1350-1359, https://doi.org/10.2138/am-1996-11-1207.

An in-situ synchrotron X-ray powder diffraction study of the thermal stability of templated ZSM-5 zeolites

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Keywords: in-situ synchrotron X-ray powder diffraction, thermal stability, ZSM-5 zeolite.

Organic species such as tetra-n-propylammonium (TPA) and Na cations have been found to be effective in directing the structure of ZSM-5 zeolite. The optimization of synthesis conditions is crucial to producing highly crystalline ZSM-5 zeolite and, consequently, to controlling the properties of the resulting material for specific applications. ZSM-5 actual symmetry (orthorhombic Pnma, with 12 crystallographically independent tetrahedral sites in the unit cell) depends on the synthesis and post-synthesis treatment, SiO_2/Al_2O_3 ratio, structural defects, temperature, and amount of sorbate organic molecules.

Through in situ synchrotron powder diffraction of four TPA-ZSM-5 samples with varying Si/Al ratios (15, 25, 50, and 100), this work examines the thermal stability and high temperature structure development. By performing Rietveld refinements on the room temperature data, it was discovered that the TPA^+ ions are situated at the junction of the sinusoidal and straight channels in every ZSM-5 sample. The refined TPA^+ content increases with the increasing Si/Al ratio of the zeolite. All four ZSM-5 samples have good thermal stability, as demonstrated by the high temperature refinements; they stay crystalline until the thermal treatment reaches its conclusion (800°C). The great degree of flexibility of the MFI framework is confirmed by the fact that burning the template does not result in any discernible changes to the channel form or framework geometry. Furthermore, thermal studies provided valuable insights into how aluminum presence affects the way TPA and zeolite structures interact.

Second world occurrence of badalovite, $Na_2Mg_2Fe(AsO_4)_3$, from the Etna volcanic complex, Sicily

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Keywords: badalovite, Etna volcanic complex, crystal structure.

Badalovite, $Na_2Mg_2Fe(AsO_4)_3$, is a member of the alluaudite supergroup (Hatert, 2019), discovered in the Arsenatnaya fumarole of the Tolbachik volcano, Kamchatka, Russia (Pekov et al., 2020). Following the examination of a suite of mineral specimens from Eastern Sicily, a new occurrence of badalovite was identified on a sample collected by the mineral amateur Gaetano Sicurella. This sample was from the Monte Calvario quarry, Biancavilla, Etna volcanic complex, Sicily, well-known for being the type locality of two F-bearing phases, i.e., fluorophlogopite and fluoro-edenite (Sicurella et al., 2010, and references therein).

Badalovite occurs as vitreous to resinous orange prismatic crystals, in some cases forming sheave-like aggregates, up to 0.5 mm in length, associated with equant to tabular crystals of hematite. This mineral was previously described as UM2 (Unnamed Mineral) by Sicurella et al. (2010), who reported the occurrence of major Na and As as main chemical constituents, with minor Fe, P, and Ca.

Badalovite from Biancavilla has unit-cell parameters a = 11.9970(4), b = 12.7731(4), c = 6.6349(2) Å, β = 112.7170(10)°, V = 937.85(5) Å^3, space group $C2/c$. These values can be compared with those given by Pekov et al. (2020), i.e., a = 11.9034(3), b = 12.7832(2), c = 6.66340(16) Å, β = 112.523(3)°, V = 936.59(4) Å^3. Electron microprobe analysis (National Museum, Prague) gave (average of 10 spot analyses): SO_3 0.05(4), P_2O_5 2.72(66), As_2O_5 54.97(56), Al_2O_3 0.12(8), Fe_2O_3 10.67(2.58), MgO 13.16(2.40), CaO 4.56(1.30), MnO 3.39(20), ZnO 0.32(14), Na_2O 9.18(79), K_2O 0.06(2), sum 99.20(70). The empirical formula, based on 12 O atoms per formula unit, is $Na_{1.68}K_{0.01}Ca_{0.46}Mg_{1.85}Al_{0.01}Mn_{0.27}Zn_{0.02}Fe^{3+}_{0.77}(As_{2.84}P_{0.11}S_{0.01})\Sigma_{2.96}O_{12}$ (Z = 4). The crystal structure was refined to $R1$ = 0.0504 for 1612 unique reflections with $Fo > 4\sigma(Fo)$ and 101 refined parameters. Its crystal structure is isotypic with other alluaudite-supergroup minerals and agrees with the structural features described by Pekov et al. (2020).

The genesis of Sicilian badalovite is probably related to the interaction between fumarolic and volcanic rocks, possibly at temperature not lower than 450°C, in accordance with the occurrence of the Russian badalovite. Moreover, badalovite is another, previously undetected, host for the high As contents identified in the Biancavilla area by previous authors (e.g., Mazziotti-Tagliani et al., 2012), who explained such high contents (up to 1000 mg/kg) as due to the As-enrichment in fluorapatite only. Actually, the finding of badalovite suggests that further mineral species hosting As may be hidden among fumarolic assemblages occurring in the Biancavilla area.

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Mazziotti-Tagliani S. et al. (2012) - Arsenic and fluorine in the Etnean volcanics from Biancavilla, Sicily, Italy: environmental implications. Environ. Earth Sci., 66, 561-572, https://doi.org/10.1007/s12665-011-1265-8.

Pekov I.V. et al. (2020) - New arsenate minerals from the Arsenatnaya fumarole, Tolbachik volcano, Kamchatka, Russia. XIV. Badalovite, $NaNaMg(MgFe^{3+})(AsO_4)_3$, a member of the alluaudite group. Mineral. Mag., 84, 616-622, https://doi.org/10.1180/mgm.2020.43.

Sicurella G. et al. (2010) - Minerali di Monte Calvario, Biancavilla (Catania, Sicilia). MICRO, 2010, 329-368.

High temperature study of fluorcarletonite from Murun alkaline complex (Russia): a synergic experimental and theoretical approach

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Keywords: fluorcarletonite, HT-SCXRD and HT-FTIR, ab initio calculations.

Fluorcarletonite, $KNa_4Ca_4Si_8O_{18}(CO_3)_4(F,OH) \cdot H_2O$, from Malyy Murun syenite massif (Aldan Shield, Siberia, Russia) was recently recognized as a new mineral species by the Commission on New Minerals and Mineral Names of the International Mineralogical Association (IMA no. 2019-038). It is described as double-layer sheet silicates with 1:2.25 T:O ratio (Hawthorne et al., 2019). Two adjacent single layers are interconnected by sharing a common oxygen of downward-pointing tetrahedra. The $[Si_8O_{18}]^{4-}$ sheets are linked with sheets consisting of $NaO_4^{2-}F^-(H_2O)$ and $NaO_5^{2-}(H_2O)$ octahedra, NaO_8^{2-}, $CaO_7^{2-}F^-$ or CaO_8^{2-} and KO_{10}^{2-} polyhedra. Finally, two independent CO_3-groups are linked to Na- and Ca-polyhedra (Kaneva, et al. 2020).

In the present study the high temperature behavior of fluorcarletonite has been investigated by combining in situ high temperature single crystal X-ray diffraction (T range 25-550°C), ex situ high temperature Fourier transform infrared spectroscopy (25-700°C) and ab initio calculations. The lattice parameters and cell volume increase in the 150-550°C temperature range while the mineral undergoes a progressive dehydration process. At 550°C about 40% water loss was observed. When compared with the fluorcarletonite structure at room temperature, the partially dehydrated fluorcarletonite shows: the same space group (*P*4/*mbm*); increased distances between the oxygens of the H_2O molecules (O11w and O12w) and their Na-centered octahedral cations (Na1 and Na2, respectively); distortion of the four- and six-member tetrahedral rings of the double silicate layer. The dehydration process mainly involves the water oxygen at the O11w site, having a different local environment with respect to the oxygen at the O12w site. At T > 600°C, the complete dehydration is accompanied by deprotonation of the OH groups substituting for the F atoms and by the collapse of the structure when the CO_2 is released. The adopted approach allowed the determination of the temperature thresholds at which modifications occur in the fluorcarletonite crystal structure under controlled heating conditions. The findings contribute to provide insights into the thermal behavior of sheet silicates with fluorcarletonite-like topology.

Hawthorne F.C. et al. (2019) - A structure hierarchy for silicate minerals: sheet silicates. Mineral. Mag., 83, 3-55, https://doi:10.1180/mgm.2018.152.

Kaneva E. et al. (2020) - Crystal chemistry of fluorcarletonite, a new mineral from the Murun alkaline complex (Russia). Eur. J. Mineral., 32, 137-146, https://doi.org/10.5194/ejm-32-137-2020.

Crystal chemistry of carpholite of the Middle Tuscan Ridge (inner Northern Apennines)

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Keywords: magnesiocarpholite, crystal chemistry, HP-LT metamorphism.

HP metamorphism has been documented in the siliciclastic successions exposed in the inner Northern Apennines, a fold-and-thrust belt belonging to the Alpine-Himalayan belt system, formed since the Late Cretaceous by the convergence and collision of the Adriatic and European plates. In the metapelitic rocks exposed in the Middle Tuscan Ridge, HP metamorphism (P = 1.2-0.8 Gpa; T = 350-420°C) gave rise to typical mineralogical assemblages composed of quartz-phengite-chloritoid-pyrophylite-rutile-hematite±chlorite±pa ragonite±kyanite±Ti oxides and developed along a syn-kinematic composite foliation. (Mg, Fe)-carpholite quartz veins, transposed along the main schistosity, have also been documented.

The carpholite group encompasses hydrated inosilicates and a recent review of chemical variation of carpholite, specifically (Fe, Mg)-carpholite, []$(Fe,Mg)\ Al_2Si_2O_6(OH)_4$, is reported in Mesto et al. (2021). In the present work preliminary data about the crystal chemical characterization of magnesiocarpholite from the northern Apennines are reported. The investigated samples, that underwent single crystal X-ray diffraction (SCXRD) analysis, are from two localities: Torrente Gonna, where carpholite occurrence was reported by Brogi & Giorgetti (2012) and from Poggio delle Vipere, where carpholite occurrence was reported by Giorgetti et al. (1998). The relevant carpholite samples are labelled G1 and PVi, respectively.

Structure refinements from SCXRD data, in the *Ccce* space group, converged at R(%) = 3.82 and 2.64 for sample G1 and PVi, respectively, with unit cell parameters a = 13.728 Å, b = 20.113 Å and c = 5.107 Å and V = 1410 Å^3 for G1 sample, and a = 13.731 Å, b = 20.114 Å and c = 5.115 Å and V = 1413 Å^3 for PVi Mg-carpholite.

In the crystal structure, there are one symmetry independent tetrahedron, three symmetry independent octahedra (M1, M2, and M3), and two hydrogen positions (H1 and H2). The M1 octahedron is Mg,Fe-centered, whereas the M2 and M3 octahedra are Al-centered. Hints of the presence of Na in sample PVi are found, coherently with the chemical composition in Brogi & Giorgetti (2012).

XMg (i.e. molar $Mg/(Mg+Fe^{2+}+Mn)$) is 0.68 and 0.61 for the G1 and PVi crystals respectively, as derived from the refined occupancy at the M1 site. This parameter is correlated to the lattice variation mainly along the a and b axes and to geometrical distortions of the M1, M2 and M3 octahedra (Mesto et al., 2021).

Brogi A. & Giorgetti G. (2012) - Tectono-metamorphic evolution of the siliciclastic units in the Middle Tuscan Range (inner Northern Apennines): Mg-carpholite bearing quartz veins related to syn-metamorphic syn-orogenic foliation. Tectonophysics, 526-529, 167-184, https://doi.org/10.1016/j.tecto.2011.09.015.

Giorgetti G. et al. (1998) - Metamorphic evolution of Verrucano metasediments in northern Apennines: new petrological constraints. Eur. J. Mineral., 10, 1295-1308.

Mesto E. et al. (2021) - Crystal chemistry and thermal behavior of Fe-carpholite from the Pollino Massif, southern Italy. Am. Mineral., 106, 123-134, https://doi.org/10.2138/am-2020-7385.

Partially crystalline silica varieties in gemmology: the case study of the blue Andean opal

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Keywords: blue Andean opal, microstructure, chemical composition.

Opal is an amorphous or poorly crystalline hydrated form of silica (usually given as $SiO_2 \cdot nH_2O$) occurring in veins and nodules of various colours. The term *opal* defines several sub-categories of aggregates with varying structural orders, from a glass-like structure to packed silica nano-spheres or nanograins (Gliozzo, 2019). Opal's intrinsic and peculiar complexities enhance its desirable aesthetic aspect, appreciated in gemmology and jewellery. A well valued and popular opal variety is the blue Andean opal, from the Acari Mine (Arequipa Department, Peru). The distinctive blue hue of this variety is commonly ascribed to the presence of copper-rich mineral inclusions (Gaillou et al., 2008; Caucia et al., 2015).

In this study, a multi-methodological approach has been used to investigate the features of the blue Andean opal. X-ray diffraction methods have been used for the characterization of the mineralogical assemblage, along with the quantification of the amorphous fraction, showing the challenge in distinguishing among opal subcategories due to their blurred boundaries. Raman mapping highlighted different silica phases and the distribution of impurities within the matrix. The microstructure of the blue Andean opal resulted emblematic of the precipitation processes of the silica aggregate. The analysis of trace elements concentration provided information about the potential composition of the original fluids, from which the Andean opal precipitated. Notably, this research highlighted that the blue colouration of the Andean opal is ascribable to the presence of a mineralogical inclusion, but it is also influenced by the combined effect of factors closely dependent on the geological processes and environment of formation.

Caucia F. et al. (2015) - New physical, geochemical and gemological data of opals from Acari Mine (Arequipa Department, Peru). Neues Jb. Miner. Abh., 192, 73-84, https://doi.org/10.1127/njma/2014/0272.

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Gliozzo E. (2019) - Variations on the silica theme: Classification and provenance from Pliny to current supplies. In: Artioli G. & Oberti R. (Eds), The contribution of mineralogy to cultural heritage, European Mineralogical Union (EMU), 13-86, https://doi.org/10.1180/EMU-notes.20.2.

Interpreting mineral transformations

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Keywords: reactions, thermodynamics, stability.

Interpreting mineral transformations is a key to get insights into processes taking place in natural and anthropic environments. In such a respect, different strategies have been developed to provide a frame in which the driving forces that trigger, on the one hand, and govern, on the other hand, transformations of mineral phases can be properly set. The extraordinary experimental potentialities which are nowadays accessible through laboratory and large scale facilities provide unprecedented possibilities of novel explorations, along with progressive improvements and consolidation of theoretical/computing tools that interplay with observations a crucial role in allowing scientists to develop coherent unitary vision of complex phenomenologies. In this light, the mechanisms of thermodynamic stability of minerals can be framed in the context of general theories, like, for instance, the catastrophe theory (Poston & Stewart, 1996), Bader bonding theory (Bader, 1994) and Landau theory (Tolédano & Tolédano, 1987). The many-phase and one-phase approaches exploiting different strategies are valuable instruments for a general interpretation of the occurrence of instability in mineral systems, and can in such a light be employed for predictions. In particular, microscopic features associated with electron density and macroscopic observables related to thermal-elastic properties provide “token” signals that, linking irreversible processes thermodynamics and catastrophe theory in a unitary vision, herald the loss of stability and announce transformation of the original mineral phase in a more stable system. Changes of state and phase transitions provide examples of application of the notions abovementioned.

Bader F.W. (1994) - Atoms in molecules: a quantum theory. International series of monographs on chemistry. Vol 22. Oxford University Press.

Poston T. & Stewart I. (1996) - Catastrophe theory and its applications, Series: Dover Books on Mathematics. Dover Publications.

Tolédano J.C. & Tolédano P. (1987) - The Landau Theory of Phase Transitions. World Scientific Lecture Notes in Physics: Volume 3. https://doi.org/10.1142/0215.

Causes of color changes in tourmalines after thermal and irradiation treatments

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Keywords: tourmaline, crystal structure refinement, electron microprobe analysis.

The tourmaline supergroup minerals are complex borosilicate belonging to the cyclosilicate class.

These minerals can be considered not only precious multicolored gemstones, but also an important minerals for geological and petrogenetic research (Dutrow & Henry, 2011). Usually, tourmalines are treated with various methods to enhance their appearance and to make them more marketable. However, the processes involved in enhancing the aspect of these minerals are still widely debated. To investigate in detail these processes, five samples from five different pegmatite provinces were analyzed through a multi-analytical approach to identify the causes of color changes after two types of treatments: e-beam irradiation and thermal treatments. The selected samples exhibited pink and blue hues and one sample highly zoned colors. Oriented sections were prepared from each crystal and used for microchemical, structural, and spectroscopic analyses. The compositional variations were investigated by scanning electron microscopy (EDS SEM), electron microprobe analysis (EMPA) and micro laser induced breakdown spectroscopy (μ-LIBS). Structural information has been obtained through single crystal X-ray diffraction (SC XRD) and structure refinement (SREF). Their electronic and vibrational spectra were collected by UV-Vis, μ-Raman, and optical absorption spectroscopy (OAS). The data show that the different colors can be attributed to the presence of multiple chromophores, such as Mn and Fe and negligible quantities of Ti and Cu. The samples were subsequently irradiated with doses equivalent to 5.1x104 Gray and heated at T ranging from 450 to 600°C. Post-treatment characterization was performed exclusively using spectroscopic techniques that are sensitive to chromophores variations. Changes in Mn and Fe valence states in the UV-Vis and OAS spectra were observed after the different treatments: irradiation induces the oxidation of $Mn^{2+} \rightarrow Mn^{3+}$ and $Fe^{2+} \rightarrow Fe^{3+}$, resulting in darker colors in tourmaline, whereas the thermal treatments induced reduction of $Mn^{3+} \rightarrow Mn^{2+}$ and $Fe^{3+} \rightarrow Fe^{2+}$, producing brightening or even loss of color. Some exceptions were observed for certain zoned samples or those containing rare elements like lutetium and ytterbium. UV-Vis and OAS spectroscopy proved to be useful techniques for characterizing color changes.

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Crystal chemistry of clinopyroxenes and spinels enclosed in mantle xenoliths (Mandakh-Mandal-Gobi area, Mongolia)

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Keywords: mantle xenoliths, pyroxenes and spinels, petrological implications.

The Mandalovo volcano is one of many relict volcanoes located in the Mandakh-Mandal-Gobi zone (MMG), a region of alkali-basalt magmatism which extends entirely in the East Mongolian Volcanic Area (EMVA), the largest Late Mesozoic intracontinental volcanic domain in East Asia (Yarmolyuk et al., 2020). The origin of the EMVA is still debated (Yarmolyuk et al., 2020; Sheldrick et al., 2018), but two are the most accredited hypothesis. Sheldrick et al. (2018) claim that alkali-basalt magmatism could have been associated with the closure of the Mongol-Okhotsk Ocean and the following development of a subduction zone and lithospheric delamination processes between Late Jurassic and Early Cretaceous. By contrast, Yarmolyuk et al. (2020) argue that it could be related to a convergent boundary initiated along the eastern Asian margin. This resulted in the formation of parallel marginal volcanic belts and further into a composite large igneous province. Numerous lithologies related to those magmatic events are now forming the MMG zone, mostly basanites, hawaiites and trachybasalts, usually containing lherzolite xenoliths (Yarmolyuk et al., 2020). Composition and site-occupancy data of certain minerals contained within mantle xenoliths can give us important constraints on the geodynamical context in which they formed and on the cooling history of the rock (Dal Negro et al., 1982; Princivalle et al., 1999). In clinopyroxenes and spinels, for instance, the abundance and distribution of Fe and Mg in M1 and M2 sites and of Al and Mg in T and M sites can provide the intra-crystalline closure temperature of the system and hints on the depth from which the xenolith could have derived (Dal Negro et al., 1982; Princivalle et al., 1999). In this study we analyzed two mantle xenolith samples from the Mandalovo volcano to determine their modal mineralogy, mineral chemistry and structure of several spinels and clinopyroxenes. To determine the modal mineralogy, we performed PXRD analysis using a Siemens D-500 powder diffractometer at the University of Trieste. Data refinement was then accomplished using the Rietveld refinement method. To determine the crystal lattice features, cell and sites volumes and sites occupancy, we carried out SC-XRD using a KUMA KM4 at the University of Trieste and, to determine chemical composition of the minerals we performed EMPA analysis using JEOL-8200 Super Probe at the University of Milano Statale. Both samples were classified as spinel lherzolites (51.3-52.3% olivine, 35.6-37.6% orthopyroxene, 9.8-11.6% clinopyroxene and 0.3-1.5% spinel, error ±5%). Intra-crystalline closure temperature of the system was calculated at 797°C and 821°C from clinopyroxenes and 784°C and 767°C from spinels for the first and second sample respectively (error ±50°C). Those data are compatible with a slow cooling rate and an alkali-basalt emplacement-related origin. Pressure conditions from which mantle xenoliths could have been taken over by the basaltic magma have been estimated between 20 and 22 kbar, compatible with a 60 km-depth origin and concordant with chemical and structural information reported above.

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Yarmolyuk V.V. et al. (2020) - Late Mesozoic Eastern Mongolia Volcanic Area: Structure, Magmatic Associations, and Sources of Melts. Petrology, 28, 491-514, https://doi.org/10.1134/s0869591120060053.

Graphene-brucite 2D heterojunctions: an ab initio crystal-chemical investigation

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Keywords: graphene, 2D brucite, optoelectronics.

The null band gap of graphene is a well-known issue that limits some specific applications of graphene in opto- and microelectronics. This led to several research studies in the so–called van der Waals composites field (known as heterostructures, or heterojunctions), where two monolayers of different materials are stacked and held together by dispersive interactions. The properties of these composite materials can be tuned by different parameters, for example, the type of 2D materials employed, the number and the stacking order of the layers (e.g. AB-AB, AAB-AAB), and their spatial orientation relative to each other (Novoselov et al., 2016). Hence, using the words of Kroemer (2001), the heterostructures presenting specific interfaces between different materials become the device.

The idea here reported is to use brucite $Mg(OH)_2$ as a bidimensional material to modulate the optoelectronic properties of graphene. In fact, brucite presents both high surface flatness and hydrophobicity, it is a dielectric with large band gap and, differently from the silanol groups of the (001) quartz surface, the hydroxyl ions in brucite are regularly aligned along the [001] direction, forming an atomic-flat surface. Furthermore, brucite is widely available, both isolated and within the structure of chlorites, low cost, non-toxic, and easily cleavable. In addition, Kelvin probe force microscopy studies revealed that the brucite-like layer of clinochlore presents a hydrophobic behaviour, despite the presence of a high number of OH groups (Valdrè et al., 2011).

In the present work, the crystallographic relationships between a single (001) brucite layer and graphene were considered by realizing several heterojunctions with different sizes to properly account for inequivalent stacking and to investigate how the crystal-chemistry and point defects/substitutions could affect the position of the electronic bands, their occupation, and the emergence of possible band gaps.

Density Functional Theory simulations carried out at the PBE-D2 and HSE06 levels of theory demonstrated that the (001) brucite substrate can deeply alter the band structure of graphene, resulting in a heterojunction with either a more conductive behaviour or a small band gap. It is worth noting that the band gap opening in the Al-bearing brucite-graphene interfaces was about 30-45 meV, which is one order of magnitude greater than the values calculated for other important heterojunctions, such as the MoS_2-1H/graphene one. The graphene-brucite composite is held together by weak van der Waals interactions, with a binding energy that increases by including gibbsite-like Al^{3+}/Mg^{2+} point defects in the (001) brucite surface.

All these observations could open to further fundamental research of the physical properties of this kind of natural materials, useful for the design and implementation of innovative heterojunctions with tailored properties and improved features (Ulian & Valdrè, 2023).

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S22.

The science of clays and zeolites: from genesis to sustainable applications

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Mineralogical analysis of clayey earthflow materials and implications for assessing susceptibility to solid-to-fluid transition

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Keywords: X-ray diffraction, clay minerals, landslide.

The evolution of earthflows is understood to be polyphasic, characterized by periods of slow movement interrupted by dormancy. In some cases, earthflows can undergo sudden accelerations and increased mobility, known as surges, under specific conditions. These surges are often associated with a shift in the earthflow mechanism, transitioning from sliding dominance to flow dominance, due to material fluidization. This study focuses on understanding surge development and the solid-to-fluid transition of clayey earthflow materials by means of geotechnical and geomorphological approaches combined with mineralogical characterization of 14 selected earthflows in the southern Apennines of Italy. The geomorphological analysis revealed a variety of kinematic behaviours among the events with some displayed prolonged periods of dormancy, while other ones showed alternating phases of activity and inactivity. Earthflows materials here analysed are characterized by a relatively wide grain size distribution with a consistent presence of clay and silt contents that in most of these cases exceed 70%. These finer fractions ($d < 75$ μm) were mixed to corundum (20 wt.%) and then micronized (grain size < 10 μm). The resulting powders have been characterized from a mineralogical point of view by means of X-ray powder diffraction analyses (XRPD) using a Bruker D2 Phaser 2nd gen diffractometer and combined Rietveld and reference intensity ratio methods (RIR) with TOPAS 5 software (BRUKER AXS Company) (Cesarano et al., 2018). XRPD analyses were conducted to identify the dominant mineralogical phases in fine-grained sediment samples. Within the phyllosilicate phases, variations in proportions of chlorite (Chl) and kaolinite (Kln) were observed. The percentage of low-order and amorphous phases (LO-AP) encompasses remaining components, including mixed-layers, as well as potential thixotropic minerals. Among non-phyllosilicate and accessory minerals, quartz (Qz), feldspars (Fsp), carbonate phases (Cal), and occasional oxides (Opq) are ubiquitous. Carbonates primarily consist of calcite, with lesser proportions of dolomite, while being entirely absent in some samples. This absence is particularly significant, as carbonate dissolution can serve as a proxy for the weathering state of investigated materials. The findings could provide valuable insights into the mineralogical composition and weathering state of the sediment samples, contributing to a better understanding of their role in solid-to-fluid transition processes.

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A comprehensive study of ammonium removal from livestock effluents using zeolites in various operational scenarios

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Keywords: ammonium adsorption, natural zeolite tuff, cattle livestock effluents.

Treatment method for recovery of NH^{4+} from livestock effluents based on the adsorption process with zeolite-rich tuff is highly promising due to its effectiveness, lack of chemicals or toxic substances and social acceptance. The adsorption process is heavily influenced by numerous factors, whose combination determines the efficiency of NH^{4+} removal, for this reason the main focus of this study is to evaluate the interaction among several variables with the aim of finding the optimal operative conditions for a wide range of possible real scenarios. Since numerous studies have been conducted on synthetic solutions and few zeolites as adsorbents, this work has investigated the NH4+ adsorption process considering the interaction between authentic cattle livestock effluents as i) separated manure (SM), ii) separated digestate (SD) and iii) microfiltrated digestate (MD) and different types of zeolite-rich tuffs as i) chabasite (CHA), ii) clinoptilolite (CLP) and iii) phillipsite (PHI). All the materials tested in this study were supplied by WAM GROUP S.p.A. The initial [NH^{4+}] are respectively 729.91±57.00, 711.25±21.62 and 861.99±13.62 mg L^{-1} for SM, SD and MD. For each zeolite two different particle sizes were tested, fine and granular. Moreover, two operating temperatures (25 and 40°C) were tested for the digestates, while the experiments on SM are only referred at 25°C. The effects of stirring speed have also been investigated in kinetic studies. The [NH^{4+}] content was measured with the Kjeldahl method and further elaborations were conducted with R, while isotherm model fitting was performed with package PUPAIM.

The non Linear Langmuir Model has been considered the most representative for the treated materials, in line with existing literature. The experimental equilibrium data reveals that higher ion exchange capacities are associated with solid-liquid ratios ranging between 3 and 5%, so subsequent kinetic studies were conducted at 3%.

All kinetic curves have similar trends, characterized by an exponential increase in adsorption capacity followed by a plateau phase. The optimal agitation time for cost-effectiveness is 120 minutes for all the conditions. Higher temperatures and fine particle are associated with increased adsorption capacities; however, the temperature effect is significantly more pronounced than the size effect. The interaction between zeolite and MD shows better performance compared to SD and SM, likely due to greater homogeneity and slightly higher initial [NH^{4+}], which is also a crucial factor in the adsorption process. CHA and CLP show the most favorable response to treatment compared to PHI. Agitation speed is a parameter with negligible impact as long as solid-liquid contact is ensured.

This research emphasizes the importance of considering the specificity of all factors involved in NH^{4+} removal utilizing zeolites in order to identify the optimal operational conditions for the treatment process.

Exploring pressure-induced crystal structure and fluid interactions in ABC-6 zeolite group

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Keywords: zeolites, adsorption processes, X-ray crystallography.

The infiltration of molecules (or solvated ions) into the nano-cavities of microporous materials opens new routes for enhancing mass transfer from fluids to molecules incorporated in the structure. Thoroughly exploring this phenomenon, in both synthetic and natural zeolites, could expand their industrial applications, such as the development of new functional materials and enhancement of catalytic performance (Gatta et al., 2018; Comboni et al., 2020). From a geological standpoint, understanding this phenomenon can unveil the role played by zeolites as fluid carriers during the early stages of subduction of oceanic sediments and altered basalts.

In this research, we examined the interaction between crystals and fluids, driven by pressure, in three distinct natural zeolites belonging to the ABC-6 group: erionite (ERI framework type, 6-membered ring sequence: ABBACC), offretite (OFF, with AAB seq.), and bellbergite (EAB, with AABCCB seq.). The objectives of the experiments were: 1) to understand the potential role of erionite as a fluid carrier during subduction, given its presence, as a secondary mineral, in altered oceanic basalts (Vitali et al., 1995); and 2) to compare the mechanisms employed by structurally similar frameworks (characterized by the presence of 6-membered rings) in accommodating bulk compression and adsorbing new molecules.

The results revealed that erionite, a common zeolite, exhibits the highest magnitude of adsorption among the studied species. Additionally, the occurrence and magnitude of the phenomena were found to be governed by the H_2O content of the hydrous P-transmitting fluids. Offretite framework allowed Ne atoms to penetrate into the 12mRs channel in response to applied pressure, exhibiting weak Van der Waals interactions with the extra-framework population.

Comboni D. et al. (2020) - The elastic behavior of zeolitic frameworks: The case of MFI type zeolite under high-pressure methanol intrusion. Catal. Today, 345, 88-96, https://doi.org/10.1016/j.cattod.2019.10.007.

Gatta G.D. et al. (2018) - The effect of pressure on open-framework silicates: elastic behaviour and crystal-fluid interaction. Phys. Chem. Miner., 45, 115-138, https://doi.org/10.1007/s00269-017-0916-z.

Vitali F. et al. (1995) - Zeolite distribution in volcaniclastic deep-sea sediments from the Tonga Trench Margin (SW Pacific). Clay Clay Min., 43, 92-104, https://doi.org/10.1346/CCMN.1995.0430111.

Magnetic properties of bauxites and pre-fused hydrothermal product (zeolite)

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Keywords: magnetic properties, LTA zeolite, bauxite.

Bauxites are natural deposits resulting from weathering of aluminosilicates rocks under warm and humid conditions. They are mineralogically characterized by main the presence of boehmite [AlO(OH)], gibbsite [$Al(OH)_3$], and kaolinite [$Al_2Si_2O_5(OH)_4$], beside Fe oxides/hydroxides such as hematite [Fe_2O_3] and goethite [FeO(OH)]. This typical composition makes bauxite deposits as primary source for aluminum extraction and, subordinately, iron production. Moreover, the presence of iron in the typical chemical composition of bauxites can take a discriminating role in their exploitation.

However, mineralogical composition also makes bauxite as inexpensive source of silica and alumina for the zeolite synthesis and Fe oxides/hydroxides can provide important additional magnetic properties to this final product. Zeolites are crystalline hydrated aluminosilicates belong to the group of tectosilicates. Beside the excellent ion exchange and sorption capacity, zeolite can be characterized by other important properties such as magnetic features making them easily removable after using an external magnetic field (Belviso et al., 2015; 2020) and thus applicable in different fields, sometimes even very innovative ones.

In this work, three bauxite samples collected from Upper Cretaceous deposits of southern Italy were characterized for their magnetic parameters and used for the synthesis of zeolite with LTA topology (zeolite A). The results indicate differences in antiferromagnetic behaviour among the three raw materials. All the synthetic products, instead, display the same antiferromagnetic behaviour thus suggesting that the method used for the zeolite crystallization neutralizes the parameters responsible for raw bauxite magnetic differences.

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Belviso C. et al. (2020) - Effect of red mud added to zeolite LTA synthesis: Where is Fe in the newly-formed material? Micropor. Mesopor. Mat., 298, 1100583.

The clays involved in the 1963 Vajont slide: mineralogy, geotechnical characterization and geomechanical implications

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Keywords: Vajont landslide, illite/smectite mixed layer, tephra.

The Vajont landslide that occurred on 9 October 1963 caused about 2,000 deaths when 300 Mm^3 of rocks slid from the Mt. Toc slope into the newly created reservoir, displacing some huge water waves that flooded the nearby villages. Basal sliding occurred within a lithostratigraphic sequence of cherty-marly limestones and clay interbeds belonging to the Fonzaso Formation of Upper Jurassic age. We investigated the mineralogical (X-ray powder diffraction), geochemical (X-ray fluorescence) and geotechnical properties of the Vajont clays, which were collected from the landslide failure surface and the surrounding area. The clayey materials contained variable amounts of clay minerals (32-93%), calcite (5-66%) and quartz (2-20%). The dominant clay minerals were illite/smectite (I/S) mixed layers with a high illite content (85-50%), which was consistent with the high percentage of K_2O of the bulk (1.17-5.77%). Clay interbeds with a prevalence of clay minerals (CM > 71%) were characterised by low values of the residual friction angle (φres = 6.7-14.9°), whereas clayey materials with a large content of granular minerals had greater values of φres (19.5-26.7°). The Vajont clays included in the Fonzaso Fm. can be referred to as K-bentonites and can be interpreted as distinct deposits of volcanoclastic materials (tephra), representing the sedimentary inputs of volcanic ashes that interrupted the "normal" calcareous sedimentation during the late Oxfordian-upper Tithonian (158-145 Ma). The clay interbeds are the result of a temporal sequence of complex geological phenomena, including: (1) initial eruption and injection into the atmosphere of volcanic ash from a distance source; (2) transport by wind and subsequent sedimentation in the Jurassic Vajont Basin; and (3) weathering and/or alteration of the original volcanoclastic material caused by diagenesis and burial-related phenomena. Clay-rich interbeds within sedimentary sequences, especially those including smectite and/or mixed layers clays with low shear strength, represent a typical example in which a relatively minor geological feature has a major impact on the behaviour of the rock mass and the related slope stability condition. The Vajont clays played a different mechanical role in the occurrence of the prehistoric rockslide and the 1963 en-block remobilisation. When referring to the ancient slope failures, distinct clay-rich layers that were concentrated within some specific lithostratigraphic intervals of the limestone sequence caused a localised decrease in the available shear strength, allowing for relative shear displacements along the dip-slope bedding planes. This caused the formation of a stepped basal failure surface. During the 1963 remobilisation, the clay layers contributed to the average shear strength decrease of the debris material forming the basal shear zone of the slide, but the main triggering factor was the increase in pore pressures caused by the reservoir-induced groundwater inflow.

Analysis of practices with the potential to create sustainable value for the natural zeolite sector

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Keywords: natural zeolites, sustainable value, sustainable development.

The main objective of this research is to identify practices in the mining sector of natural zeolites with the potential to create sustainable value according to the dimensions of the framework developed by Hart & Milstein (2003). To this end, a theoretical foundation was made on the definitions of sustainable value and its implications for business models, especially those related to the mining sector, in which the natural zeolite industry is inserted. Following, the dimensions of the Hart and Milstein framework was characterized, namely pollution prevention, product stewardship, clean technologies, and vision of sustainability, with the aim of raising elements that could support the identification of practices with potential of sustainable value as the premises of each dimension. Supported by the theoretical foundation, an applied research was carried out, with a qualitative and exploratory approach, using semi-structured interviews with specialists, five of them professionals in the mining sector of natural zeolites and four stakeholders from the scientific community. As results, it was identified 41 practices which were analyzed, first, considering the conceptual foundations of this research and then, were associated with 18 different potentials ways of creating sustainable value. Finally, these practices were classified according to the concepts of the four dimensions of the framework proposed by Hart and Milstein. In the dimension of pollution prevention, techniques for collecting dust generated in the process to be sold as value-added products were mentioned. Regarding the dimension of product stewardship, it was discussed, among other practices, the challenges in reducing emissions in the distribution chain and which may present opportunities for partnership between companies in the sector. From the perspective of the clean technologies, the practices relate to the ability of natural zeolites to reduce the environmental footprint through technologies of the future were the main point of discussion. Finally, in the dimension vision of sustainability, practices related to the development of products that meet the needs of less favored countries were highlighted.

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Mineralogical characterization and alkaline activation of commercial metakaolins: potential applications

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Keywords: clay minerals, metakaolin, environmental sustainability.

Thanks to physical and chemical peculiarities, kaolin is an important resource both for environmental protection and for the prominent role it can play in sustainable technological development. After suitable heat treatment, it provides metakaolin (MK), a raw material that finds large implementation in industries field. The calcination of kaolin produces an amorphous phase with high pozzolanic hydraulic reactivity suitable for the manufacturing of ceramic-like materials after alkaline activation by means of Na or K silicate and Na or K hydroxide. The good physical-mechanical properties of these alkali-activated materials (AAM), combined with the low CO_2 emission in production processes, make them a viable sustainable alternative to traditional cementitious binders.

The present research stems from the collaboration among DST (UniSannio), DISTAR (UniNa) and BI-QEM SPECIALTIES SpA enterprise, to formulate and test new mix design of ceramic-like materials based on MK activated by alkaline solutions, as well as to test in the mixtures the superplasticizers produced by BI-QEM SPECIALTIES SpA, generally used for traditional cements.

This contribution reports preliminary data on the mineralogical characterization of two commercial MKs produced by IMERYS SpA (ARGICAL M1000S and M1200S) and the mixtures obtained to verify their alkaline activating capacity. The preliminary characterization was performed by using Fourier transform infrared spectroscopy with attenuated total reflectance module (ATR-FTIR), thermogravimetry and differential scanning calorimetry (TG-DSC) and X-ray diffractometry on powders (XRPD).

Typical absorption bands referable to the presence of kaolinite and quartz were observed in the ATR-FTIR spectra of both MKs. XRPD analyses confirm the presence of these phases along with anatase and illite/mica and, only for M1000S, of halloysite and chlorite. Thermal analyses confirm such mineralogical differences as well as a different total weight loss (LOI) (3.23 wt.% for M1000S and 1.58 wt.% for M1200S).

The heat treatments did not bring about a complete transformation of kaolinite in MK, particularly for M1000S which shows higher residual amounts of kaolinite, likely due to quite short calcination time or low temperatures. It is worth to note that the above reported mineralogical composition likely affects also physical properties such as Pozzolanic Index and Activity Index, which are 1100 mg $Ca(OH)_2$/g and 1.03 for M1000S and 1400 mg $Ca(OH)_2$/g and 1.10 for M1200S, respectively.

An ongoing phase of the present research is the evaluation of the geopolymerization reaction of commercial MKs with Na-AAM (in different proportions) and their compatibility with superplasticizers through comprehensive mineralogical, chemical and physical-mechanical tests.

Detailed characterization of mixed-layer illite/smectite provide new constraints for the geodynamic reconstruction of the Southern Apennines

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Keywords: mixed-layer illite/smectite, geodynamic evolution, southern Apennines.

Reconstructing the thermal history in thrust and fold belts is crucial to define the pattern of tectonic loading in thrust sheets that underwent exhumation during the subsequent evolution of the orogen, providing fundamental information for the geodynamic reconstructions.

In this study, differences in thermal maturity, indicating the original extent of regional thrust sheets in the axial sector of southern Apennines, were ascertained by using data on clay mineralogy. The area is characterized by the presence of clayey sequences that underwent tectonic loads of a few kilometres during their evolution. In particular, to deduce thermal maturity, we analysed illite-smectite (I-S) mixed layers by X-ray powder diffraction in 56 samples collected in the Lower Cretaceus Galestri Formation, which is characterized by a monotonous lithologies consisting of beds of micritic limestones intercalated in prevailing shale. This formation was originally deposited within the Mesozoic Lagonegro basin, representing a wide deep-sea domain located between the Apennine and the Apulia carbonate platforms. During the Miocene orogenic evolution, the Lagonegro Units were incorporated in the Apennine fold and thrust belt, and were in turn overthrusted by the Apennine Platform and by internal units derived from the Ligurian Tethys Ocean, such as the Sicilide and the Liguride Units. Finally, the Calabria Basement was tectonically superposed on the Liguride Units, as shown in northern Calabria. The Lagonegro Units presently make up two major thrust sheets (Patacca & Scandone, 2007). The upper thrust sheet (Lagonegro Unit II) consists of middle Triassic to lower Cretaceous proximal deposits, with abundant carbonate debris, whereas the lower thrust sheet (Lagonegro Unit I) is composed of upper Triassic-lower Cretaceous deep-sea deposits displaying distal facies.

The data show a strong variation in terms of thermal maturity between the two Lagonegro units. In fact, samples collected from the Lagonegro Unit II are characterized by the presence of R0 illite (25-55%)/S and R1 illite (60-70%)/S, whereas the samples from the deeper Lagonegro Unit I display R1 illite (65-85%)/S. More interestingly, mineralogical data show a general increase of thermal maturity from North to South along the axial zone of the chain, consistent with a higher tectonic loading in the southern sector of the fold and thrust belt. This is explained by a variation in the thickness of the tectonic pile originally present above the Lagonegro Units from North to South. In the northern sector, the Lagonegro Units were covered tectonically only by the Sicilide thrust sheet, whereas in the central sector the pile of tectonic units was significantly thicker since it included the Apennine platform and the Sicilide/Liguride Units. Even higher thickness is recorded in the southern sector, were the same units occurring in the central sector were possibly overthrusted by the eastern margin of the Calabria basement.

Patacca E. & Scandone P. (2007) - Geology of the Southern Apennines. Boll. Soc. Geol. It., Spec. Issue 7, 75-119.

Relationships between mineralogical and microstructural features in low-T metapelites from the Pollino area

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Keywords: P-T estimates in metapelites, microstructural analysis, southern Apennines.

Correlation between T conditions and deformation intensity in metasediments affected by low-T metamorphism in orogenic complexes can be documented by microstructural and mineralogical studies. This is because deformation significantly influences metamorphic reactions, promoting the growth of new minerals during development of cleavage planes (e.g., Knipe, 1981). The Pollino area represents an ideal area for studying these relationships since metapelitic rocks of the Liguride Complex show a nearly continuous variation from diagenetic to low-grade metamorphic conditions. Deformation and metamorphism are connected to the evolution of the Liguride accretionary prism, developed on top of the W-dipping subduction of the Ligurian Tethys oceanic crust from the Cretaceous to the Oligocene (Cello & Mazzoli, 1999).

The study has been performed by comparing mineralogical analyses of phyllosilicates obtained by XRD (Cavalcante et al., 2012) with microstructures observed by FE-SEM in rock fragments. Samples have been collected along a transect oriented about NE-SW which crosses metapelites characterized by different T overprint. In the northeastern sector, samples have been collected in the non-metamorphic North Calabrian Unit, where the presence of mixed I/S layers R1 and R3 indicate T varying from 110-140°C in the Saraceno Formation to 130-150°C in the Crete Nere Formation. Microstructures are mainly characterized by a S1 foliation, nearly parallel to the S0 bedding planes. Only in the Crete Nere Formation, microfolds are connected with the development of an incipient axial plane cleavage (S2).

The Southwestern sector is characterized by the low-grade metamorphic Frido Unit, characterized by strongly variable overprint from north to south, documented by variations in the Kübler Index (KI) of potassic white mica. Minimum T, corresponding to the transition from diagenesis to anchimetamorphism, can be estimated in the northern sector of the Frido Unit, while the highest T (300-350°C) can be determined in the southern sector. In the central sector estimated T ranges between 230 and 290°C. According with T estimates, a dominant S1 schistosity, overprinted by an S2 cleavage that develops along the axial plane of incipient crenulations, is observed in the northern sector. The situation changes markedly in the central sector, where the S1 appears intensely deformed by evident crenulations leading to the development of a marked axial plane schistosity (S2). In the central-southern sector, the Frido unit shows a dominant S2 schistosity, with relicts of the former S1 that can be observed in microlithons. The most intense deformation is observed in the southernmost sector, as indicated by an almost total disappearance of the S1 foliation, outlined by relicts of phyllosilicates orthogonal the main S2 schistosity. Results of the study indicate a marked relationship between T conditions and microstructural features in the metapelites of the Liguride Units.

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A sustainable use of carbonates-rich clays for alkali activated materials manufacturing

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Keywords: carbonates-rich clay, mechanical pre-treatment, alkali activated materials.

Kaolinite clay represents the main natural aluminosilicate precursor used as for manufacturing geopolymers and alkali activated materials (AAMs) owing to its high reactivity in alkaline environments. However, this natural source is no widespread on the Earth and suffers of competitive markets, so large-scale use of this type of clay cannot be considered. The use of polymineral clay sediments, on the contrary, could represent an viable alternative solution in the view of valorizing local resources. However, the chemical and mineralogical variability of polymineral clays can influence their potential suitability as AAMs precursors.

Among polymineral clays, carbonates-rich clay from Apulian region (Italy) was successfully tested in the formulation of AAMs alone and in combination with several industrial by-products (Clausi et al., 2023; D'Elia et al., 2023; 2020). Furthermore, it been noted that the performance of this clay during alkaline activation can be improved significantly after a combined mechanical-thermal pre-treatment (D'Elia et al., 2018). However, in a perspective of reducing the environmental impacts related to the thermal activation, more sustainable activation methods need to be evaluated.

This contribute is aimed at studying alkali activated materials obtained from carbonates-rich clay subjects to the sole mechanical pre-treatment as activation method to increase the clay reactivity. Mineralogical and textural changes occurred in the clay after the use of two different milling equipments (high energy vibro-miller and conventional ball miller) were prior investigated and showed a variable delamination of clay minerals and reduction of calcite grain size.

Different AAMs were prepared modifying both the alkaline activator used (NaOH 8M or a sodium silicate solution) and the curing temperature. The obtained samples were characterized by XRPD, FTIR, OM, SEM/EDX and mechanical tests.

Results showed as mechanical activation method strongly influences the microstructures of pastes. Compacted pastes with mechanical strengths up to 10 MPa and 17 MPa were obtained using sodium silicate as alkaline activator and a curing temperature of 85°C, from clay activated by conventional ball miller and vibro-miller, respectively.

Although further studies are needed to optimize compositional and technological parameters, the obtained findings are encouraging, enough to aiming further studies towards applications in construction industry and soils stabilization.

Clausi M. et al. (2023) - Alkali Activation of Clay and Water Potabilization Sludge Binary Blends: Influence of Composition and Curing Conditions. Sustainability, 15, 16623, https://doi.org/10.3390/su152416623.

D'Elia A. et al. (2018) - Effects of processing on the mineralogy and solubility of carbonate-rich clays for alkaline activation purpose: mechanical, thermal activation in red/ox atmosphere and their combination. Appl. Clay Sci., 152, 9-21, https://doi.org/10.1016/j.clay.2017.11.036.

D'Elia A. et al. (2020) - Effect of Alkali Concentration on the Activation of Carbonate-High Illite Clay. Appl. Sci., 10, 2203, https://doi.org/10.3390/app10072203.

D'Elia A. et al. (2023) - Alkali-Activated Binary Binders with Carbonate-Rich Illitic Clay. Polymers, 15, 362, https://doi.org/10.3390/polym15020362.

Red clays as alternative raw materials in porcelain stoneware tiles: the effect of iron on the sintering process

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Keywords: red clays, porcelain stoneware, iron effect.

The ceramic tile industry requires annually a huge amount of raw materials. Clays represent the 40% of them, while feldspars and quartz sand represent the remaining 60%. It is thus straightforward how the supply chain of these materials, mainly imported from outside the European Union, strongly affect the economy of the European ceramic districts. In Italy, before 2022, most of ball clays was imported from Donetsk basin, in Ukraine. The recent geopolitical upheaval poses serious questions on the supply chains. Moreover, there is recently a growing pressure for greater resource efficiency and the transition to a circular economy. From a technological viewpoint, it would be desirable to find other raw materials with suitable properties, such as appropriate plasticity, easy sinterability, and light color. Actually, porcelain stoneware classically consists of a batch with low iron content, typically below 1% by weight, which imparts light coloration. However, the new body formulations designed under the needs of higher sustainability entail a significantly higher iron content than the typical values. The understanding of the iron effect on the firing behaviour and performance of finished products has long been very little or at most limited to the colouring of the fired material. In this work, we present the characterization of two red clays deriving from quarries located near the Sassuolo ceramic district iron-rich (~7% Fe_2O_3). The features of these samples were compared with those of a German ball clay containing lower levels of iron (~3% Fe_2O_3). Moreover, we tested the effects of a partial substitution of Ukrainian ball clay body (used as benchmark) with the most suitable Italian red clay and the German ball clay into a standard batch for porcelain stoneware. The obtained bodies were fully characterized from milling to firing. Results demonstrated that the effect of relatively high iron content on the firing behaviour of porcelain stoneware tiles must be assessed together with the overall variation in the mineralogical and chemical composition of the batches. The use of red clays of different mineralogical composition has a clear impact on vitrification paths and on the temperatures at which maximum densification is achieved. This in turn affects the phase composition and the chemical composition of the vitreous phase at the optimal firing temperature. The firing transformations of Fe-bearing minerals consist in the formation of hematite (at expenses of Fe-oxyhydroxides) and incorporation in the liquid phase of iron made available by the breakdown of clay minerals. The Mössbauer analyses allowed to observe that in overfiring conditions the partial reduction of Fe^{3+} to Fe^{2+}, with release of oxygen, induces a significant bloating, higher in the Italian red clay bodies than German ball clay ones.

Enhanced adsorption of mycotoxin zearalenone by clay-chitosan-surfactant composite

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Keywords: clays-chitosan-surfactant composites, mycotoxin-zearalenone, adsorption.

Mycotoxins are a large group of highly health-hazardous contaminants which are frequently found in animal feeds, foods for human consumption and agricultural products. Aflatoxins, ochratoxin A, zearalenone (ZEN), fumonisins and trichothecenes are the most frequently occurring mycotoxins. Zearalenone is a common contaminant of corn and possess strong estrogenic activity causing serious reproductive problems in humans and animals. Various methods (physical, chemical and biological) have been taken to remove mycotoxins from contaminated animal feed. Among physical methods, adsorption is considered as the most efficient in treating mycotoxins contamination. Clay minerals (bentonite - BENT) as naturally abundant, green, non-toxic and low-cost are shown to be effective adsorbents for aflatoxin B1 - AFB1, but they are ineffective in binding other mycotoxins, like ZEN. In order to increase ZEN adsorption, modification of BENT with organic molecules such as surfactants is necessary (Lian et al., 2019). Recently, composites of natural biopolymers (e.g. chitosan) and clays have been studied as adsorbents for AFB1 and ZEN (Wang et al., 2020). Chitosan is a particularly interesting biomaterial due to its biocompatibility, biodegradability, antimicrobial activity and adsorption properties. In our previous work, a natural BENT from Beretnica deposit in the Republic of Serbia was modified with chitosan isolated from mushroom *Agaricus bisporus* under laboratory conditions - CM (composite BCM) (Kozarski et al., 2023) and subsequently with surfactant - hexadecyltrimethyl ammonium bromide in amount equal to 50% of the CEC of BENT (composite BCMS). Both composites were characterized by Fourier transform infrared (FTIR) spectroscopy and tested as adsorbents of ZEN. Characterization results confirmed presence of chitosan and/or surfactant in composites. The results on adsorption of ZEN showed that BCMS composite had a high adsorption of ZEN, while its adsorption by BCM and BENT was low, at pH 3 (Smiljanić et al., 2023). The aim of this research was to further investigate the adsorption of ZEN by BCM and BCMS composites. Composites were characterized by DSC/TGA analysis and by determination of zeta potential which additionally confirmed presence of chitosan and/or surfactant in composites. Adsorption of ZEN was followed at different amounts of composites in suspension at pH 7 and results were compared with toxin adsorption at pH 3. Adsorption of ZEN by BCM was also low at pH 7, while presence of surfactant in BCMS significantly increased toxin adsorption. Adsorption of ZEN by BCMS composite was followed at different initial ZEN concentrations at pH 3 and 7 and its adsorption increased with increasing of the initial toxin concentration at both pH values. Results confirmed that although surfactant ions in BCMS are responsible for adsorption of ZEN, composite also contains biocompatible chitosan isolated from mushroom with potential antimicrobial activity.

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Smiljanić D. et al. (2023) - Clay-chitosan-surfactant composites as efficient adsorbents of zearalenone. In: Sokić M., Marković B., Manojlović V. (Eds.), Proceedings of the 5th Metallurgical and Materials Engineering Congress of South-East Europe, Association of Metallurgical Engineers of Serbia, Trebinje, Bosna and Herzegovina, 371-376.

Innovative modified natural zeolites: effective strategies for hexavalent chromium removal from polluted waters

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Keywords: water, zeolites, filtration, chromium.

Industrial activities produce large volumes of wastewater containing harmful chemicals such as nitrogen compounds, heavy metals, anionic species like chromium, and surfactants. Improper disposal of these substances can adversely affect the environment and human health. Among the various cost-effective technologies for removing these contaminants, adsorption stands out as particularly effective.

Zeolites are affordable, eco-friendly natural minerals known for their impressive adsorption capabilities. These crystalline aluminosilicate minerals feature a symmetrical structure that creates a porous, three-dimensional framework. This structure gives natural zeolites the ability to act as cation-exchangers and molecular sieves, making them widely used in separation and purification processes to remove cations such as ammonium and heavy metals.

This study focuses on developing modified natural zeolites designed to exchange anions, particularly targeting chromate and dichromate ions. These ions are the two main forms of toxic hexavalent chromium [Cr (VI)] in water, posing significant environmental and health risks. Two modified zeolite formulations, BIZ and TIZ, were developed using saline exchange and surface metal modification techniques, respectively, starting from a natural zeolite consisting mostly of clinoptilolite, albite, orthoclase, muscovite, and quartz, with a Si/Al ratio of 4.8-5.5. The structural and morphological characteristics of the zeolites were analyzed using powder X-ray diffractometry (XRD) and transmission electron microscopy (TEM). Their effectiveness in removing chromium was tested through adsorption experiments using both synthetic and real contaminated water samples in batch and column tests.

The results highlighted the natural zeolite's inability to remove Cr (VI) effectively. However, the chemical modifications significantly enhanced the zeolite's selectivity for Cr (VI), substantially improving retention through surface adsorption, chemical reduction, and anion exchange mechanisms. While BIZ demonstrated higher adsorption capacities, TIZ showed quicker kinetics in chromium removal from water.

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Rosa M.I.G. et al. (2022) - Mechanisms of chromium(VI) removal from solution by zeolite and vermiculite modified with iron(II). Environ. Sci. Pollut. R., 29, 49724-49738, https://doi.org/10.1007/s11356-022-19366-w.

Unceta N. et al. (2010) - Chromium speciation in solid matrices and regulation: A review. Anal. Bioanal. Chem., 397, 1097-1111, https://doi.org/10.1007/s00216-009-3417-1.

The clays from the Campania sector of southern Apennines (Italy): new mineralogical and geochemical insights to reconstruct their sedimentological and stratigraphic evolution

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Keywords: clay successions, isotope fingerprint, geological origin.

Clay sediments are a relevant part of several stratigraphic records, and the study of their composition is a valuable tool for unravelling issues related to basin sedimentation and tectono-stratigraphic evolution.

This study aims at deciphering the relationship among clay successions from the Campania sector of the southern Apennines by combining mineralogical and geochemical investigations. These include mineralogical (X-ray diffraction), bulk chemistry (XRF), and Sr-Nd-isotope analyses. The investigated clays have already been the object of an extensive programme of survey and analyses carried out to identify the potential sources of clays used as raw materials for ceramics in antiquity in the Campania region of Italy (De Bonis et al., 2013). They are mainly associated with Lower Cretaceous to the Upper Miocene preorogenic/foredeep basin sediments and more recent Neogene synorogenic foredeep and postorogenic wedge-top basin deposits (Vitale & Ciarcia, 2018). The latter are mostly associated with carbonate sedimentation, which accounts for the Ca-rich chemical character of the clay sediments and for the presence of calcite. Feldspar is detected in most clayey sediments, while quartz is ubiquitous. Clay phases are composed of different phyllosilicate minerals generally including chlorite, kaolinite, and mixed layers, mostly represented by illite-smectite.

Isotope fingerprinting provides very interesting results that were already spotted during the implementation of this approach for the provenance study of archaeological ceramics (De Bonis et al., 2018). The extreme sensitivity of the Sr and Nd isotopes pinpointed the differences of clay sediments from a genetic point of view. Actually, distinctive isotopic fingerprints characterise the clay sediments of the investigated successions according to their geological origin and age.

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Vitale S. & Ciarcia S. (2018) - Tectono-stratigraphic setting of the Campania region (southern Italy). J. Maps, 14, 9-21, https://doi.org/10.1080/17445647.2018.1424655.

Alkaline and acid red mud-metakaolin based geopolymers: mineralogical and morphological characterization

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Keywords: red mud, geopolymer, zeolite.

Red mud is the primary waste product generated through the Bayer process for alumina production from caustic digestion of bauxite. It requires a proper management due to its high alkalinity (pH between 10 and 12) and for this reason its disposal represents one of the biggest issues in the mining industry. In the past, these bauxite residues were disposed of in natural or artificial water basins, but this management led to problems with the release of pollutants resulting in the contamination of the aquifers and the basins themselves. The annual production of red mud is higher than 150 million tons per year and for this reason new technologies are being developed for its treatment and reuse, according to circular economy and environmental protection. (Khairul et al., 2019).

Red mud combined to metakaolin represents a suitable material for developing geopolymer formulations. The composition of geopolymers is similar to that of zeolites, but unlike the latter, geopolymers have an amorphous structure. In fact, similar to zeolites, geopolymers are usually obtained from aluminosilicate precursors by polycondensation in an alkaline environment using sodium or potassium silicate. During this reaction, a three-dimensional network of SiO_4^{4-} and AlO_4^{5-} tetrahedra, with bridging oxygen atoms, is formed, characterized by the presence of rings of various sizes. Na^+ or K^+ from sodium or potassium silicate are used to balance the negative charges that are formed on the Al tetrahedral site. In addition to activation in an alkaline environment, in recent years an acid-type activation has also been developed regarding the geopolymerization reaction. As for the acid activating solution, a phosphoric acid solution can be used. Acid activation allows the production of poly(silico-alumino-phosphate) characterized by the presence of $[AlO_4]^{5-}$, $[SiO_4]^{4-}$ and $[PO_4]^{3-}$ units (Occhicone et al., 2024).

In this work, starting from red mud and metakaolin, both basic- and acid- geopolymer samples with dense, foamed (with the addition of foaming agent) or hybrid structure (with the addition of polydimetilsiloxane) were synthesized and characterized form chemical and mineralogical point of views by means of X-ray diffraction, optical and scanning electron microscope, Fourier transform infrared spectroscopy, mercury intrusion porosimetry. The obtained samples show excellent chemical and physical properties and high compressive strength (up to 63 MPa), suggesting their application in the building sector. In addition, preliminary tests suggest the effective use of these materials for the adsorption of organic pollutants, heavy metals and surfactants due to the presence of active sites and mobile metal ions. A comparison with the technological performance of clay- and zeolite-rich materials is provided as well.

Khairul M.A. et al. (2019) - The composition, recycling and utilization of Bayer red mud. Resour. Conserv. Recy., 141, 483-498, https://doi.org/10.1016/j.resconrec.2018.11.006.

Occhicone A. et al. (2024) - Synthesis and characterization of new acid-activated red mud-metakaolin geopolymers and comparison with their alkaline counterparts. J. Clean. Prod., 435, 140492, https://doi.org/10.1016/j.jclepro.2023.140492.

Mechanochemical technologies for decontamination of soils polluted by organic and inorganic xenobiotics based on the use of clay substrates and oxides/hydroxides

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Keywords: mechanochemistry, organic and inorganic pollutants, clay minerals.

The mechanochemical method, based on grinding reactants in solid phase, has recently attracted attention for its capability to degrade both organic and inorganic pollutants. Compared with other techniques, the mechanochemical method offers advantages for simple operations on a large capacity of materials, including toxic chlorinated compounds, by eliminating the use of organic solvent and facilitating the estimation of overall kinetic and thermodynamic parameters for the degradation process. The aim of this review is to highlight the models of xenobiotics-mineral surfaces reactions in mechanochemical treatments in which direct contact, i.e. without any solvent mediation as in the case of batch-type experiments, between the mineral surface and the organic ligand is achieved. The catalytic efficiency of mineral surfaces in degrading xenobiotics was investigated and the most probable xenobiotic degradation mechanisms and the adsorption sites most suitable for their catalytic degradation were identified. The phyllomanganate was the most efficient in removing both organic molecules and the degradation was also revealed by the release of increasing amount of Cl^- (for PCP) and Mn^{2+} ions (for both PCP and CAT) during the time of milling and the subsequent incubation time (Di Leo et al., 2012; 2013). From the spectroscopic analyses it is clear that Mn^{4+} octahedra represent the preferential sites for oxidative mechanism of PCP and CAT, by means of the formation of a monodentate and bidentate inner-sphere complex, respectively. Mechanochemical interaction of PCP molecules with the trioctahedral smectite is weak and mainly occurs on the external surfaces, thus causing amorphization of the trioctahedral clay mineral by formation of a double film of PCP molecules onto the mineral surfaces. On the contrary, the dioctahedral smectite exhibits strong mechanochemical interactions with PCP molecules via the phenolic group. Mechanochemical interactions of both pollutants with kaolinite mainly occurs via adsorption on external clay mineral surfaces through the phenolic group and, in the case of PCP, do not involve the chlorine atoms of the ring (Ancona et al., 2016).

Long-time grinding of expandable clay mineral (24 h) allowed Cd sorption on two sites (Di Leo et al., 2019): Type I, exhibiting characteristic of an outer-sphere complex likely localized in the montmorillonite interlayers and coordinated by two water molecule shells, i.e. in an exchangeable position; Type II sites, where Cd was more tightly bound to the TOT layers, either onto broken edges via the new OHs formed during the mechanochemical treatments or onto montmorillonite surfaces likely bridged via a water molecule. Desorption isotherms also confirmed a two-adsorption site model. This information could be useful to understand, develop and manage new remediation technologies based on mechanochemical treatments.

Ancona V. et al. (2016) - Sequestration of Catechol and Pentachlorophenol By Mechanochemically Treated Kaolinite. Clay Clay Miner., 64, 513-522, DOI: https://doi.org/10.1346/CCMN.2016.064031.

Di Leo P. et al. (2012) - Mechanochemical transformation of organic pollutants on mineral surfaces: the catalytic efficiency of phyllomanganate in catechol degradation. J. Hazard. Mater., 201-202, 148-154, https://doi.org/10.1016/j.jhazmat.2011.11.054.

Di Leo P. et al. (2013) - Mechanochemical degradation of pentachlorophenol onto birnessite. J. Hazard. Mater., 244-245, 303-310, https://doi.org/10.1016/j.jhazmat.2012.11.037.

Di Leo P. et al. (2019) - Cadmium decontamination through ball milling using an expandable clay mineral. Appl. Clay Sci., 182, 105256, https://doi.org/10.1016/j.clay.2019.105256.

Characterization and pre-treatment of low grade-clays for the preliminary evaluation of their suitability as precursor for alkali-activated binders

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Keywords: clay, clay characterization, AAMs.

In the current landscape of materials research, there is a growing interest in the development of low environmental impact binders and construction materials, such as the so-called alkali-activated materials (AAMs). Traditionally, attention has been primarily focused on the use of kaolinitic clays and waste materials as precursors for AAMs (above all fly ashes and blast furnace slags), due to their high content of silica and alumina, which constitutes a fundamental requirement for the synthesis of AAMs. However, the demand for more widespread and abundant source material has led to a shift in perspective, highlighting the importance of natural polymineralic clays as suitable alternative raw materials for AAMs owing to their high abundance throughout the world. Nevertheless, the use of polymineralic clays as viable aluminosilicate precursor for AAMs poses several problems due to their high chemical and mineralogical variability in nature, so further investigations are needed.

The present research deals with the characterization and pre-treatment of different types of clays from natural outcrops and originated as waste from anthropic processing, to evaluate their suitability as precursor for AAMs. Specifically, the investigation involves three natural clay samples, as well as several samples of clays from tunnel sludges and sediments dredged from port areas, showing significant difference in term of mineralogical and chemical composition. Samples under study were characterized based on a multi-faceted approach utilizing various analytical techniques such as X-ray fluorescence (XRF) and X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FT-IR) and grain size distribution analysis to evaluate their chemical, mineralogical and structural composition properties. Additionally, geotechnical and geomechanical tests, including oedometer and unconfined compression tests, were conducted to assess the soil mechanical properties. Furthermore, the selected clays were subjected to either mechanical and/or thermal treatment to increase their amorphous content and then their degree of reactivity during the alkali activation. Characterization of selected natural clay samples showed a great compositional variability depending on the type of clay and the geological context to which they belong. Specifically, the three natural clays samples consist of carbonate-illite-rich clay, illite-smectite interstratified clay and illite-rich clay, respectively. Tunnel sludges and port dredging sediments consist of illite-smectite dominated and carbonate-illite-rich clays, respectively, with relevant contents of organic matter.

The preliminary data of this study are part of a PhD research project aiming to gain a holistic understanding of the properties and behaviour of studied clays, elucidating their potential as both AAMs precursors and their performance as a binder suitable for various uses, e.g. for the mechanical improvement of soils or as supplementary cementitious materials.

Characterization and valorization of dam sediments: potential use in building materials

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Keywords: sediments, ceramics, clays.

In recent years the possibility of reusing large amounts of secondary raw materials has been investigated as it represents an important opportunity in terms of environmental preservation. In this respect, this study aims to explore the potential use of dam sediments as a raw material (for ceramic use such as in clay bricks, lightweight aggregates, ceramic tiles and cementitious materials). At first, the large artificial reservoirs present at a national level were identified and investigated in terms of capacity, geological characteristics, etc. Based on this information, the Mignano reservoir (Piacenza, Italy) was identified as suitable for the irrigation of approximately 14,000 hectares at a theoretical water flow rate of approximately 0.16 litres/sec per hectare. In this reservoir, sediment sampling was carried out in three different areas: upstream, central area and downstream. We subsequently carried out sample analysis in terms of physical-chemical and technological properties (chemical and mineralogical compositions, plasticity (Atterberg), thermal behaviour, optical dilatometry, plasticity, and particle size distribution). As a result, the dam sediments investigated are mainly made up of carbonates (22-25%), quartz (31-33%) and clay minerals (42-45%). Based on these findings, a feasibility study was carried out to explore the use of these sediments in the ceramic sector, particularly as partial substitutes for clay raw materials in clay brick mixtures.

Chitosan-clay composite films: investigation of functional and antibacterial properties for potential biomedical application

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Keywords: bentonite-chitosan composite films, functionality, antimicrobial activity.

The preparation of polymer-clay composites is gaining increasing attention as these functionalized materials can be used in biomedical fields (Dong et al., 2021). Chitosan is the most abundant natural cationic polysaccharide polymer, frequently used because of its special properties such as non-toxicity, biocompatibility, biodegradability, antibacterial activity, and film-forming ability (Jagdale et al., 2024). In this study, chitosan-based composite films with or without natural clay were prepared, and their functional properties (mass, thickness, and swelling), as well as their antibacterial activity, were investigated. The natural bentonite from the Beretnica deposit in the Republic of Serbia (BB) (CEC = 120 meq/100 g), commercial low molecular weight chitosan (Sigma-Aldrich, USA), glycerol (as plasticizer) and a 1% acetic acid solution were used for the preparation of composite films by casting and solvent evaporation, at polymer/clay ratios: 1.5:0.0 and 1.5:1.0. The samples were designated as F0 and FBB, respectively. The average mass and thickness of the FBB composite film (24±2 mg, *i.e.*, 140±6 μm) were increased compared to the parameters of the film prepared without clay (F0) (12±1 mg, i.e., 75±8 μm). The swelling capacity of the films after 4 h (pH phosphate buffer 5.8 at 37°C) was 536±54% for F0 and 302±43% for FBB. Although the FBB sample showed slightly lower swelling, the obtained results indicated that the composite film could absorb a considerable amount of water, which is very important in the case of its application as a wound dressing (Morgado et al., 2015).

The antibacterial activity of the prepared films was tested against *Enterococcus faecalis* and *Escherichia coli* using the log-reduction method. Both F0 and FBB inhibited the growth of *E. coli,* by 0.64 log10 CFU/mL for F0 and 1.60 log10 CFU/mL for FBB, compared to the 100% cellulose film used as control, although the inhibition of F0 was not significant. On the other hand, sample F0 showed pronounced inhibitory activity (by 1.56 log10 CFU/mL) against *E. faecalis*, while the sample FBB showed bactericidal activity inhibiting the chosen Gram+ bacteria growth by 4.0 log10 CFU/mL, compared to the control sample. The results indicate that the addition of BB significantly increases the antibacterial activity of chitosan films.

Considering the wide distribution of natural bentonite (such as BB in this study), which significantly improves the properties of chitosan film in terms of antimicrobial potential, these results have a future perspective in the production of affordable and effective dressings, with still high swelling capacity, for the topical treatment of damaged and/or infected skin.

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Enhancement of Microbial and plant Biodiversity by Restoration of degraded soils in Mediterranean Areas through marine Compost and zeolites Exploitation (EMBRACE project)

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Keywords: zeolite, marine bio-waste, soil restoration.

The endemic seagrass species of the Mediterranean Sea, *Posidonia oceanica* (L.) Delile, appears to be highly effective in C storage and its decline, due to direct anthropogenic activities and indirect disturbances, unbalances C sequestration dynamics. In addition, high amounts of *P. oceanica* litter deposit along the coasts of the Mediterranean Sea every year after leaves detaching from the rhizome during Autumn. Notwithstanding the fundamental ecological role of such deposits against coastal erosion, the use of beaches for tourism purposes currently implies the removal of these deposits, which are negatively considered by stakeholders. At the same time, fishing activities, comprising industrial and small-scale fishing, are responsible for high necromass production that also turn as an undesirable bio-waste.

In the last few years, valorisation of *P. oceanica* litter throughout anaerobic digestion and aerobic stabilization processes has been proposed as a valid alternative to landfill or incineration disposal, although the presence of sea salts can negatively affect these processes (De Sanctis & Di Iaconi, 2019). Zeolite-rich rocks, working as ionic exchanger of NH_4^+ (Langella et al., 2000), can be useful to reduce its content during anaerobic digestion process and loss of ammonia, via NH_3 generation, in atmosphere during the composting process. The moderate affinity of zeolites for Na^+ would also lower the salinity of the suspension marine waste/anaerobic sludge with presumable positive effects on both anaerobic digestion process efficiency and final properties of the marine compost originated from the aerobic stabilization of the digestate. Moreover, the natural zeolites can improve the properties of compost and of receiving soils, in terms of cation exchange capacity (CEC), porosity, aeration and water holding capacity. In this general frame, EMBRACE project (PRIN 2022 PNRR) aims at reaching two major objectives, represented by i) valorisation (in terms of both energy and matter) of a marine bio-waste and of a natural zeolite-rich quarry dust; ii) use of the obtained products (quality compost with natural zeolites) in restoring degraded soils of Mediterranean coastal areas (in terms of increase of both above- and belowground biodiversity).

This contribution provides the preliminary results about the chemical and mineralogical characterization of selected zeolite-rich rocks coming from abandoned quarry of Neapolitan Yellow Tuff Formation (i.e., ex Cava Suarez, Naples, Italy). This raw material shows a total zeolite content of ca. 40 wt.% mainly consisting of phillipsite and chabazite, and sporadic analcime. The amount of low-ordered and amorphous phases, that also could contribute to ion exchange processes, is estimated up to 29 wt.% whereas non-sorbent minerals are formed by feldspars (mainly sanidine), and subordinately clinopyroxene and micas. The total CEC values is ca. 2.5 mEq/g (0.95 mEq/g for Ca^{2+}, 0.83 mEq/g for K^+, 0.60 mEq/g for Na^+ and 0.13 mEq/g for Mg^{2+}).

Acknowledgements: These results, after a comparison with the technological features of zeolitic materials already available on the market, provide valuable information for a proper setting of the pilot tests of EMBRACE project (PRIN 2022 PNRR).

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Tailored porous geopolymers for efficient ammonium adsorption: towards sustainable agricultural nutrient recovery

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Keywords: porous geopolymer, ammonium removal, agricultural sustainability.

Geopolymers have emerged as highly eco-friendly adsorbents for wastewater treatment, offering promising potential in various applications. This study focuses on the development of porous geopolymers tailored for efficient ammonium adsorption, specifically targeting agricultural use. This research aims to synthesize different porous geopolymers using varying concentrations of foaming agents (H_2O_2) and natural surfactants, aiming to enhance porosity and optimize adsorption properties. Various porous geopolymers were synthesized by incorporating different concentrations of H_2O_2 and surfactants to induce a saponification reaction and promote porosity formation (Bai et al., 2018). Geopolymers with low bulk density ($0.44 < \rho b < 0.83$), water absorption ranging from 30% to 97%, and compressive strength between 0.2 MPa and 10.80 MPa were successfully produced. Characterization techniques including FTIR, SEM, and XRD were employed to analyze the structure and properties of the geopolymers. Analysis revealed a positive correlation between foaming agent content and open porosity, water absorption, and a negative correlation with bulk density and compressive strength. Similarly, surfactant content exhibited a positive correlation with open porosity and compressive strength while negatively impacting bulk density (Vitola et al., 2020). Batch adsorption experiments with different concentrations of ammonium demonstrated that adding hydrogen peroxides enhanced removal efficiency compared to the blank condition (Samarina & Takuloma, 2019). However, higher surfactant concentrations did not necessarily improve performance. The findings underscore the potential of tailored porous geopolymers for effectively adsorbing ammonium and removing it from water, to valorize this nutrient in agricultural settings. These insights contribute to advancing the development of sustainable wastewater treatment technologies, with implications for environmental and agricultural sustainability.

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Suitability of zeolitized tuff use in porcelain stoneware tiles production

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Keywords: zeolitized tuff, porcelain stoneware, technological properties.

In recent times, there has been an increasing demand for white-firing clay materials in ceramic tile production, due to a progressive shift towards porcelain stoneware bodies. Furthermore, geopolitical events have challenged the ability of industries to source raw materials for porcelain stoneware production from well-established European commercial channels. In this framework, there is a need to expand the possibility to use Italian raw materials to produce porcelain stoneware. For this purpose, residues of extraction and processing of zeolitized tuff (ZT) from two active quarries in Sorano (Tuscany) have been studied. The experimental work was carried out to characterize ZT, in terms of physical and chemical properties, and test it in porcelain stoneware formulations in place of feldspar. Four residues were characterized in terms of thermal properties by hot stage microscope (HSM) and the best material was defined by the higher thermal stability (lower bloating). Two different amounts were tested (10-20 wt.%) in comparison with a reference porcelain stoneware batch. The tile-making process was replicated at the laboratory scale. Tiles of 11 x 5.5 x 0.5 cm were shaped by uniaxial pressure then dried overnight. The industrial process was simulated by fast firing in electric roller kiln at maximum temperature in the 1180-1230°C range. The microstructure of the fired specimens at maximum densification was observed by scanning electron microscopy and colourimetric parameters were measured directly on fired tiles. Waste addition led to a reduction of green and dry bulk density of about 10%, not followed by a decrease in mechanical properties. All the studied batches show a maximum in linear shrinkage and bulk density at 1200°C, reaching the standard requirement for water absorption (<0.5 wt%). For mixture with 20 wt.%, the desired values is reached already at 1180°C leading to reduce thermal energy demand. An increase in firing temperature (1210°C) led to bloating more evident for the higher waste content, followed by an increase in water absorption. For the greatest addition of ZT, a clear worsening of technological properties can be observed passing from 1200 to 1210°C. At maximum densification temperature, mechanical properties are reduced by waste addition, passing from 41 to 37 MPa (always higher than the threshold of 35 MPa till overeating conditions). Feldspar substitution, given by the increase in iron content (3.75% in place of 0.13% Fe_2O_3), is followed by a limited colour change, with a ΔE value of 3.7 and 6.8 for samples fired at 1200°C. On the base of the achieved results, in terms of technological properties and thermal stability, both the ZT concentrations can be selected as suitable for porcelain stoneware production and industrial scale up.

Secondary and authigenic phase formation in the 50-year-old tuff from Surtsey (Iceland)

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Keywords: Surtsey ICDP, zeolite, hydrothermal alteration.

Subaerial and submarine lapilli tuff samples retrieved from a 152 and 192 m-deep vertical boreholes and a 283 m-deep inclined borehole drilled in 2017 in the frame of the SUSTAIN-ICDP drilling project on the island of Surtsey (SW Iceland), which is one of the Earth's best-monitored volcanic sites, were characterized throughout petrographic studies, X-ray powder diffraction analysis and systematic SEM-EDS imaging and chemical analyses. The island of Surtsey formed over a near continuous 3.5-year effusive and explosive basaltic eruptions from 1963 to 1967 (Jakobsson & Moore, 1986). Since its formation, the island was affected by authigenic alteration and secondary minerals precipitation. Surtsey volcaniclastic deposits consists in armoured lapilli tuffs in which authigenic phases, either amorphous or crystalline, formed from a fresh basaltic precursor glass (i.e., sideromelane; Peacock & Fuller, 1928). Sideromelane experienced alteration to palagonite, a metastable alteration product (Prause et al., 2020; Montesano et al., 2023) composed of a variety of amorphous/slightly-to-highly crystallized mineral products, the latter exhibiting characteristics of smectites (Montesano et al., 2023). Secondary minerals are instead considered to precipitate from interstitial fluids in pores or vesicles and primarily consist of calcium-aluminum silicate hydrate (zeolites, tobermorite and xonotlite), together with minor carbonates and sulphates.

The alteration path along the analysed subaerial and submarine sequences was identified through the integrated results, trying to develop a minerogenetic model to explain their genesis. This model would provide a reference framework for assessing the mineralogical evolution in other Surtseyan-type volcanoes.

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Application of Rietveld refinement for quantitive phase analysis of clays containing illite-smectite mixed-layer structures: the case study of Vajont bentonites

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Keywords: Vajont clays, I/S mixed layers, Rietveld.

The accurate mineralogical investigation of clays is very important for geological interpretations, as well as in applied studies. X-ray powder diffraction (XRPD) remains nowadays the most suitable and powerful technique for both clay minerals identification and quantification. However, whereas the identification of clay minerals by XRPD is today relatively feasible, their quantification remains challenging mainly in case of clays characterized by highly disordered or interstratified clay minerals. This work deals with the mineralogical quantification of the clay interbeds included in the limestone Jurassic Fonzaso Fm. outcropping in the Vajont valley, which are presently considered as a key factor in the occurrence of the famous Vajont landslide (Hendron & Patton, 1987; Bolla et al., 2020). The Vajont clays were referred to as K-bentonites and were interpreted as distinct deposits of volcanic ashes (tephra) that were included within the calcareous sedimentation during the late Oxfordian-upper Tithonian (158-145 Ma) (Paronuzzi et al., 2021). The investigated clays consist of very complex mixtures of illite/smectite (I/S) mixed-layer clay minerals, with five samples showing a prevalence of I/S mixed layers with *R0* stacking order (~50 % illite) and, subordinately, I/S *R1* type, whereas four samples are characterized by a prevalence of I/S mixed-layers with *R1* stacking order and variable illite content. Kaolinite, illite and chlorite were found in traces as further clay minerals, whereas calcite, quartz, and traces of K-feldspar were identified as non-clay minerals (Bolla et al., 2020; Paronuzzi et al., 2021). Quantitive Phase Analysis (QPA) of high disordered clays from Vajont was here performed using BGMN Rietveld software and structural models of disordered clay minerals developed by Ufer and co-authors (Ufer et al., 2012). QPA by Rietveld method showed very different mineral contents in the investigated samples, with total CM varying from 32 to 93 wt.%, calcite varying from ~5 to ~66 wt.% and amounts of quartz ranging from ~2 to ~20 wt.%. The soundness and validation of the here obtained results has been performed based on the comparison with XRF chemical data and calcite contents determined independently by calcimetry.

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Ethylene capture using natural and altered zeolites during the storage period of kiwifruits

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Keywords: zeolites, ethylene, climacteric fruits.

Fruit ripening is governed by ethylene, a plant hormone that plays a crucial role in various stages of plant life, including fruit maturation and senescence. Climacteric fruits, which continue to ripen post-detachment due to ongoing ethylene production, can have their shelf life extended by managing ethylene levels post-harvest. Ethylene can be absorbed using various methods and materials, such as potassium permanganate and zeolites. Zeolites are cost-effective, eco-friendly minerals with exceptional adsorptive abilities. Leveraging their cation-exchange capacities and molecular sieve characteristics, zeolites are predominantly employed in separation and purification tasks, particularly for extracting cations like ammonium and heavy metals. Enhancements to natural zeolites through methods like thermal treatment, acid activation, and organic or metal modification enhance their selectivity for specific targets.

This study explores the impact of natural (ZeoNat), acid-activated (ZeoH), iron-modified (ZeoFe), and copper-modified (ZeoCu) zeolites on ethylene adsorption during the postharvest ripening of kiwifruits under various storage conditions. Previous research has demonstrated these modified zeolites' capabilities in absorbing CO_2 and ethylene, with copper-modified zeolite proving most efficient. Two weeks post-incubation with these zeolites, ZeoCu significantly outperformed others in ethylene absorption, contributing to the highest firmness and lowest soluble sugar content in kiwifruits, thus indicating a delay in the ripening process. While kiwifruits with ZeoFe exhibited considerable weight loss over time, those stored with ZeoCu and ZeoH maintained substantial firmness levels even after three weeks of incubation.

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Clay sediments for health in the special geological area of the Euganean Hills

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Keywords: clays, mud therapy, raw materials.

The responsible use of natural resources can prove to be a formidable system for a sustainable management of our Planet. Clay minerals and zeolites are raw materials that could be widely used to support human health, and a lot of traditional and modern examples can be mentioned. Unfortunately, the cultural gap between the different disciplines makes everything complicated and the geological contribution to human health is a typical example of this problem. Today geologic materials are not considered as possible resources for health, both under routine or emergency conditions.

An example that partially bucks this trend is reported here for the Euganean Hills area. The Euganean Hills belong to a structural high, bordered by a main fault system which separates them from the Veneto-Friuli foreland. The fault system drives the strong thermal anomaly of the Euganean area, also represented by the rise of thermal water (Na-Cl type). The Hills form an isolated body within the alluvial plain, basically formed by magmatic bodies intruded at shallow depth during Eocene to Oligocene time (Pola et al., 2020). The magmatic masses intruded older marine sediments, so, it is common to observe isolated, densely forested peaks with steep slopes (magmatic lithology) and bordered by deformed sediments. Lake and marsh sedimentation occurred before reclamations, especially at the external border of the Euganean Hills (peri-Euganean depressions). Currently, two ponds are still active, they are also fed by hot springs and, being within a park area, these places are particularly picturesque. Raw materials used for therapies are traditionally taken from these small lakes, with the advantage of producing no dust, no visual impact, and no need for grinding (no additional cost, no silicosis). The lake sediments contain quartz, feldspars, carbonates and sheet silicates (low-ordered illite, mica, chlorite and kaolinite). Gypsum, pyrite and abundant organic matter are always present (Calderan et al., 2020). The particular sedimentary environment of peri-Euganean depressions possibly stimulates peculiar microbial activity, as diatoms frustules are abundant in the lake muds and non-fossilizing microorganisms occur in the same material aged at approximatively 40°C at the thermal centers (Gris et al., 2020). Selected molecules from an Euganean cyanobacteria show great therapeutic capabilities (Ulivi et al., 2011). The interaction of organic molecules and clays of the peri-Euganean depressions are poorly studied until now, possibly because only in the clay fraction minerals such as mixed layers illite-smectite are detectable. However, preliminary FT-IR data show that interactions already occur with bulk sediment.

The Euganean spas represent a worldwide benchmark for mud therapy and also thermal water is used for healing. An additional health tool is the natural landscape itself, which has a great potential for the rest and recovery of fatigued attention.

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Thermal stability of some natural zeolites from Georgia, Kazakhstan, and Armenia

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Keywords: heulandite, clinoptilolite, chabazite.

The thermal stability of zeolites is a critical parameter for their catalytic applications. Structural transformations that occur upon heating in three natural zeolites (Tsitsishvili et al., 2022) were studied by thermogravimetric analysis and X-ray powder diffraction. Our results show that tuff from the Tedzami deposit (Georgia) contains ~80% heulandite and ~10% chabazite and had a bulk chemical composition described by the empirical formula $(Na_{0.25}K_{0.06}Ca_{0.19}Mg_{0.15})$ $[AlSi_{3.6}O_{9.2}]\cdot 3H_2O$. This material loses H_2O in three stages: 60% at temperatures < 250°C, another 24% in the range 250-650°C, and the remaining 16% when heated to 800°C. A sharp endotherm was recorded on the DTG curve at 780°C. The thermograms do not show a sharp endothermic peak at 430°C and the heulandite/clinoptilolite 020 reflection in the X-ray diffraction pattern of the calcined sample does not decrease, which indicates the absence of a transition to the metastable phase heulandite B, although amorphization begins. At temperatures > 700°C albite begins to form; complete amorphization of chabazite occurred above 1100°C, leaving crystalline quartz, cristobalite, albite, and impurity iron oxides magnetite and hematite. The zeolite-containing rock from the Chankanay deposit (Kazakhstan) with empirical formula $(Na_{0.115}K_{0.079}Ca_{0.228}Mg_{0.175})$ $[AlSi_{2.96}O_{7.92}]\cdot 3H_2O$ contains heulandite, chabazite and quartz in approximately equal quantities and has a high adsorption capacity for water vapor after calcination at 400 and 800°C. The DTG curve shows sharp endothermic-effects at 629, 701 and 835°C; amorphization begins at 350°C and continues until the crystalline structure of chabazite is completely destroyed at ≈ 1000°C. At higher temperatures, the XRD patters shows peaks of quartz, albite, magnetite and hematite. The tuff from the Nor Kokhb deposit (Armenia) with empirical formula $(Na_{0.05}K_{0.07}Ca_{0.36}Mg_{0.08})$ $[AlSi_{5.12}O_{12.24}]\cdot 3H_2O$ contains more than 80% of clinoptilolite, the tuff loses 70% of water when heated to 450°C, the rest up to 900°C. Upon heating, the material transforms into a heulandite-B phase at ~ 457°C, and at temperatures > 600°C, Ca-feldspar begins to crystallize. The DTG curve shows a weak endothermic effect at ~ 690°C, and the clinoptilolite 020 and 200 *d* values over the temperature range 500-700°C first increase and then decrease, indicating expansion followed by collapse along the *b*-axis by 0.13 Å and along the *a*-axis by 0.18 Å. Amorphization begins at ~ 500°C, but the broadened diffraction peaks of clinoptilolite remain in X-ray diffraction patterns up to ~ 950°C when the dehydration process is completed. The results obtained will be useful for determining the possibilities of using the studied zeolites as catalysts or supports.

Acknowledgements: This work was supported by the International Science and Technology Center (https://www.istc.int/) under the project GE-2506.

Tsitsishvili V. et al. (2022) - Characterization of Georgian, Kazakh and Armenian natural heulandite-clinoptilolites. Bull. Georg. Natl Acad. Sci., 16, 115-122, http://science.org.ge/bnas/vol-16-4.html.

S23.

Assessing and mitigating natural risks: a multidisciplinary path from Geosciences to Citizen Science

CONVENERS & CHAIRPERSONS

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An early warning system experiment for landslides in Grassano (Matera, Basilicata, Italy) with the active participation of the local population and self-made open-source instruments

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Keywords: landslide, long distance monitoring, citizen science.

Can the concept of Citizen Science be applied to the field of landslide warning systems? Italy is certainly a geologically unstable country with vast areas at risk of landslides, some of which, despite having been studied at an academic level, do not have any warning system that can save the population involved at the first signs of ground movements (Budmir et al., 2022). In Grassano, a small city in the Basilicata Region, in the summer 2023, the authors started an experiment to monitor some landslide risk points together with the retrieval of historical studies on the stability of the soil and moments of dissemination for the local population. Two types of instruments were deployed: two self-made sensors, sensitive to surface ground movements, and one SAR reflector (Morigi, 2015) sensitive to micro movements of a crumbling house, covering an area of about 1 square km. The two vibration sensors were built and installed by the authors, using open source hardware and software. The ground sensor is similar to others already used in landslide risk situations with the aim of issuing alarms to the population living nearby (Biansoongnern et al., 2016), but it uses a new transmitting technology, the radio LoRa (https://www.semtech.com/lora/what-is-lora), that is a low power and autonomous radio digital transmitting system. An iron pipe about 2 m long and 4 cm in diameter is buried about half in the ground. Inside, a smaller tube, containing a shock sensor, is suspended by a thread and free to oscillate. Both the inclination of the tube, due to the slow movement of the ground measured by an accelerometer, and the impact with stones or rapid movements of the pipe, generate the emission of an alert message. It is picked up by a receiver located in a house approximately 1 km away, where it is forwarded on the Internet. Power is provided by a LiPo battery re-charged by a small solar FV panel. The receiving node selects only the messages coming from the desired TX nodes. The vibration sensors have proven to be autonomous for at least 6 months.

The people of Grassano, including some authors of this article, were fundamental to the success of this first experiment in terms of helping to install the instruments and finding information on previous studies on soil stability. Furthermore, during a day organized in the Municipal Theater, the project was presented to the local population and a debate ensued, demonstrating the interest in these topics.

The Grassano experiment has demostrated the feasibility of a sensor network system based on a new low cost transmission technology with long battery life and without the need for third-party infrastructure. More sensors, even of different variables such as precipitation, or soil moisture, can be placed in other points within the receiver's sensitivity range and using the same transmission technology. People can be involved in sharing the costs and the responsibility for decisions to be made before and during possible emergencies.

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Biansoongnern S. et al. (2016) - Development of Low Cost Vibration Sensor Network for Early Warning System of Landslides. Energy Procedia, 89, 417-420, https://www.semtech.com/lora/what-is-lora.

Morigi M. (2015) - Osservazione dei fenomeni deformativi nel centro di Roma. Dall'applicazione di tecniche avanzate DInSAR, all'analisi qualitativa della natura del rumore dei dati COSMO Sky-Med. Archeomatica, 6(2), https://doi.org/10.48258/arc.v6i2.883.

Climate change adaptation and mitigation strategies in the Kenyan Rift Valley: the case of Baringo and Bogoria lakes

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Keywords: adaptation and mitigation strategies, cost-effectiveness analysis, inland water management.

Over the past decade, the rising water levels of the Rift Valley lakes (Eastern Africa) have left trails of destruction, with the consequential loss of farmland and homesteads. The current study aims to identify the most affected and vulnerable areas in Baringo county, Kenya, where two lakes' - an alkaline one (Bogoria) and a freshwater one (Baringo) - have been expanding over the past fifteen years. In the present paper, a multi-disciplinary approach leveraging remote sensing and georeferenced household data is carried out to assess the socio-economic vulnerability of the affected communities. Upon the identification of the most vulnerable communities and in-field visits, a set of sustainable adaptation and mitigation interventions including sensitization workshops, plantation interventions, and naturalistic engineering works. Furthermore, such measures are evaluated via a cost-effectiveness analysis, to provide policy valuable costing insights and actionable recommendations to the local authorities.

Citizen Science for the enhancement and knowledge of the territory: the YouthMappers@Uniba experience

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Keywords: citizen science, collaborative mapping, OSM.

Mapping practices and policies have evolved considerably over recent decades. Advances in geoinformation technologies have changed the way information is collected, analysed, stored and distributed (Olteanu–Raimond et al., 2017). In this sense, it is important to underline the emerging role of the citizen as a source of data. Due to the proliferation of location-aware devices and the opportunities of Web 2.0, it is now possible for citizens to easily acquire, share and use geographical information (See at al., 2015). One of the most famous tools, in this sense, is OpenStreetMap (OSM), a free, open geographic database updated and maintained by a community of volunteers via open collaboration. Contributors collect data from surveys, trace from aerial imagery and also import from other freely licensed geodata sources.

In recent decades, the tourism sector has represented a great resource for our country: it guarantees constant attraction and use of new resources for the valorisation and promotion of the national heritage, in line with the pursuit of Sustainable Development Goals. The Puglia region (Southern Italy) is one of the most famous regions in the world for its vast geological, natural and historical heritage. The region, in fact, is characterised by the presence of important Geosites, non-renewable geological-geomorphological assets of scientific and environmental value, and consequently great potential for the development of geotourism. However, numerous itineraries for trekking and hiking are available, these are not adequately signposted or accessible, and therefore tied to poor information.

In this perspective, the activities of the YouthMappers@Uniba (YM@Uniba), a group of young volunteer mapping students and researchers from the Department of Earth and Geoenvironmental Sciences of the University of Bari 'Aldo Moro', aim at mapping paths and amenities, within OpenStreetMap, of areas included in the National Park of Alta Murgia. This area is famous for the geological uniqueness and potential geotouristic appeal and is the first territory in Puglia aspiring to become a UNESCO Global Geopark (Tropeano et al., 2023). In addition, this part of territory is characterised by the presence of sinkholes, natural cavities produced by karst processes in soluble rocks, and man-made cavities deriving from different types of human activities in different historical ages. The related hazard is extremely high, so thematic maps (also derived from collaborative mapping) are crucial to manage and monitor sinkholes occurrence. The mappers acquired various data about (not only) paths, amenities and landscape features, through field trips, involving students from the Department's degree courses and transversal skills. This allowed the mappers to put their skills and background at the service of the large OpenStreetMap community.

The importance of such activities that include collaborative mapping lies in the possibility of continuously updating the information of the territory, a limitation that a 'traditionally' published map presents for obvious reasons.

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Tropeano M. et al. (2023) - Geological Uniqueness and Potential Geotouristic Appeal of Murge and Premurge, the First Territory in Puglia (Southern Italy) Aspiring to Become a UNESCO Global Geopark. Geosciences, 13(5), 131, https://doi.org/10.3390/geosciences13050131.

The (un)stable stewardship: The Earth Sciences amid accrued vulnerabilities, climate disruption, and resource management

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Keywords: poly-crises, strategic interests, solutions.

Back in the XVIII century, the Earth sciences were born out of deciphering ancient life forms teeming in an aboriginal environment, unfolding on a planet that could be explained only by looking at the Solar system. In our complex and vulnerable times, modern Earth Sciences, cross-disciplinary by nature, are among the best tools to gauge location, amount, economic turnout, and societal costs of managing a delicate, densely populated landscape and the need to exploit natural resources – finite, dwindling, or more costly, not just economically.

Often depicted as the "natural aircraft carrier of the Mediterranean", Italy's landmass intrinsically holds a formidable combination of geodynamic, environmental, and strategic factors that have concocted a remarkable landscape, a host of resources, and a number of interests – some far beyond what the layperson may perceive.

Projections concerning global population rise indicate that 70% of the world's population will concentrate in urban areas (as opposed to 70% in rural areas in 1950). Such redistribution is also driven by systemic, long-term migration shifts – due to climate, resources, risks – and by unpredicted factors – from vulnerabilities to instabilities. The resulting, complex pattern is expected to pressure the environment (natural and built) at an unprecedented scale – a phenomenon already revealed by geophysical evidence in critically expanded coastal agglomerations.

More, larger cities are thus expected to draw larger amounts of energy and subsurface resources, and to compound fragile coastal environments. While such evolution may more acutely affect world regions further away, selected Italian coastal stretches are of course exposed to various natural hazards, of diverse wavelengths and spatial patterns (earthquake, tsunami, drought, sea-level rise). Some of these are in part accrued by the unique dynamics of the Mediterranean basin, while pre-existing, overlain vulnerabilities in the built environment (not merely the one belonging to our cultural and historical heritage) make for a critically delicate case of remarkable relevance throughout the Mediterranean Sea.

Since striking a balance between exploiting (ever-changing) resources and adapting to (broadening) hazards is a task that may elude any single country, the Earth Sciences should be inherent to national and international strategic choices, in the best interest of societies and governments. Such interest includes deciphering the novel challenges revealed by poly-crises and hybrid threats that mark the XXI century since its very outset.

Our collective perception about global strategies, international positioning, and existential outlook should therefore evolve, both as global societies and as a scientific community not just entitled but dearly needed to lead ways and prospect co-designed solutions, both realistic and imaginative.

Coastal and marine hazard awarness throught citizen science in School

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Keywords: citizen sciences, beach, anthropogenic pressures.

Citizen sciences activities can actively reduce the effects of natural hazards on the territory, because they spread awareness and responsiveness in individuals.

The Taranto area is infamous for the anthropogenic pressures affecting natural systems and sedimentary environments of extreme beauty and in some cases unique to the entire Mediterranean basin.

As part of this project, we chose to make a group of about 250 children attending elementary school in Taranto (Istituto Comprensivo Statale Cesare Giulio Viola) to make them active citizens of the future.

Specifically, in this project called "RicercAttori dei due Mari" the participants were shown how the beach system works, what sedimentary dynamics act on the system, and what pressures cause the greatest sediment volume losses. In addition, through experiments analogous to the real environment, participants understood how exceptional events acting in the coastal marine environment are triggered and are expected to increase in response to ongoing global climate change.

Finally, participants learned how to classify the grains that constitute beach sands in order to assess the health of beaches in a simplified manner compared to the procedure proposed by Lapietra et al. (2022) and classified sands from beach samples from Lizzano (Taranto). These sediments are particularly rich in bioclasts, so the connection between beach health and that of the shallow marine environment is particularly evident for this coastal stretch. such a data collection activity allowed participants to understand that the sandy beach environment is the result of a delicate balance between physical, biological and anthropogenic processes; that the risk of coastal erosion is linked both to land management and to our daily choices; and, finally, that active citizenship can act as a needle in the balance and direct the choices of decision makers, and act directly for a sustainable exploitation of the coast.

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Students' engagement in coastal monitoring activities: preliminary outcomes from the Marevivo NauticinBlu project

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Keywords: citizen sciences, beach, monitoring.

Coastal areas are directly and indirectly affected by anthropogenic impacts. Worldwide coastal sectors are suffering from the high densities of litter items, whose sources are located both inland and offshore. To assess the beach litter (BL) distribution and to define litter composition and origin, monitoring programs are periodically carried out following standardized procedures.

In this contribution, we describe the monitoring activities carried out in the period February-March 2024 in the frame of the MAREVIVO NauticinBlu

The program has involved a total of 250 students from 3 high schools of Apulia Region, who participated in the field activities carried out along the urban beaches in Bari, Molfetta (BA) and Brindisi.

BL monitoring has been performed by analyzing the emerged beach sector, from the shoreline to its inland limit, represented by the seaward limit of the vegetation or by an anthropogenic structure (e.g. street, sidewalk). BL elements have been counted and classified according to their composition (metal, glass, plastic) and typology (e.g., bottles, cans, fragments).

Collected data have been synthesized in the form of graphs and maps, by exploiting the use of GIS software.

Active involvement of students is an appropriate way to raise their awareness toward one of the main critical issues affecting the coastal marine environment. A higher awareness is aimed at making students active citizens in prevention activities and promoting their involvement in data acquisition as part of citizen science initiatives to support scientific research activities.

Submarine fluid escapes: their role on ground instabilities. Learning examples of RETURN project

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Keywords: fluid escapes, ground instabilities, submarine landslide.

The submerged structures associated with the term "Fluid escapes" are morpho-structural evidences of particular importance, linked to processes of fluid uprising, such as water or gas, from the seabed. Depending on their depth, the nature of the emitted fluid, their extent, and the area involved, both superficially and, especially, in the stratigraphy of the seabed, these effusions can play a significant role in the formation and triggering of submarine landslides. Studies conducted under the RETURN Project have allowed the analysis of these structures from geological, morphological perspectives, and to undertake an initial geo-mechanical approach. Analyzing the possible geomechanical variables associated with structures such as Pockmarks, Mounds, and Mass Transport Deposits (MTD) (Sultan et al., 2004) is indeed necessary to extract quantitative data and to study the geological evolution of these structures and the submarine landslides associated with them. The offshore of Palermo gulf and Sciacca gulf (Ag) are Sicilian marine areas where such structures are observed. In the Palermo gulf, Pockmarks are observed along the continental slope (Lo Iacono et al., 2011), and two large submarine landslides are connected to them. The formation of landslides is linked to the presence of unconsolidated sediment associated with these structures because the uprising fluids also impregnate the sediments of the flowed layers, thus causing the rupture of cohesive forces. In contrast to the pockmarks, which are depressions, the offshore area of the Sciacca Gulf (Servizio Geologico d'Italia, 2024) exhibits Mounds ([MM1] mud volcanoes). They are distributed along at least three lines of weakness, each about 2 km long and perpendicular to the coastline. The presence of these structures also indicates submarine areas with the active presence [MM2] of loose sediments susceptible to submarine landslide formation. Free gas accumulations (highlighted by enhanced seismic reflections) can be found below mass-transport deposits (MTD), whose seal capacity is attributed to its intensive consolidation in response to differences in capillary pressure and porosity. As demonstrated for the Pearl River Mouth Basin (South China), a retrogressive slope failure could be responsible for a lateral migration of free gas (Sun et al., 2017). Therefore, the identification and analysis of Pockmarks, Mounds and MTD lateral extensions comprise an important geohazard in terms of fluids escape structures prevention and control.

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Probabilistic hazard maps of pyroclastic density current at Vesuvius volcano (Italy): a new strategy for risk reduction

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Keywords: probabilistic hazard maps, pyroclastic density current, Vesuvius.

Pyroclastic density currents are ground-hugging gas-particle flows that can originate during a volcanic explosive eruption. Dilute pyroclastic density currents are one major source of hazard at Vesuvius volcano (Italy). By combining data of deposits of the explosive eruptions of the last six thousand years and interpolating data of impact parameters (velocity, density, particle volumetric concentration, temperature, dynamic pressure), which were calculated by modeling the currents as stratified turbulent boundary layer flows, probabilistic hazard maps were obtained. They show the decay trend of the impact as a function of distance from the vent and allow depicting the expected damage. This outcome can help civil protection authorities to more precisely-implemented mitigation measures and communicate more effectively the risk to decision-makers and the population.

Zoning of territorial hazard for the evaluation and mitigation of hydrogeological risk: morphometric, meteorological, climatic, geolithological and hydrogeological - hydraulic analysis of the Rio Corr'e Pruna basin (Sardinia - Italy)

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Keywords: zoning, hydrogeological risk.

In October 2018, the Province of Southern Sardinia had to carry out 9 emergency interventions due to adverse meteorological phenomena that struck the Sarrabus region. In the first planning phases, historical analyzes were carried out on the extreme phenomena that affected the south-eastern areas of Sardinia (Sarrabus – Gerrei). The cyclical model detected identified frontal movements coming from the coastal plains which propagated from the sea, from the South-East quadrants ("Scirocco wind") towards the inland reliefs. The exceptional dimensions of the storm phenomena have been classified as "Mediterranean cyclones". Historically, exceptional meteoric events have hit the Sarrabus areas in the years 1900, 1907, 1910, 1940, 1951, 1953, 1971, 1986, 1993, 2013, 2018, 2021.

The particular conformation and geographical exposure, as well as the geological structure of the territory characterized by Hercynian plutonites (Leucogranites and Granodiorites of the Upper Carboniferous - Permian plutonic complex), periodically exposes the encountered terrains, formed by alteration materials and related pedogenic horizons, to intense surface flow events that fuel important movements for solid transport.

From the analysis of the archive data recovered it was possible to highlight a differentiation of the vulnerability parameters detected during the flood events that occurred over time. In fact, the demonstrations of the first half of the 20th century highlighted huge problems localized above all in the countryside and therefore in agricultural activities (typical of generalized flow regimes, i.e. non-organised/non-channeled flow networks).

The subsequent flood events (late 20th century and first decades of the 21st) also caused extensive damage to roads, works of art, bridges and embankments (built in these periods). The latter, responsible for regulating the large flow contributions on artificial drainage networks, have historically been sized on the basis of scientific knowledge of the time and basin planning which is no longer appropriate.

The morphometric, geolithological, hydrometeoric study, carried out at the time by the author on the Rio Corr'è Pruna Basin, was partially revisited and updated by the same during the planning of the 9 safety and refunctionalization interventions carried out by the Southern Province Sardinia (financed in accordance with the provisions of O.C.D.P.C. n° 558 of 15.11.2018).

The greater in-depth studies carried out using the aforementioned study as a basis have made it possible to use part of the data in order to evaluate and size the safety interventions according to the geological-hydraulic hazard zoning of the Rio Corr'è Pruna Basin.

Hazard from endogenous gas emission in the north and center Lazio Region

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Keywords: carbon dioxide -CO_2, hydrogen sulfide -H_2S, gas hazard.

Lazio Region is characterized by the presence of several endogenous gas discharges, mainly hosted in the Quaternary volcanic complexes, which release large quantities of CO2 into the atmosphere. The total CO_2 emission varies from few to hundreds tons/day, and some discharges have gas fluxes comparable to those of quiescent volcanoes. The origin of CO_2 is attributed to a deep mantle source or to a magmatic source, as for the dormant volcano of the Colli Albani. In many areas, H_2S is also present and is the second most abundant gas. Both CO_2 and H_2S are toxic and tend to accumulate in morphological depressions where dangerous or lethal concentrations can be reached. In Lazio Region, several accidents have occurred to people and animals due to the inhalation of endogenous gases, as reported in the catalog of Italian dangerous degassing sites (Googas Catalogue, 2009). The most recent lethal accidents are worth mentioning: in 2000 two hunters in Vejano (VT); again in 2000, at Cava dei Selci gas discharge (Marino, Rome) the gas killed 29 cows, then over time also six sheep and many other animals (Carapezza et al., 2003); in 2001 a man also died in Cava dei Selci; in 2005 in Fiumicino (RM) an entire family suffered gas poisoning without lethal consequences; in 2011 a man died and three others were poisoned in Lavinio (Anzio, RM) (Barberi et al., 2019) and two people died in a spa in Suio (Castelforte, LT). Obviously, the number of episodes of intoxication due to natural gases is much higher. Gas discharges are found in rural areas (i.e., Palidoro, Vejano and Latera), in natural reserves (i.e., Tor Caldara, Caldera di Manziana, Canale Monterano) as well as in urban areas (i.e., Cava dei Selci-Marino, Ciampino, Lavinio, Fiumicino) and here the risk associated to the gas emissions is higher due to the presence of people living nearby. We present the results of a systematic study carried out on most of the gas discharges of Lazio Region aimed at investigating their chemo-physical characteristics and at assessing the gas hazard.

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Carapezza M.L. et al. (2003) - Gas hazard assessment in a densely inhabited area of Colli Albani volcano (Cava dei Selci, Roma). J. Volcanol. Geotherm. Res., 123, 81-94, https://doi.org/10.1016/S0377-0273(03)00029-5.

Googas Catalogue (2009) - Results of the INGV-DPCV5 project: the catalogue of Italian gas emissions, http://googas.ov.ingv.it/.

Sinkhole risk perception in the urban area of Altamura (Southern Italy)

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Keywords: sinkholes, risk perception, urban context.

Collapse sinkholes (Gutierrez et al., 2014) may occur in territories characterized by both anthropogenic and natural underground voids. In both cases they force local communities to deal with significant sinkhole hazards that are characterized by the absence of clear precursory signals and the rapid kinematics. In most cases, communities seem to underestimate the sinkholes formation since the underground voids are out of sight. Collapse sinkholes have occurred above galleries of the underground quarries (Pepe et al., 2013) in the municipality of Altamura (Apulia Region, Southern Italy) causing problems and fear among the population.

Starting from these considerations, the purpose of this research is to investigate the perception of the sinkhole risk among the local residents with the aim to uncover patterns of perception or lack thereof and to understand their correlates. By examining the residents perceptions of the sinkhole risk, this study aims at identifying the specific factors influencing the individuals awareness and understanding of the sinkhole hazard. Moreover, it aims to discern whether there are consistent patterns in perception across demographic groups. Understanding these patterns can inform targeted risk communication strategies tailored to address the needs and concerns of different segments of the population. Additionally, insights gained from this research could contribute to the development of more effective policy actions for sinkhole risk mitigation and management. These might potentially include the improvement of land-use planning regulations, the implementation of early warning systems, and the enhancement of infrastructure resilience in vulnerable areas. Ultimately, the findings of this study have the potential to enhance the community resilience and minimize the societal impacts of sinkhole occurrences in Altamura and similar places.

Gutierrez F. et al. (2014) - A review on natural and human-induced geohazards and impacts in karst. Earth Science Reviews, 138, 61-88, https://doi.org/10.1016/j.earscirev.2014.08.002.

Pepe P. et al. (2013) - Lessons learned from occurrence of sinkholes related to man-made cavities in a town of southern Italy. Proc. 13th Multidisc. Conf. on Sinkholes and the Engineering and Environmental Impacts of Karst, Carlsbad (New Mexico, USA), 6-10 May 2013, National Cave and Karst Research Institute, p. 393-401.

Citizen Science for seismic risk reduction strategies and sustainable management

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Keywords: volunteers, trained citizen, Civil Protection.

Volunteer-based initiatives and trained citizen science projects both engage the public in scientific research. However, they diverge in the level of expertise and training participants receive. Volunteers typically join out of interest or passion without formal training, while trained citizen scientists undergo formal instruction in scientific methods, ensuring data accuracy and consistency.

In this study, we introduce two case studies concerning seismic risk mitigation, focusing on the engagement of citizens and societal stakeholders. The first case involves a volunteer-based citizen-science initiative implemented in Trieste, located in north-eastern Italy, following the 2020 Mw 6.4 earthquake in Petrinja, Croatia. We analyzed data gathered through online macroseismic questionnaires disseminated via social media showing their capacity to assess the geological characteristics of the city. We also demonstrated the importance of social media platforms in facilitating the crowd-sourcing of data.

The second case presents findings from a trained citizen science project that has operated for nearly a decade in partnership with the Civil Protection of Friuli Venezia Giulia. This initiative involves training civil protection volunteers in essential seismological principles and guiding them through the completion of a macroseismic questionnaire. Upon receiving notification of a seismic event, the trained volunteers promptly assess impact within their local community . The collected questionnaires from volunteers across the region augment the impact assessment derived from analyzing recorded ground motion data.

Assessing and mitigating natural gas risk at Cava dei Selci (Colli Albani volcano) through combined geochemical, epidemiological and agro-environmental studies

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Keywords: volcanic gas hazard mitigation

Cava dei Selci is a residential neighbourhood of Marino (Rome) hosting a natural gas discharge, where in 2000-2001 a man and dozens of cows and sheep have been killed by gas asphyxiation. Gas originates from Colli Albani quiescent volcano and consists mostly of CO_2 (up to 98 vol.%) with ~1 vol.% of H_2S.

A densely urbanized zone with 4000 residents surrounds the gas discharge. In recent years, several gas-related accidents occurred in this urbanized zone, including gas blowouts during shallow drillings, road collapses and permanent evacuation of four families because of hazardous air gas concentration inside their houses.

The related gas hazard has been assessed by soil CO_2 flux and concentration surveys and indoor and outdoor measurements of CO_2 and H_2S air concentrations. All open spaces of the zone, including house gardens, released a high quantity of CO_2 (32.23 tonnes*day-1 from 0.4 m2) and in-soil CO_2 and H_2S concentrations at 50 cm depth reached values up to 90 vol.% and ≥1000 ppm respectively. Inside most houses, CO_2 air concentrations exceeded ALTER (Acceptable Long Term Exposure Range, 0.1 vol.%) and, in several houses, both CO_2 and H_2S exceeded the IDLH level (Immediately Dangerous to Life and Health, 8.3 vol.% and 100 ppm respectively).

An epidemiological cohort study was carried out on the residents of two Cava dei Selci zones with high (zone A) and medium (zone B) gas hazard exposure, using the rest of Marino as reference zone. We found excess mortality and emergency room visits (ERV) related to high exposure to CO_2 and H_2S. In particular, an increased risk of mortality and ERV for diseases of central nervous system (HR 1.57, 95% CI 0.76–3.25 and HR 5.82, 95% CI 1.27–26.56, respectively) was found among men living in zone A (Carapezza et al., 2023).

Given that the main gas emission occurs from a 6000 m2 former stone-quarry very close to houses, we conducted studies on the quarry soils in order to pick the most resilient and promising trees and bushes to be inplanted as CO_2-absorbers and barriers against the diffusion of endogenous gases towards houses.

Carapezza M.L. et al. (2021) - Health impact of natural gas emission at Cava dei Selci residential zone (metropolitan city of Rome, Italy). Environmental Geochemistry and Health, 45(3), 707-729, https://doi.org/10.1007/s10653-022-01244-6.

Protects and heats

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Keywords: earthquakes, seismic waves, geothermal probes.

Ongoing climate change is the cause of recent geo-environmental disasters, such as floods and landslides, which occur more and more frequently and derive from the growing consumption of energy and the consequent increase in CO_2 emissions. A change can only happen with the belief that the first thing to do is to reduce energy consumption derived from fossil fuels.A positive contribution in this sense could be given by a new "Protect and heat" project. This project aims to safeguard the environment, reduce CO_2 emissions and reduce the risk of collapse of buildings affected by earthquakes.The "Protect and Heat" project is a way to heat and cool buildings, which uses a low-enthalpy, zero-emission geothermal system to simultaneously protect and attenuate seismic vibrations produced by earthquakes on buildings located in seismically sensitive areas.To mitigate the catastrophic and destructive effects produced by earthquakes on the soil and existing structures and to produce geothermal energy, it will be necessary to create a series of works outside the buildings to be protected that intercept the vibrations and dampen them before they reach their final objectives.

The works will mainly consist of a double row of vertical poles placed side by side made of ferrous and plastic materials which allow the emptying and replacement of part of the surface soil. By taking advantage of the perforations of the works carried out for the attenuation of vibrations, of the vertical poles, it will be possible to lay low-cost closed-circuit geothermal probes in the ground outside the buildings to be heated/cooled using the energy poles. It should be underlined that, since specific tests have not yet been carried out for this new project, even if the tests on energy poles, with which it shares many aspects, have been widely documented (see Delmastro's manual and Savino Basta's publications), the tests Yield GRT of the new coaxial geothermal probes will have to be planned and executed during the first testing phase of the works. Encouraging results, even if only partial, for the damping of vibrations produced by mechanical presses have been successfully obtained with the use of vertical HDPE poles, located outside production warehouses, while the use of energy poles is commonly used for cooling and heating buildings.

Data and maps on natural hazards to support risk mitigation measures

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Keywords: landslides, hazard, Italy.

Landslides and floods represent a very important issue for Italy due to the impacts on population, environment, cultural heritage, communication infrastructures and economic activities. Over 622,000 landslides (2/3 of those in Europe) have been mapped in the Italian Landslide Inventory by the Italian Institute for Environmental Protection and Research (ISPRA) together with the Regions and Autonomous Provinces. 28% of Italian landslides are rapid phenomena, such as rock falls or debris flows, characterized by high rate of movement, up to a few meters per second, often with serious consequences in terms of loss of human lives. Every year a few thousand of landslides occur on the national territory and a few hundred of main events cause dead, injured, evacuated people and damage to buildings, cultural heritage, and primary transportation infrastructures. In addition to a territory naturally prone to instability, the urban growth that has occurred in Italy since the Second World War, often in the absence of correct territorial planning, has led to a considerable increase in the elements exposed to risk (artificial surfaces have gone from 2.7% in the 1950s to 7.1% in 2022). Moreover, Italy is located in the so-called "Mediterranean hot spot", an area identified as particularly vulnerable to climate change, which is causing an increase in the frequency of intense rainfall, and therefore of extremely rapid debris flows. The increase in temperature in high altitude areas is causing permafrost degradation, with a consequent increase in slope instability phenomena in the Alpine area.

ISPRA develops the National mosaics of landslide and flood hazard maps and risk indicators which constitute key information to support risk mitigation strategies at national, regional, and local scales, management of civil protection emergencies, design of civil infrastructures, and environmental impact assessment. Data and maps can also be useful for sustainable finance and for assessment and management of financial risk of climate-related hazards and natural disasters.

In 2021, ISPRA estimated that 20% of the Italian territory was classified as landslide hazard zones, of which 8.7% in high and very high classes. 1.3 million inhabitants, almost 548,000 families, over 565,000 buildings (3.9% of the total), 84,000 industries and services, and 12,500 cultural heritage were exposed to landslide risk in Italy (Trigila et al., 2021).

Data and maps are published on the national IdroGEO web platform (Iadanza et al, 2021), an easy-to-use, multilingual, multi-device, open access and open source web application. IdroGEO, which is currently being upgraded in the framework of Geosciences Research Infrastructure funded by Next Generation EU, allows to view, query, download and share information, providing services to Public Administrations, companies, professionals, and citizens. It contributes to increase citizens' awareness of the risks affecting their territory.

Iadanza C.et al. (2021) - IdroGEO: A Collaborative Web Mapping Application Based on REST API Services and Open Data on Landslides and Floods in Italy. ISPRS International Journal of Geo-Information, 10, 89, https://doi.org/10.3390/ijgi10020089.

Trigila A. et al. (2021) - Dissesto idrogeologico in Italia: pericolosità e indicatori di rischio - Edizione 2021. ISPRA, Rapporti 356/2021.

Beyond fault scarps: the role of geologists in the assessment of seismic hazard and risk

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Keywords: earthquakes, seismic hazard.

Geologists are the "historians of the planet", as they investigate its evolution and preserve the memory of past natural events. But earthquakes are sudden and instantaneous occurrences: how can geologists contribute effectively to the assessment of seismic hazard?

Geology is governed by basic laws, such as Lyell's motto "The Present is the key to the Past", from his Principles of Geology (1830); combining it with David Hume's principle (1777) "...all inferences from experience suppose... that the future will resemble the past..." allows us to state also that "The Past is the key to the Future".

Geologists know that an earthquake is just a snapshot documenting how and how fast tectonic deformation adds up over time. They do not and should not guess what the Earth may do in the future, but simply learn from earthquakes and project it in the future, to make the planet safer for everyone.

Earthquake Geology is a youthful discipline, especially in Italy. Nevertheless, in less than 40 years geologists have overturned and profoundly innovated the understanding of Italy's active tectonics, active faulting and seismogenic processes. It was not an easy task: the complexity of the recent tectonic evolution of the Italian peninsula is almost legendary, mostly due to the superposition of the effects of subsequent tectonic regimes, and specifically to the youthfulness of the regime that is responsible for the largest earthquakes.

Other geologists have further developed the methodologies used for seismic microzonation, thus contributing to assess more precisely the hazard posed by the identified seismogenic sources.

Italian geologists have learned how to interact profitably with instrumental seismologists, historical seismologists and geodesists, filling in effectively the inevitable gaps among these rather distant disciplinary fields.

Thanks to the manifold contributions of geologists, Italy is currently the most advanced European country in the assessment of seismic hazard, and one of the most advanced in the world. Our community may be proud of this accomplishment, that rightly honours the memory of the fathers of Italian geology.

S24.

Assessment of multihazards and seismic microzonation in urban areas

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P4Quad a Pre- and Post-Processor for QUAD4M 2D site response analyses

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Keywords: numericalmodelling, siteresponse, quad4m.

It has been long known that local conditions are often responsible for earthquake-induced damage exacerbation. These observations, came out of both to recent and historical seismic events, stress out the need to implement an effective urban planning and optimize the territory use in relation to local amplification and the co-seismic effects. In this respect, the Seismic Microzonation (SM) represents a fundamental tool for assessment and mitigation of the seismic risk in urban areas and cultural heritage sites. SM identifies and maps zones characterized by homogeneous seismic behavior (Level1), but above all, besides to give information on susceptibility to main ground instability (soil liquefaction, landslides, fault ruptures), associates a synthetic quantitative parameter representative of the ground shaking intensity to each one (Level 2/3). To this end, 1D or 2D numerical analyses of local seismic response represent a key point to realize an adequate Level 3 seismic microzonation study. In particular, the 2D response analysis is mandatory for complex geometries surficial or buried morphologies (e.g. alluvial valleys, sedimentary basins; elongated reliefs).

The equivalent linear 2D finite element QUAD4M code represent one of the most used computer tools for site response analysis (Hudson et al., 1994). The program operates in the time domain and incorporates a compliant base. The code has been compiled in Fortran language and can be run under Microsoft Windows or DOS starting from input text files. No graphical interface is available from the developers of the code. In this contribution we present P4Quad a pre- and post-processor to help QUAD4M users in setting up the input files and elaborate the numerical results. In particular, the pre-processor allows the creation of the mesh using triangular finite elements starting from a sketch of the subsoil model, the input of geotechnical parameters for all layers and bedrock, the loading of input accelerograms by a simple graphical interface. Moreover, a library of several literature nonlinear curves (i.e. normalized stiffness modulus and damping curves) is provided to the users. The input text files to be run with QUAD4M executable file (not provided with P4QUAD) is finally produced. The post-processor loads the text output files produced by QUAD4M allowing the processing of the results in terms of most relevant ground motion parameters: acceleration time histories and response spectra at selected nodes, peak ground and maximum shear strain distribution at selected profiles, amplification factor, spectral acceleration and spectral amplification contouring at the surface of the model. The P4Quad code can be downloaded together with an user's manual from the web site of the Center for Seismic Microzonation - CentroMS (https://www.centromicrozonazionesismica.it/it/strumenti/software/) and the license for research, educational and academic use can be requested for free at the CentroMS mail address.

Hudson M. et al. (1994) - QUAD4M: A computer program to evaluate the seismic response of soil structures using finite element procedures and incorporating a compliant base. Rep. Prepared for Dept. of Civil and Environmental Eng, Univ. of California Davis, Davis, California., 45 pp.

Dynamic properties of soils obtained by means of combined resonant column and cyclic torsional shear tests for the Seismic Microzonation studies of Apulia (SE Italy)

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Keywords: dynamic properties, soils, laboratory tests.

In seismic risk assessment procedures, the vulnerability factor plays a remarkable role and involves comprehensive evaluations of the Local Seismic Response. The last one relies on an adequate knowledge of the soil geotechnical properties, especially the stress-strain relationships under dynamic and cyclic loading, to be determined through specific field and laboratory investigations and tests. Within the framework of the Seismic Microzonation studies of Italy, the third level of investigation is applied to stable areas susceptible to local amplification, *i)* in cases of complex geological and geotechnical conditions that cannot be solved using abaci, *ii)* for significant structural projects requiring special calculations, or *iii)* for areas prone to particularly severe instability, not resolvable through simplified methods.

For the third-level Seismic Microzonation studies currently on-going in the Apulia Region, combined resonant column and cyclic torsional shear tests were carried out to derive the normalized shear modulus (G/G0) and damping ratio (D) curves as a function of the shear strain level for the involved soils.

The main objective was to establish empirical reference trends in the analysis of the Local Seismic Response for the tested soils, as well as for those having similar physical characteristics, but that are difficult to sample, or for which undisturbed specimens cannot be easily obtained. Among the physical parameters, Plasticity Index and OCR were used for soils with a predominant silty-clayey component, while grain-size distribution, relative density, and lithostatic stress were considered for those with a predominant sandy-gravelly fraction. Lastly, a comparison was made between the experimental curves and those found in the literature for similar materials, aimed at defining reference models of the soil dynamic behavior based on the basic physical properties.

From top to bottom: characterizing the strategic site of Palazzo Valentini (Rome)

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Keywords: local seismic response, Palazzo Valentini, strategic building.

The historical Palace Valentini, built in the first half of the 18th century, is located in the centre of Rome, besides the Trajan Column. Consistently with the millenary history of the Eternal City, the Imperial Fora area underwent many transformations over the centuries (Clementi, 1978). In 113 A.D., the Emperor Trajan entrusted the architect Apollodorus of Damascus with the construction of his own Forum, excavating the saddle between the Quirinal and Capitol Hills. In the Middle Age, the area became a marshland fed by the runoff of the Quirino Valley (the present-day Via Nazionale). In the late 16th century, the Cardinal Michele Bonelli, great-nephew of Pope Pius V, ordered the reclamation of the so-called "Pantano" (swamp) area; hence, the architect and Dominican friar Domenico Paganelli designed a new palace, completed in 1585 over the remnants of the Deified Trajan temple, and later renovated and expanded in 17th century. With the decline of the Bonelli family, it changed owner, passing to the cardinal Giuseppe Spinelli, and then to Vincenzo Valentini, banker and politician, husband of Luciano Bonaparte's daughter. Following the annexation of Rome to the Kingdom of Italy, the Provincial Deputation of Rome bought the Palace in 1873. Nowadays, it hosts the Metropolitan City of Rome Capital (CMRC) and the Prefecture of Rome. Therefore, besides its historical, artistic and architectural value, the building has a strategic importance for emergency management as well, being the venue of the "Centre for the Coordination of Rescue" in case of relevant disaster, according to Italian seismic and civil protection legislation.

Considering its strategic purposes, we investigated and verified the stability of Palazzo Valentini, considering aboveground structures, underground spaces and foundation soil.

In the framework of an agreement of cooperation between CMRC and the National Department of Civil Protection (DPC), a permanent system of instrumental monitoring has been installed in 2020, including the building in the national Seismic Observatory of Structures (OSS). Concurrently, vibration measurements on each floor were performed, as a first step towards the application of the SMAV methodology (Spina *et alii*, 2019). In addition, a permanent station of the National Accelerometric Network (RAN), managed by DPC, is installed in the archaeological spaces of basement. Conversely, as part of the agreement between CMRC and the National Institute of Geophysics and Volcanology (INGV), a detailed Local Seismic Response study of the substrate was performed, considering available subsurface data. Ambient noise measurements at single stations were made as well, to investigate the fundamental resonance frequency.

The "top to bottom" characterization of the strategic site of Palazzo Valentini allowed thus the identification of its dynamical properties and the observation of the building/subsoil complex behavior over time.

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Spina D. et al. (2019) - A probabilistic simplified seismic model of masonry buildings based on ambient vibrations. Bull. Earthquake Eng., 17, 985-1007, https://doi.org/10.1007/s10518-018-0481-y.

A systematic analysis on Italian national territory to test the role of local topographic effects

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Keywords: local topographic effects, seismic codes, GIS.

The Italian seismic code (NTC18) provides indications about the expected effects of some morphological configurations on the expected ground motion during earthquakes. In particular, two main 2D morphologies are identified as reference: cliffs and crests. Based on numerical simulations, the value of St is assumed to depend on the steepness of the cliffs and aspect ratio of the crest. A critical aspect of these estimates is that the considered configurations are defined in terms of steepness angles and aspect ratios, without any scale indication. Moreover, the considered morphologies are very schematic, and this prevents their simple application in the natural context: in most case an expert judgement is necessary, and this makes the final estimates potentially controversial and difficult to validate on the basis of empirical observations. To face this problem, in the frame of the PRIN project "SERENA", a procedure has been developed for the automatic identification of areas prone to morphological amplification effects by following NTC18 prescriptions, based on the Digital Terrain Model. The proposed approach allows the full exploitation of topographical data at the maximum resolution available. After a first application to restricted areas, the proposed procedure has been applied at National scale at the seismometric and accelerometric sites managed by INGV. The aim is twofold: first comparing outcomes of the new approach with the ones proposed by other Authors at the same sites, second to provide a sound basis of a coherent and reproducible estimate of St values to be compared with possible empirical evidence. In the presentation, the results obtained about the first aim will be presented and discussed.

Multirisk analysis of the city of Naples (Italy) using the Rock Engineering Systems (RES) method

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Keywords: RES, MaxEnt algorithm, multihazard and damage maps.

Cities can be defined as an "*agglomeration of people and economic activities*" (Scott & Storper, 2015). As such, they tend to grow and expand despite the constant presence of negatively impactful events throughout history. Their expansion can be a source of safety problems when it includes areas affected by geohazards. The city of Naples (Italy), located between the Somma-Vesuvius and the Phlegraean Fields volcanic districts, is an example of a city impacted by geohazards (Totaro et al., 2020). Volcanic hazard, earthquakes (caused by either the activity of the Phlegrean Fields or by tectonic processes related to the Apennines), landslides, and sinkholes also affect the urban fabric. A multirisk analysis of the city of Naples has been conducted using the Rock Engineering Systems (Hudson, 1992) methodology. As a first step, the Maximum Entropy (MaxEnt) (Phillips & Dudìk, 2008) algorithm was employed to obtain landslide, sinkhole and flood susceptibility maps, implementing two techniques to increase the performance of the algorithm: i) the K-Fold Cross-validation and the ii) Variance Inflation Factor (VIF). The sinkhole and the landslide inventories were obtained from literature data. The Susceptibility maps obtained showed satisfying performances (ROC/AUC score above 0,85). The Susceptibility (Relative Hazard) was used instead of the Hazard, as two out of three inventories did not contain exhaustive temporal data. The Multihazard was evaluated using the Rock Engineering Systems (RES) method. The Multihazard was set as the system of the Interaction Matrix, using the Relative Hazard maps as parameters. The Interaction Matrix was then compiled by attributing the (i) cause scores (C - impact of one parameter over the other ones) and (ii) effect scores (E - impact of the other parameters against the analyzed one). In the following step, the interactivity of all the parameters was evaluated as the percentage ratio of C+E for the parameter against the sum of all the parameters' scores (ΣC+E). The Vulnerability evaluation, due to the heavily complex and heterogeneous territory, is a challenging task. As a precautionary measure, the Vulnerability has been set as the maximum (1) to the entire area, making the Damage map equal to the Elements at Risk map. The latter includes various layers such as i) population density, ii) railroad network, iii) road network, iv) natural reserve areas, and v) buildings. The product between the Interactivity Map (Multihazard) and the Damage Map is the Multirisk map. The results obtained are adequate to expectations, although a specific validation process is difficult to perform, due to the heuristic nature of the RES. In the future, the integration of further geohazards which have a recognized influence on other parameters would allow a more detailed definition of the Multirisk system in an urban context.

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Scott A.J. & Storper M. (2015) - The nature of cities: The scope and limits of urban theory. International journal of urban and regional research, 39(1), 1-15.

Totaro F. et al. (2020) - The key role of hazard indices and hotspot in disaster risk management: the case study of Napoli and Pozzuoli municipalities (Southern Italy). Journal of Maps, 16(2), 68-78.

The neglected side of post-disaster temporary settlements: how to manage it with NbS for sustainable urban development

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Keywords: post-disaster management, modelling, ecosystem services, landscape and urban planning.

The impacts of not-climate related hazards such as landslides, tsunami, volcanic activities and earthquakes determine towns reshaping and planning, thus the post disaster management must be handled under sustainable urban development framework following the 'build back better' and 'greener' approach (Mabon, 2019). Considering that earthquakes are not only a natural phenomenon, but also a cultural one, the natural component represents a chance to highlight fragile relationships among communities and the landscape (Albarello, 2011). Italian risk management policies based on public emergency actions are driven by economic compensation and physical rehabilitation, ignoring a strategic planning and prevention vision (Galderisi et al., 2020). This approach neglects socioeconomic, environmental, and cultural spheres. During the early recovery phase post-disaster temporary settlements usually change the urban morphology (e.g., sprawl when new settlements are built at the urban peripheries, but also densification when new settlements occupy urban voids and open spaces within the existing urban matrix), generally lacking social integration (e.g., people displacement, and job loss), while causing soil consumption (i.e., habitat fragmentation and biodiversity loss as well as reduction of urban green spaces). This means having a multiplicity of small post-event territorial interventions, without a systemic and organic approach. Such interventions exploit many resources for the construction and preparation of the temporary urban reconstruction areas. Eventually, these areas often have been integrated within urban planning tools, as a new building zone while changing the previous land use mostly irreversibly.Therefore, the early recovery phase constitutes the crucial moment in which the progress of recovery begins and when it is possible to intervene with actions to change the current trend of post-earthquake reconstruction.

In this work we aim at evaluating the opportunities, advantages and limitations related to the implementation of Nature-based Solutions (NbS) (UNEA, 2022) during the early recovery phase and at developing a multidisciplinary approach to identify the areas for temporary settlements. For this reason, we developed an environmental accounting model based on the integrated use of spatial analysis tools such as i-Tree canopy and industrial ecology tools such as life cycle analysis (LCA). The modelling endpoint is to determine environmental cost-benefit profiles for the post-disaster early recovery interventions. Considering past seismic events in Italy, it is possible to investigate ex-post land use change impacts on a range of ecosystem services (i-Tree modelling framework) and simulate ex-ante NbS-based scenarios (LCA analysis) in comparison with business-as usual practices. In other terms this approach can constitute a decision-supporting tool also in other contexts vulnerable to earthquake risks as well as other calamities.

Albarello D. (2011) - Pericolosità e rischio sismico nell'Italia post unitaria: proposte per una storia sociale della normativa sismica. In Silei G. (Ed) Ambiente, rischio sismico e prevenzione nella storia d'Italia, Piero Lacaita Editore, Manduria Bari-Roma.

Galderisi et al. (2020) - Geografie del rischio. Nuovi paradigmi per il governo del territorio. Roma, Donzelli.

Mabon L. (2019) - Enhancing post-disaster resilience by 'building back greener': Evaluating the contribution of nature-based solutions to recovery planning in Futaba County, Fukushima Prefecture, Japan. Landscape and Urban Planning, 187, 105-118, https://doi.org/10.1016/j.landurbplan.2019.03.013.

UNEA (2022) - Resolution adopted by the United Nations Environment Assembly on 2 March 2022 (UNEP/EA.5/Res.5). United Nations.

Lithological control on the indoor radon concentration: the case study of western Liguria

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Keywords: geogenic radon, gamma-ray spectrometry, logistic regression.

Radon is a geogenic radioactive gas originating from the decay of uranium contained in rocks and soils. When it accumulates indoors, it can reach dangerous concentrations to human health. Since extensive monitoring over wide regions is often impracticable and radon measurements in dwellings are generally irregularly distributed, mapping potential high-hazard areas is troublesome. In this paper, we investigated whether the lithological features and in particular the uranium content can be used as a proxy of indoor ^{222}Rn levels. Our study combined various techniques: uranium content measurements on outcrops by using gamma-ray spectrometry, soil radon concentration analyses with an ion-chamber meter and direct assessment of indoor radon concentration with alpha-track detectors (CR-39). The study was conducted in Liguria (northern Italy), an area geologically belonging to the western Alps and characterised by considerable lithological variability. Gamma-radiation measurements revealed that metamorphic rocks, particularly acid lithotypes, have the highest uranium concentration (up to 7 ppm). Metasedimentary rocks, like quartz and mica schists, also showed elevated uranium levels (about 5 ppm) compared to sedimentary rocks (3 ppm). Alpha-track detectors showed that nearly half of the surveyed buildings exceeded the indoor radon reference threshold of 200 Bq/ m^3. The radon concentration in soils was investigated at a depth of 50-80 cm, i.e. where radon gas is expected to diffuse from the soil into buildings. The highest radon concentrations (from 40 to more than 400 kBq/ m^3) occurred in soils derived from acid lithotypes, i.e. gneiss and metarhyolites. Metasediment soils exhibited radon concentrations of 20-40 kBq/m^3, whereas soils formed from sediments are characterised by less than 20 kBq/m^3. The lowest concentrations (< 10 kBq/m^3) were typical of metaophiolitic soils. In addition, high radon values (from 40 to 100 kBq/m^3) were recorded near faults and tectonic contacts. Although a significant number of data was collected, the uneven distribution of the radon measurement sites made it difficult the detailed mapping of potentially high-concentration areas. To overcome this problem, a machine learning algorithm was applied to predict the probability of exceeding the attention threshold of indoor radon based on lithology. In the study area, a background uranium content of 3 ppm implies a 50% probability of exceeding the attention threshold. The probability increases to 85% for an increase of U concentration of 1 ppm. Further logistic regression pairing U concentration measured in buildings with indoor radon pointed to no influence of the building fabric in controlling the indoor radon. Therefore, a significant relationship between indoor radon concentration and rock uranium content is confirmed and geological data can be effectively utilized to identify high-risk areas of radon exposure.

Update of the Level 2 Seismic Microzonation in Umbria Region: methodology and perspectives

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Keywords: level 2 seismic microzonation, Umbria, amplification factors, seismic risk.

The quantitative assessment of the stratigraphic amplification of seismic motion at the site is an essential element for seismic risk reduction and mitigation. The distribution of amplification factors (AFs) over the territory is represented in Seismic Microzonation Maps as foreseen by Level (or Grade) 2 of Seismic Microzonation (SM) according to Guidelines and technical standards. In the Umbria Region, the Level 2 SM studies, carried out until now, present calculated AFs only for some localities. A cartographic updating project was started up to know the AFs of all ISTAT localities over the entire territory of 53 selected municipalities, to guarantee effective planning for reduction of seismic risk. A multidisciplinary working group, composed of geologists, numerical modelers, cartographers, and database reviewers from CNR (IGAG and IGG), University of Siena, and the Geological Section of Umbria Region, worked in synergy and continuous exchange to revise the Level 2 SM studies. The workflow began with the analysis and interpretation of available geognostic, geophysical, and geotechnical data, analyzed to identify representative parameters of each geological-technical (GT) unit. Then, the geophysical and mechanical parameterization of the stratigraphic columns necessary for the Afs calculation was carried out, with each column considered representative of a MOPS: Homogeneous Microzone in Seismic Perspective. These data were used by numerical modelers to calculate the AF for each MOPS. AFs were calculated through numerical simulations adopting a linear-equivalent approach using the NC92Soil software (Acunzo et al., 2024). Damping and decay curves of the shear modulus taken from the available scientific literature (Gaudiosi et al., 2023) were associated with each GT unit composing the stratigraphic columns. Following this phase, the team of cartographers and database reviewers proceeded to update the database and cartographies following the current technical standards (Technical Committee MS 3907, 2020). The activity used the MzS Tools plugin, created for the cartography and data management of SM studies (Cosentino et al., 2018).

The workflow adopted revealed several critical issues following the processing of a test sample of studies:

- previous studies following obsolete standards led to the absence of some information or the presence of obsolete codes.
- the discrepancy between the past information and that derived from the updating studies: this necessitated a global revision of the study taking into account the new elaborations.

The work carried out allowed an improvement of the MS study in terms of coherence and understanding of the territory and cartographic production: spatial coverage of the study, updating to recent standards of archiving and cartographic representation and uniformity of products and graphic rendering.

Acunzo G. et al. (2024) - NC92Soil: A computer code for deterministic and stochastic 1D equivalent linear seismic site response analyses, Computers and Geotechnics, 165, 105857, ISSN 0266-352X.

Cosentino G. et al. (2018) - QGIS Plugin for Italian seismic microzonation. (https://plugins.qgis.org/plugins/MzSTools/)

Gaudiosi I. et al. (2023) - Shear modulus reduction and damping ratios curves joined with engineering geological units in Italy. Scientific Data 10, 625, https://doi.org/10.1038/s41597-023-02412-8.

Technical Committee for the support and monitoring of Seismic Microzonation studies Opcm n. 3907 (2020) - Microzonazione sismica. Standard di rappresentazione e archiviazione informatica, versione 4.2, dicembre 2020; Dipartimento delle Protezione Civile Nazionale, Roma. https://www.centromicrozonazionesismica.it/documents/1/StandardMS_4_2.pdf.

Integrating remote sensing and geophysical techniques for assessing landslide hazard in an Italian Apennine town

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Keywords: landslide, SAR, geophysics.

The geomorphological fragility of territories along the entire Italian Apennine range stems from stems from various factors including lithology, relief morphology, neotectonics, seismicity, climate, and vegetation. The gradual abandonment of lands surrounding small towns and villages in this area, along with other factors such as inadequate urban planning and construction, improper management of water and wastewater, and insufficient measures against landslides, has worsened soil erosion and increased the frequency of landslide events. These areas, abundant throughout Italy, where the primary concern is not uncontrolled urban growth but rather unchecked urban decline, serve as laboratories for experimenting with and refining methodologies for studying natural processes that lead to increased risk in urban settings.

Here, we present the results of a methodology for studying hydrogeological instability phenomena based on the use of remote sensing, both satellite-based and ground-based, as well as in-situ geophysical techniques. The study aims to provide valuable information for assessing residual landslide risk to facilitate planning and implementation of risk mitigation actions. The investigation focused on the urban area of a small town located in the low mountain region (~800 m a.s.l.) of the Basilicata region in southern Italy. In the municipality of Gorgoglione, which has approximately one thousand inhabitants, a state of emergency was declared, evacuation orders were issued, and, when necessary, demolition orders were issued for buildings used for residential and/or commercial purposes. The assessment of the instability phenomenon's activity was supported by interferometric techniques using SAR data acquired from satellite and ground-based platforms. The reconstruction of the geological and lithostratigraphic setting of the subsurface was achieved by integrating geological and geomorphological knowledge of the area with geophysical discontinuities, electrical and mechanical, derived from the use of electrical resistivity tomography (ERT) and horizontal-to-vertical spectral ratio (HVSR) analysis performed on single-station recordings of ambient seismic noise. Given the pronounced directional characteristics revealed by the HVSR analysis, efforts are underway to understand whether this can be related to the direction of landslide movement highlighted by SAR interferometry.

Accelerogram selection for site response modelling in seismic microzonation

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Keywords: site response modelling, seismic input, spectrum-compatibility.

Seismic microzonation studies of Level 3 involve in-depth analysis in order to define the characteristics of the local seismic response through numerical simulations.

A critical stage in such a procedure is the definition of the seismic input, a set of accelerograms representative of the ground motion locally expected at the bedrock for seismic scenarios most contributing to the local seismic hazard. However, in strong motion databases there may be insufficient availability of recordings that, for certain scenarios, satisfy spectrum-compatibility requirements. A new approach is proposed to solve this problem by integrating 4 real accelerograms with 3 simulated ones, calculated with the non-stationary stochastic procedure proposed by Sabetta et al. (2021). The simulated accelerograms are selected among a large number of them, stochastically generated for relevant seismic scenarios.

The new procedure is organized into different steps. First, the spectral parameters of the local design spectrum used as reference are defined according to the local building code provisions (for Italy, cf. Ministero delle Infrastrutture e dei Trasporti, 2018). Then, a seismic hazard disaggregation analysis provides the earthquake parameters (magnitude, source distance and style of fault) of a number of seismic scenarios most contributing to the basic seismic hazard: for such scenarios, real accelerograms are extracted from available accelerometric databases. The final seismic input is provided by a code that optimizes the selection of 4 accelerograms, among the real ones extracted, and 3 simulated accelerograms, among a large number of them obtained for all the previously identified scenarios, so to best fit the design spectrum. This allows to cover relevant scenarios not represented by the real recordings and to improve the median spectrum compatibility of the total set of accelerograms.

The procedure has been applied to the 84 Apulian municipalities involved in seismic microzonation studies. For each seismic input, the spectrum-compatibility has been verified, with special reference to the tolerance limits prescribed by the Italian Building Code, which admits deviations only between -10% and +30% from the design spectrum.

The compliance with such rules was checked on the mean response spectrum of the accelerogram set. This was first regularized so to conform to the standard spectral shape required by the Code, according to the procedure recommended by national technical bodies (cf. Commissione Tecnica per la Microzonazione Sismica, 2022).

The effectiveness of the seismic inputs so obtained was finally tested through 1D modelling of the local seismic response in a variety of geological and seismo-tectonic contexts, carried out by the code STRATA (Kottke et al., 2013). In such modelling, set of accelerograms provided by this new procedure and by the tools currently in use for this purpose were comparatively adopted.

Commissione Tecnica per la Microzonazione Sismica (2022) - Microzonazione sismica - Linee guida per la gestione del territorio in aree interessate da amplificazione. Vers. 2.0. Roma, 65 pp. https://www.centromicrozonazionesismica.it/it/strumenti/linee-guida-ms/.

Kottke R. et al. (2013) - Technical Manual for Strata. Geotechnical Engineering Center, 800 Department of Civil, Architectural, and Environmental Engineering. University of Texas.

Ministero delle Infrastrutture e dei Trasporti (2018) - Aggiornamento delle "Norme tecniche per le costruzioni." Supplemento Ordinario n. 8 alla Gazzetta Ufficiale n. 42 del 20 febbraio 2018.

Sabetta F. et al. (2021) - Simulation of non-stationary stochastic ground motions based on recent Italian earthquakes. Bulletin of Earthquake Engineering, 19, 3287-3315, https://doi.org/10.1007/s10518-021-01077-1.

Mapping seismostratigraphical amplification effects at regional scale from geological data

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Keywords: seismic microzonation, site response analysis, map of amplification factors.

The amplification of ground motion during earthquakes is widely recognized to be caused by the interference of seismic waves trapped between the free surface and impedance contrasts in the shallow subsoil. Seismic Microzonation (SM) studies focus on assessing these site effects, but applying them in large contexts can be hard and costly. To estimate seismic site effects at a regional scale, the most practical approach is to utilize detailed geological and geomorphological data (scales of 1:10,000 to 1:50,000), which are widely available for large parts of Italy. As part of the national research project "SERENA," this study introduces and tests a procedure aimed at quantifying 1D seismostratigraphic ground motion amplification using geological information. Specifically, amplification factors are estimated for different Seismically Homogeneous Microzones (SHM) defined according to the information contained in the geological map. Each SHM is represented as a stack of flat, homogeneous layers, with each layer characterized by engineering-geological units according to the SM standards (Commissione Tecnica, 2018; SM Working Group, 2015). The seismic properties of each layer (Vs, density, damping, and G/G0 curves) along with their respective ranges of variability, are determined based on the most recent literature (Romagnoli et al., 2022; Gaudiosi et al., 2023).

To take account of the uncertainties which affect the construction of the SHMs, 100 random profiles were created for each SHM based on the variability of the parameters just mentioned. The relative expected seismic response at each profile is computed considering the Inverse Random Vibration Theory (Kottke and Rathje, 2008) and a linear-equivalent approach. In this way, distributions of the three amplification factors were obtained for each SHM. This methodological approach has been applied to the Tuscany, Marche, and Umbria Regions, which boast detailed geological maps covering their entire territories. In this process, tens of thousands of SHM were initially identified using dedicated ArcGIS Pro™/ArcPy™ scripts, and then analyzed as described above to obtain the seismic response in terms of amplification factors (AFESM). The 50th percentile of the AFESM distribution for each SHM was assigned to the corresponding outcropping formation, aiming to generate a new map of amplification factors for the study areas with an optimal spatial resolution. To evaluate the reliability of the results obtained from numerical simulations, the outcomes (AFESM) were compared with those provided by detailed SM studies (2° and 3° levels) available in the three study regions. This comparison aimed to validate and verify the accuracy of the amplification factor maps. This analysis revealed significant differences in the AFESM based on the geological composition and surface conditions of the SHMs. Moreover, despite the extensive nature of the actual approach, it proves to led to unbiased estimation of the amplification factors. It is important to emphasize that the proposed approach should not be viewed as a replacement for detailed local studies. However, it can be valuable for conducting preliminary evaluations and serving as a reference for large-scale risk analysis.

Commissione Tecnica MS (2018) - Standard di rappresentazione e archiviazione informatica degli studi di MS vers.4.1.
Gaudiosi I. et al. (2023) - G/G 0 (γ) and D(γ) curves joined with engineering geological units in Italy. Sci.Data, 10(1), 625.
Romagnoli G. et al. (2022) - The possible use of engineering-geological qualitative characterization of shallow subsoil for a preliminary estimate of the Vs profile in seismic microzonation studies. Soil Dyn. Earthq. Eng., 161, 107347.
SM Working Group (2015) - Guidelines for Seismic Microzonation, Conference of Regions and Autonomous Provinces of Italy - Civil Protection Department, Rome.

First results from level 3 Seismic Microzonation of Sulmona (AQ), Central Italy

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Keywords: seismic microzonation, numerical analysis, geotechnical model.

Relevant site effects related to impedance contrast can be expected in basins filled by a thick sequence of soft sediments above a stiff pre-Quaternary carbonate bedrock such as in the intermontane basins of the Italian Apennines.

We investigate the Sulmona basin, a tectonic depression elongated for ~22 km in the NW-SE direction and up to 5-7 km wide, in the Abruzzi's Central Appennines. The origin of the basin is due to the Quaternary activity of the Mt. Morrone normal fault which dips to the southwest limiting the NE edge of the basin, able to produce Mw 6.5-6.7 earthquakes.

The basin infill of such a half-graben shows a typical triangular geometry thickening toward the Mt. Morrone fault plane, where the fluvial-lacustrine sequence should reach up to 500-600 m of thickness (Miccadei et al., 1999). However, the entire sequence has never been observed in either an outcrop or in a borehole.

The detected unfavorable local site effects condition that emerged from level 1 of Seismic Microzonation determines a high seismic hazard level for the city of Sulmona and neighboring villages. The present work focuses on the geotechnical characterization of lacustrine soils cored and sampled hundreds of meters deep. The shear wave velocity profile and the cyclic nonlinear properties in the lacustrine sediments have been determined.

A stiffness-depth relation from cyclic laboratory tests is derived and calibrated with available in-hole tests. Results have been integrated with VS profiles from 2D seismic arrays that constrained the whole thickness of fluvio-lacustrine sediments. A validation of the Vs profile has been finally realized by comparing computed resonance frequencies with experimental values derived from HVSR analyses on microtremor measurements.

We present a geological cross-section, selected to investigate the seismic response through 2D numerical analysis in the 3rd level of the seismic microzonation study, as a representative geotechnical model of the Sulmona city center.

Miccadei E. et al. (1999). La geologia quaternaria della Conca di Sulmona (Abruzzo, Italia centrale). Geologica Romana, 34, 58-86.

Automated tools for the reconstruction and spatialization of stratigraphic successions to support seismic site effects analysis

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Keywords: Python, stratigraphies, amplification factors.

In the frame of the PRIN project "Mapping seismic site effects at regional and national scale – SERENA", we have developed a collection of both standalone and QGIS-based Python scripts for the identification and spatialization of stratigraphies starting from outcropping geological units. Our aim is to divide a given territory into stratigraphically homogeneous areas defined by a representative stratigraphic column, needed to model and spatialize the seismic amplification factor (AF).

Several criteria for the reconstruction of the columns are available, allowing scripts to operate from a fully-unsupervised to a semi-supervised mode. This latter provides user with greater control over the results, allowing the progressive check of the reconstructing stratigraphic column by working on vector cartographic bases in a GIS environment. Our scripts process an input raster geological map in a pixel-wise fashion, identifying the lateral contacts between the outcropping units, placing them in a stratigraphic order based on a pre-defined geometric position index (Cesarano et al., 2022), and calculating the cumulated thickness. At the same time, this raster-based approach allows for a punctual spatialization of the reconstructed stratigraphies.

The scripts were validated on the 428 km2 wide Territorial Context (TC) of the town of Cariati (Calabria, Italy), where the reconstructed stratigraphic columns are already available (Cesarano et al., 2022). As input, we used the Engineering-Geological Units (EGU) (Technical Commission for Seismic Microzonation, 2020), since they had already been geometrically indexed for the test area (Cesarano et al., 2022). We found that our scripts successfully reproduced, just in a few minutes, the same stratigraphic columns manually obtained by Cesarano et al. (2022), confirming the efficiency of our approaches.

The achievable results, combined with geophysical and geotechnical data, such as the variability of shear wave velocity in relation to EGUs (Romagnoli et al., 2022) and shear modulus reduction and damping ratio curves (Gaudiosi et al., 2022), represent a significant advancement in the analysis of seismic hazards on a wide scale. The detailed and realistic stratigraphies provided for local seismic response analysis greatly contributes to improve the calculation of seismic amplification factors.

Cesarano M. et al. (2022) - Multiscale geothematic maps for using the database from the Italian Seismic Microzonation Project: an example of application in the Calabria Region (Southern Italy). Ital. J. Geosci, 141(1), 35-52, https://doi.org/10.3301/IJG.2022.03.

Gaudiosi I. et al. (2023) - Shear modulus reduction and damping ratios curves joined with engineering geological units in Italy. Sci. Data 10(1), 625, https://doi.org/10.1038/s41597-023-02412-8.

Romagnoli G. et al. (2022) - Constraints for the Vs profiles from engineering-geological qualitative characterization of shallow subsoil in seismic microzonation studies. Soil Dyn. Earthq. Eng., 161, 107347, https://doi.org/10.1016/j.soildyn.2022.107347.

Technical Commission for Seismic Microzonation (2020) - Graphic and data archiving standards. Version 4.2. Department of Civil Protection of the Presidency of the Council of Ministers. Rome.

Realization of the database of geometries and characteristic parameters of "Microzone Omogenee in Prospettiva Sismica" (MOPS) throughout the National territory

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Keywords: seismic microzonation, MOPS, database.

Seismic Microzonation (MS, sensu ICMS) has as key element the determination of areas (the so-called "Microzone Omogenee in Prospettiva Sismica**"** or MOPS) within which the expected seismic effects are assumed to be homogeneous. From the geometrical point of view, the MOPS is made up of one or more portions of the morphological surface, also not contiguous with each other, whose seismic-structure stratigraphic makes assume values like the parameters that determine the seismic effects found or expected on the surface. The structure of a MOPS is usually schematized by a succession of horizons characterized by a series of parameters detectable in the countryside (and if necessary, in the laboratory) and by direct and indirect (geophysical) underground investigation techniques. These parameters include: the depth with respect to the p.c. of its upper limit (or lower or its centre of gravity), a thickness, a geological-technical class according to defined standards (the so-called Technical Geological Units or UGT), a mass density, a representative value of the propagation velocity of the S-waves, a decay curve of the shear modulus and one of the damping. Where appropriate, each layer may be assigned a speed value representative of the P-waves from direct measurements or assuming a standard value of the Poisson module. Each MOPS is also characterized by the representative values of the resonance frequencies of the S-waves assuming that the fundamental one (f0) is the lower one in the range 0.5-10 Hz. The MOPS can also be characterized by a value representative of the average speed (harmonic) of the cutting waves in the first 30m from the ground plane and the estimated depth of the water table. The synthesis of the conceptual aspects that define the MOPS and consequently the activity of MS shows how in fact the quantity and the quality of the parameters of MOPS is currently rather articulated and above all has evolved and refined in recent years, due to the consistent commitment expressed by the scientific context (Research Organization) and executive (Regional and Municipal Administrations and Professional Associations) that have been involved in the activities of MS. Despite the effort to homogenize the quality standards adopted over time and in the different areas of MS are rather heterogeneous and especially poorly comparable with each other. If the development of MS activities has led to the availability of a large amount of data related to the MOPS of the municipal territories, the same cannot be said about the actual increase in knowledge about territorial seismicity, based on the comparison of the data constituting the individual MOPS. To overcome this problem, we have created a database that, based on an analysis of the requirements and a subsequent development of a conceptual and logical model, allows as well as a systematization of the detailed knowledge of the individual MOPS, also their comparison and correlation between different areas, so as to allow an effective capitalization of knowledge.

Why should we bother about risk reduction at the urban scale? A methodology to assess the effectiveness of seismic prevention measures on urban system functionality

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Keywords: urban risk prevention, post earthquake recovery, urban functionality indicators.

Earthquakes that occurred in Italy in the last 50 years have produced indirect damages of around 108 billion euros (Coviello & Somma, 2021). Despite these numbers, the predominant position in the field of risk management keeps being oriented towards emergency public actions of physical restoration of individual assets, instead of comprehensive urban prevention strategies.

This approach has very high costs, strongly impacting both territorial functionality and local communities: losses, services interruption, population and businesses displacement, socio-cultural disequilibria. So, the role of speed in the recovery process is crucial, because it can affect whether community members decide to stay and rebuild or leave a community for good (Arendt & Alesch, 2014).

To accelerate post-quake recovery, disaster risk reduction policies based on prevention strategies are fundamentals. But, they remain a difficult goal, due to high costs implied, long time needed to achieve objectives, and a general lack of a seismic risk culture regarding both the civil society and the political leadership.

A step toward this direction has been made by the Italian government, after the 2009 Abruzzo earthquake, issued the National Plan for seismic risk prevention. This represents the first initiative that tries to see prevention issues also from an urban point of view, overcoming the single building perspective.

Urban vulnerability, in fact, depends not only on building features but also on functional systems (Braga et al., 2015). Prevention, therefore, has to be framed in a wider urban vision, aiming at a broader goal, that is maintaining the vital settlement functions (Fiore et al., 2018). But it is evident that to protect the entire settlement is unrealistic. So, the challenge is to identify a minimum core of functions, whose preventive safety measures could avoid, in the event of a quake, the total collapse, reducing urban vulnerability and consequently enabling the recovery to begin. In this paper we hypothesize a system composed by the strategic elements for the emergency management, healthcare facilities, schools and the areas for temporary settlements, called Early Recovery System (ERS). ERS may represent a further step towards the construction of an urban seismic prevention instrument for early recovery. To evaluate its effectiveness, a set of indicators was built to assess urban functionality decrease. The indicators, calculated in different time intervals, were calculated on a pilot case study: the city of L'Aquila, severely affected by the 2009 earthquake. For each progressive scenario of urban safety, two diverse configurations were hypothesized, to demonstrate how the different ways to systemize the ERS elements may have different impacts on the recovery speed. This work aims at demonstrating that looking at seismic prevention from an urban perspective could guide the public actor in the construction of a strategic prevention programme based on common goals of territorial safety.

Arendt L.A. & Alesch D. (2014) - Long-term Community Recovery from Natural Disasters. CRC Press, Boca Raton, Florida.

Braga F. et al. (2015) - Post-seismic assessment of existing constructions: Evaluation of the shake maps for identifying exclusion zones in Emilia. Earthquake and Structures, 8(1), 37-56, https://doi.org/10.12989/eas.2015.8.1.037.

Coviello A. & Somma R. (2021) - I rischi catastrofali. Azioni di mitigazione e gestione del rischio. Studi e ricerche per l'innovazione. CNR edizioni, Roma.

Fiore A. et al. (2018) - Seismic vulnerability assessment of historical centers at urban scale. International Journal of Architectural Heritage, 12(2), 257-269, https://doi.org/10.1080/15583058.2017.1402969.

Modelling site amplification as factor of slope susceptibility to co-seismic failures in hill-top towns

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Keywords: co-seismic slope failures, ambient noise analysis, local seismic response.

Seismic Microzonation of hill-top town requires identification of peri-urban slopes that may be affected by co-seismic failures. Therefore, we are developing and testing a procedure for the identification of slopes potentially susceptible to earthquake-induced failure by i) estimating the resistance demand placed by local seismicity on the slopes, ii) comparing it to the actual slope resistance and iii) classifying slopes according to their susceptibility. A step forward in this effort consists in considering the increase of the resistance demand caused by site amplification effects that can occur on slopes, especially where softer slope materials overlie a stiffer substratum. In the first phase of this work, we are incorporating site effects through 1D modelling of the local seismic response. For our tests, we benefit from the large amount of data acquired in the Seismic Microzonation studies ongoing in the Apulian region, especially in the Daunia Mts., which include many hill-top towns characterized by slopes consisting mainly of clay-rich flysch materials susceptible to rainfall-triggered landsliding (Wasowski et al., 2010). It is likely that some moderate magnitude earthquakes that occurred in the surrounding areas could have also caused slope failures, but the direct evidence (e.g., historical records) is limited (Wasowski et al., 2022). In particular, we are using the results of pre-existing borehole and geophysical investigations, collected during the level 1 Seismic Microzonation studies, integrated with purposely conducted geological surveys and ambient noise data analysis. On this basis, simplified geological models of the study areas are first obtained to calculate the local seismic response through 1D modelling, whereas, further insights will be obtained through more advanced numerical modelling (2D and 3D) when more data have been made available from level 3 studies. At this stage, among the investigation techniques used, the analysis of ambient seismic noise recordings plays a special role. These were first analysed through the Nakamura method (Nakamura, 1989) and, then, using the HVIP technique (Del Gaudio, 2017). Indeed, the HVIP technique, measuring the ellipticity of Rayleigh waves isolated within noise recordings, generally provides more stable H/V values, which are better correlated to the local amplification factor. The HVIP technique can thus provide: i) a useful support for modelling site conditions (through the inversion of the ellipticity curves of Rayleigh waves in terms of Vs vertical profiles) and ii) a comparison term for the possible definition of empirical relationships to estimate amplification factors directly from the noise analysis results. Such estimates could be used where ambient noise data are available or can be easily obtained, while data from more costly investigations are lacking or are insufficient to provide a reliable modelling of the local seismic response.

Del Gaudio V. (2017) - Instantaneous polarization analysis of ambient noise recordings in site response investigations. J. Geophys. Int., 210(1), 443-464, http://dx.doi.org/10.1093/gji/ggx175.

Nakamura Y. (1989) - A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Q. Report Railway Tech. Res. Inst., 30, 25-33, http://worldcat.org/oclc/3127232.

Wasowski J. et al. (2010) - Influence of land-use change and precipitation patterns on landslide activity in the Daunia Apennines, Italy. Quarterly J. Eng. Geology and Hydrogeology, 43(4), 387-401, https://doi.org/10.1144/1470-9236/08-101.

Wasowski J. et al. (2022) - Unravelling the origin of large ancient landslides in low elevation Daunia Mountains, Italy. AGU Fall Meeting Abstracts 2022, NH22A-07.

Geological mapping and structural analyses in seismic microzonation for Jv-based subunit discrimination: preliminary results from Gravina in Puglia (Southern Italy)

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Keywords: seismic microzonation, geological mapping, Gravina di Puglia.

The correct mapping of boundaries between different geological-tecnical units is a fundamental objective for seismic microzonation (SM), but is particularly challenging in urbanized areas, where SM is mainly focused. Indeed, irregularities of the boundary geometries can lead to conditions for local site amplification (cf. Commissione Tecnica MS, 2020; 2021), but they are difficult to reconstruct in built-up areas. Equally important is the evaluation of the age, geometry, kinematics and lateral extent of fault zones affecting the geological-tecnical units. These structures can modify physical-mechanical properties and Jv values of the geological-tecnical units so to lead to a further subdivisions into distinct sub-units. The SM studies carried out for the town of Gravina di Puglia offered site conditions favouring the use of different investigation techniques to analyse the above-mentioned issues. Gravina in Puglia is located on the south-western margin of the Apulian foreland, on the border of the Quaternary Apennine Foredeep. From bottom to top, the geological-technical column characterizing the urbanized area of the town, following the representation standards of Commissione Tecnica MS (2021), consists of: i) LPS and SFLPS, both corresponding to upper Cretaceous Calcare di Altamura, with the latter differentiated for the high Jv values along faults; ii) GRS (Calcarenite di Gravina, Late Pliocene – Early Pleistocene); COS (Argille subappennine, Early Pleistocene). GRS and COS belong to the transgressive succession of the Plio-Pleistocene Apennine foredeep on the Apulia Foreland and are both bounded by a regular surface. These two units rest on LPS (bedded limestones of the Cretaceous calcareous platform) through an important regional unconformity. This is characterized by a buried complex morphology shaped by subaerial erosion and fault steps, from the Late Cretaceous to the Early Pliocene. The analisis of geognostic boreholes in the urbanized area coupled with data from large-scale geological mapping carried out on natural exposures along the Gravina stream allowed to partially reconstruct the geometry of SFLPS. In order to fill this gap, the integrated use of different investigation methodologies was planned including: i) analysis of high quality fotogrammetric models based on the collection of high-resolution drone photos; ii) analysis of fracture distribution, density, and orientation by scan-line and scan-box methods on key exposures; iii) kinematic and geometric analyses on the fault zones and related damage zones; iv) active and passive seismic surveys. The whole dataset will make it possible to categorize the geological-technical units with homogeneous Jv value, whereas the comparison with the results of geophysical investigation should improve our understanding of how fracture distribution (and related Jv value) and geometrical setting of the unconformity can impact on the local seismic effects.

Commissione tecnica MS (2020) - Microzonazione sismica. Standard di rappresentazione e archiviazione informatica. Versione 4.2. Dipartimento della Protezione Civile Nazionale, Roma. https://www.centromicrozonazionesismica.it/documents/1/StandardMS_4_2.pdf

Commissione tecnica MS (2021) - Linee Guida per la realizzazione della carta Geologico-tecnica per la microzonazione sismica con adattamento ai contesti vulcanici. Versione 1.0. Dipartimento della Protezione Civile Nazionale, Roma. https://rischi.protezionecivile.gov.it/static/7dd80c62a6d4a3919df09db4c6abed0e/linee-guida-la-realizzazione-della-carta-geologico-tecnica-la-microzonazione-sismica-con-adattamento-ai-contesti-vulcanici.pdf

Mapping social vulnerability to multi-hazard scenarios: a GIS-based approach at census track level

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Keywords: social vulnerability, multi-hazard, GIS.

Floods and landslides cause continuous damage to ecosystem, infrastructures and population. Particularly, the occurrence and the existence of different natural hazards in the same territory highlight the need to improve risk mitigation strategies for local authorities and community resilience solutions for inhabitants. Analyzing and mapping social vulnerability provides information about the capacity of a specific community to anticipate, cope with, and recover from a natural event. Specifically, the interaction between multi-hazards and the socio-economic environment suggests multidisciplinary assessments that merge the physical and the socio-economic features of the affected territories providing a useful approach to support risk reduction planning. In this context, the article focuses on integrating landslide and flood hazard scenarios with social vulnerability in Basilicata Region (southern Italy) at census track level. 13 municipalities were chosen as a multi-hazard hot spot, whereas open-source platforms were selected for hazard and social vulnerability data collection. A Geographic Information System (GIS)-based approach was applied to combined different hazard scenarios with social vulnerability distribution among 1331 census tracks to detect the most vulnerable sub-municipality areas that need special attention in multi-risk reduction strategies. The results are presented in form of maps which highlight their relevant use in local emergency planning.

Uncertainties of soil profiles for seismic response analyses

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Keywords: seismic response analyses, soil profiles, shear wave velocity.

When planning in areas affected by earthquakes, a reliable estimation of the seismic site response should take into consideration all possible sources of uncertainties. Among these, the most relevant highlighted in the scientific literature are: the variability of the input signals; the geometrical configuration of the buried settings; and the constitutive properties of soils in terms of stiffness, damping and strength.

The present work shows some results inferred from seismic site response analyses considering the variability of the stiffness properties profiles and the position of the bedrock in two districts of Naples (Licata et al., 2019).

Specifically, in order to provide a more robust estimation of ground shaking, the analyses were performed on seven soil columns by Monte Carlo method, in one-dimensional (1D) conditions and by adopting the linear-equivalent method.

The selected soil columns are representative of the geo-litological complexes of the study area and the geotechnical models were addressed on the basis of the wide collection of VS data: for each profile the median values of Vs were defined. Moreover, the results of the cyclic torsional shear tests allowed defining the shear modulus decay and the damping curves.

The analyses were performed by propagating twenty accelerograms with different features in terms of duration and peak ground acceleration, PGA. For each soil column, the surface amplification was determined considering the dispersion of the shear wave velocity, VS, profiles, and the variability of the depth of the bedrock by assuming a log-normally distributed random variable.

The results are synthetized in terms of amplification factors, AF, of PGA and Housner Intensity, distinguishing the response due to the weak and the strong motions. The major conclusions highlighted that the distribution of the amplification factors is quite homogenous in the reference area and the uncertainty of VS significantly affects the soil response. Moreover, the effect of bedrock depth is very significant, since ground amplification at high periods increases with its depth.

Licata V. et al. (2019) - A multi-level study for the seismic microzonation of the Western area of Naples (Italy). Bull. Earthquake Eng., 17, 4711-4741, https://doi.org/10.1007/s10518-019-00665-6.

A new soil constitutive model for nonlinear 1D seismic site response analyses

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Keywords: seismic site response analysis, constitutive soil model, nonlinearity.

This work presents a simple nonlinear constitutive model to perform one-dimensional (1D) seismic site response analyses considering both nonlinearity and strength parameters of the soils. The main advantage of the proposed model consists in providing a good compromise between an accurate representation of the soil response under cyclic loading, along the whole strain range, and the definition of simple constitutive laws, whose parameters should be easy to calibrate based on standard laboratory and in situ tests.

The 'Modified Hardin-Drnevich' (MHD) model, thoroughly described in Conti et al. (2020), combines the hyperbolic functional form, originally introduced by Hardin & Drnevich (1972) for the backbone, with the unloading-reloading rule suggested by Phillips & Hashash (2009). The key idea of the MHD model consists into using the soil shear strength, τ_{lim}, as a constitutive ingredient both to limit the allowable shear stress and to describe the dependence of the nonlinear soil properties on the effective mean stress, p', and the plasticity index, PI.

The MHD model is completely described by just six parameters: the soil shear strength, τ_{lim}, the initial stiffness, G_0, easily inferred from conventional in situ investigations tests (such as SPT, CPT, VS measurements), and four fitting parameters.

To highlight the accuracy of the MHD model, it was applied to a case study and compared with another nonlinear model. The reference site is located in the Eastern Napoli (Italy) and twenty natural strong earthquakes, selected based on a site specific hazard analysis, were propagated thorough a representative 1D soil profile. The results highlighted that the MHD model provides a better interpretation of the amplification phenomena of the soil deposit and a better estimation the stress state of the deeper soil layers, which are far from reaching failure under the earthquake-induced shear stresses.

Conti R. et al. (2020) - Nonlinearity and strength in 1D site response analyses: a simple constitutive approach. Bull. Earthquake Eng., 18, 4629-4657, https://doi.org/10.1007/s10518-020-00873-5.

Hardin B.O. & Drnevich V.P. (1972) - Shear modulus and damping in soils: Design equations and curves. J. Soil Mech. Found. Eng. Div., 98(SM7), 667-692.

Phillips C. & Hashash Y.M.A. (2009) - Damping formulation for nonlinear 1D site response analyses. Soil Dyn. Earthquake Eng., 29(7),1143-1158.

A geological and geophysical database of the Po Plain and the northern Adriatic Sea (northern Italy) as potential tool for the assessment and mitigation of natural and anthropic hazards

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Keywords: Po Plain, 3D geological model, geological and geophysical data.

The Po Plain (northern Italy) hosts many urban areas where a large population lives and numerous economic activities and historical and cultural sites are located. Moreover, this area is historically affected by different geological hazards (i.e., seismic, subsidence and flooding hazards) which, in some cases, interfere each other and with human activities. For these reasons it is necessary to implement strategies for safeguarding the population, the economy and the historical and cultural heritage, first of all the evaluation and mitigation of geological hazards and the impact of human activities. This requires an accurate knowledge of the subsurface geology which, in the study area, is made possible by the availability of a large amount of subsurface data acquired for hydrocarbon exploration purposes since the early 1950s (i.e., seismic reflection profiles and wells) and many literature data.

In this work, geological (i.e., stratigraphy information) and geophysical (i.e., Spontaneous Potential, Resistivity, Gamma Ray and sonic logs) public data from 160 deep wells, 61 geological cross-sections and 10 geological maps of the Po Plain and the facing northern Adriatic Sea were collected, georeferenced and digitized. The data of five geological horizons (i.e., from bottom to top, magnetic basement top, carbonate succession top, Pliocene base, the Calabrian base, and base of recent continental deposits) were also interpolated and the related unfaulted surfaces were reconstructed. In this way a simplified 3D geological model of the study area subsoil was reconstructed.

The resulting dataset, consisting of both the digitized geological and geophysical data and the reconstructed geological surfaces, may be used in a wealth of applied and scientific studies, including studies for the assessment and the mitigation of geological hazards and the impact of human activities. Through the elaboration of the digitized logs, for example, it is possible to directly extract or derive mechanical and geophysical properties of the rock volume interposed between the reconstructed surfaces, such as Young's modulus or Poisson ratio, that find applicability in geomechanical simulations aimed at evaluating the ground subsidence/uplift phenomena or the stress field change in a specific area in response to natural processes or anthropic activities, and seismic velocity values, which may be used to improve the earthquake location procedure and to reduce the uncertainties. The reconstructed 3D geological model may also be used as input-model in seismic wave-propagation and ground-motion simulations performed for defining the local seismic response.

This dataset, available in open access format (Livani et al., 2023), can therefore represents a useful tool to define the most effective territorial protection strategies, particularly for urban areas, and to detect areas where further data collection and more detailed studies are needed.

Livani M. et al. (2023) - Digitized geological and geophysical data from the Po Plain and the northern Adriatic Sea (north Italy) collected from public sources. (Version 1.1) [Data set], Zenodo, https://doi.org/10.5281/zenodo.8126519.

Geological and stratigraphic setting of the metropolitan area of Milan (Italy): implications for site-dependent seismic hazard assessment through high-resolution geophysical investigation

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Keywords: seismic active, long period analysis, site effects.

Milan is located in the north-western sector of the Po Plain, a large and deep sedimentary basin between the south-verging thrust system of the Alps and the north-verging thrust system of the Apennines. The paper shows the results of a detailed urban-scale seismo-stratigraphic model for the metropolitan area, in a context where the understanding of the spatial variability and influence of seismic site response of the shallow and deep (~1.5 km) alluvial deposits for the Milan urban area (Massa et al., 2022), is fundamental as a contribution to reducing seismic risk. In this perspective, in 2023, a 1.4 km long high-resolution reflection seismic profile was acquired at Vettabbia Park (south of the city) through a linear spreading of 240 4.5 Hz-geophones and a high-frequency vibratory source (IVI-Minivib). Despite the challenge posed by the urban context (Picozzi et al., 2009) of a metropolis like Milan and its significant noise, the resulting seismic image reveals in detail the stratigraphic setting of the area, showing a good agreement with the previous geological reconstruction based on existing geological data (Villani et al., 2024). Since it is widely recognized that a significant proportion of the variability of earthquake ground motion is related to local geological conditions, the seismic site effect estimation plays a crucial role. In order to determine the Rayleigh-wave dispersion curves from passive array, the data were analysed by the frequency-wavenumber, the modified spatial autocorrelation and the extended spatial autocorrelation methods. The obtained shear-wave velocity profiles, together with other required geotechnical parameters, were used to perform a 1D equivalent-linear hazard analysis at the studied site. Seismic inputs are selected on the basis of compatible combinations with target-spectra derived from the Italian building code. Amplification factors obtained from numerical analyses were suggested as a benchmark for future more advanced analysis, such as 2D/3D non-linear models important to address a site response analysis in a metropolis context.

Massa M. et al. (2022) - Seismo-Stratigraphic Model for the Urban Area of Milan (Italy) by Ambient-Vibration Monitoring and Implications for Seismic Site Effects Assessment. Frontiers in Earth Science, 10, 915083.

Picozzi M. et al. (2009) - Site Characterization by Seismic Noise in Istanbul, Turkey. Soil Dyn. Earthq. Eng., 29(3), 469-482, https://doi.org/10.1016/j.soildyn.2008.05.007.

Villani F. et al. (2024) - High-resolution geophysical investigations in the central Apennines seismic belt (Italy): Results from the Campo Felice tectonic basin. Tectonophysics, 871, 230170.

Natural and anthropogenic sinkhole in Italy: the importance of an interdisciplinary approach

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Keywords: natural sinkhole, antropogenic sinkhole, urban areas.

Understanding the relationship between geology, anthropogenic factors, and sinkhole hazards is crucial for effective risk management and land-use planning. Over the last few decades, the Italian Geological Survey (ISPRA) has analysed collapse phenomena (sinkholes) in Italy, but now, as part of the PNNR project Geosciences-IR (WP.3.2), the previous censuses have been extended and expanded, especially regarding the anthropogenic sinkholes. Because of their thousand-year history, the urban centres of the beautiful Italian art cities have a subsoil rich in cavities, mostly anthropic, but in some cases also natural. These cavities may be subject to sudden collapse, damage to the above buildings and infrastructure, and loss of historical monuments or human lives. There are sometimes extensive tunnels networks and hydraulic structures of archaic and Roman times that extend to peripheral and rural suburbs. The dimensions and purposes of these underground environments are very varied, and to be understood and mapped requires interdisciplinary knowledge from historical and archaeological research to field surveys (Madonna et al., 2023). A wide body of literature connects natural sinkholes to the underlying lithological characteristics, but the relationships between lithology and anthropogenic sinkholes have been little investigate. If we exclude areas where marine units are subject to karst and pseudokarst phenomena, the majority of natural sinkholes developed (sedimentary cover) within alluvial sediments, followed by pyroclastic and volcanoclastic deposits, continental carbonate deposits (travertine and calcareous tufa), and coastal sandy and clay deposits (Nisio et al., 2007). However, Recent studies (Puzzilli et al., 2023) have shown that the natural sinkhole hazard in volcanic deposits is often underestimated. Regarding the anthropogenic sinkhole, this distribution changes completely. The census of the anthropogenic cavities and the related sinkholes is still in the early stage of making representative statistics. However, with extensive layers of volcanic deposits such as Lazio or Campania, pyroclastic deposits become the main units. However, this type of phenomenon generally can affect any widespread lithology with mechanical properties suitable for supporting underground cavities. Each region presents specific challenges that require tailored approaches to mitigate risks associated with natural and anthropogenic sinkholes. Urban areas in Italy also face the risk of anthropogenic sinkholes due to human interventions such as altering natural water paths. These activities can lead to the collapse of subterranean spaces or exacerbate the leakage from subservice networks like sewage and water pipelines. Notably, channelling rivers into underground conduits in cities such as Rome has sometimes led to unexpected and dramatic sinkhole incidents, posing risks to buildings and infrastructure.

Madonna S. et al. (2023) - The role of historical-archaeological sources integrated into the GIS environment with geological and geophysical data in the mitigation of geological risks in some urban areas. Rend. Online Soc. Geol. It., 61,50-57, https://doi.org/10.3301/ROL.2023.46.

Nisio S. et al. (2007) - Sinkholes in Italy: First results on the inventory and analysis. Geological Society London Special Publications 279(1), 23-45, https://doi.org/10.1144/SP279.4.

Puzzilli L.M. et al. (2024) - Natural Sinkhole Monitoring and Characterization: The Case of Latera Sinkhole (Latium, Central Italy). Geosciences, 14, 18, https://doi.org/10.3390/geosciences14010018.

Multi-hazard map of the coastal area of Rome near the Fiumicino airport

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Keywords: hazard mapping, geological risks.

Urban areas with historical buildings are susceptible to disasters, which can cause detrimental effects to both humans and the historical structures themselves. In this situation, the risks can be determined by the combination of multiple potential hazards (including those related to climate change), the vulnerability and exposure of historical building users, and the physical characteristics of the environment, such as its morphology, typology, and grade of urbanization.

The coastal area of Rome, located on the eastern Tyrrhenian margin along the Tiber delta, includes the village of Ostia Antica, a significant location encompassing important cultural, environmental, and archaeological sites. However, over the past few decades, the area has experienced considerable urbanization mostly because of its proximity to Rome and the Fiumicino International Airport.

Due to its cultural and natural heritage, the expansion of the urban area and the presence of an international airport, it is crucial to safeguard this area from significant local geological risks, including flooding, subsidence, and hazard due to endogenous gas emissions.

The area is affected by subsidence processes and rates up to 30 mm/yr as highlighted by Synthetic Aperture Radar-interferometry datasets (SAR interferometry). Actual subsidence rates, mainly due to soil compaction, represent a risk to cultural heritage and buildings. The area is also highly susceptible to floods, both Tiber floods and groundwater flood (e.g., floods triggered by intense rainfall and consequent rising of the shallow groundwater level). Furthermore, over the past few years, the occurrence of spontaneous gas explosions during shallow drilling has emerged as a novel hazard for the region; the existence of gas vents that emits at surface high levels of CO_2 (up to 90%) poses a serious risk to human health, especially during construction-related activities.

This study describes a comprehensive multi-hazard risk assessment model for an urban area, aimed at the evaluation of three distinct hazards such as floods, subsidence, and gas release from soil. The relationship between hazard susceptibility and predisposing factors was evaluated by using machine learning algorithms. Then, the maps of single hazards were summed obtaining the map of the complete multi-hazard assessment. In addition, the model integrated various other factors, including the socioeconomic background.

Places reborn. Two cases of regenerated historic villages in Liguria and Umbria (Italy)

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Keywords: abandonment, rebirth, vulnerability, damage, earthquake.

The recovery of historical places affected by collapse and depopulation is explored by focusing on two recovered Italian villages: Colletta di Castelbianco (Liguria) and Postignano, Sellano (Umbria), located in two areas relevant for the development of seismology. These settlements also represent emblematic examples of the redevelopment of ghost towns emptied following significant natural phenomena. In fact, they were initially abandoned and subsequently underwent major restoration interventions that brought them back to life. The analysis of the aspects of material and immaterial regeneration of places underlines the importance of those actions that can trigger virtuous processes in the territory in order to save an important heritage, otherwise destined to be lost.

Geological complexity vs. seismic risk reduction strategies: preliminary results from level III seismic microzonation studies of Etnean municipalities (eastern Sicily, Italy)

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Keywords: seismic microzonation, field geological surveys, subsurface model.

The Mt. Etna (eastern Sicily) is an active volcano composed of lavas and volcanoclastic deposits, over a substratum of sedimentary rocks having a complex buried topography. The eastern flank, affected by active and capable faults (FACs), was hit by a Mw4.9 earthquake on 26/12/2018. Starting from 2022, the Regional Department of Civil Protection of Sicily funded a scientific project aimed at: 1) produce new investigation protocols for the study of FACs in active volcanic areas, and 2) apply these new protocols to carry out the third level seismic microzonation studies (SM3) for 23 municipalities. The project is managed by the Centre for Seismic Microzonation and its Applications, consisting of Universities and Research Institutions, including ISPRA which is involved for the SM3 studies in 9 municipalities.

The Etnean territory is peculiar due to lithological-geotechnical aspects, 3D subsurface geometries, and presence of FACs. This is compounded by intense urbanisation, which makes geological surveys and geophysical measurements extremely difficult. In SM3 perspective, these features imply numerous uncertainties in identifying the location of FACs, the depth of the seismic bedrock and the correct assessment of the local seismic response. In order to define a reliable subsurface model for the SM3 purposes within this complex framework, the most suitable approach to be adopted consists of: proper processing of borehole data, very detailed engineering geological surveys, combined with extensive use of various geophysical investigation methods, integrated with each other.

Starting from a critical review of the SM1 studies, at present we carried out detailed field geological surveys, integrated with new geophysical and geotechnical investigations: n. 4 boreholes with downhole tests, 100 microtremors recordings (HVSR), 1 seismic refraction survey (SR), 3 ground probing radar profiles (GPR) and n. 24 surface-wave surveys (MASW).

We present the two case studies of Motta S. Anastasia and Pedara (S and SE of Mt. Etna). In the first, the substratum, made of marly clays covered by sands and gravels, is well exposed but the whole sequences show no remarkable differences in terms of stiffness (i.e. shear-wave velocity values, Vs). In Pedara, a thick, highly variable alternation of lavas and volcanoclastic deposits, shows velocity inversions (Vs ranging from 500-700 m/s to 300-400 m/s). Despite the different geological setting, the HVSR investigations at both locations show very similar frequency-peak values (1 Hz or less) suggesting the presence of a buried impedance contrast at depth greater than 50 m.

The results obtained so far provide evidence that, in active volcanic areas, detailed geological survey integrated with borehole data and multi-method geophysical investigations can be an effective strategy for the characterization of FACs and also to define and/or constrain the subsurface model on which the numerical modelling of the local seismic response is based on.

Exploring the relationship between anthropogenic sinkholes and pluvial flooding in the urban area of Rome: a comprehensive evaluation of multiple hazards

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Keywords: anthropogenic sinkholes, pluvial flooding, Rome.

Anthropogenic sinkholes represent a frequent and significant danger in urban settings. They have the potential to cause significant and unexpected damage to buildings, infrastructure, and humans. Over the past twenty years, Rome, a major city in Italy, has experienced significant ground subsidence events, known as anthropogenic sinkholes. These sinkholes are caused by the collapse of man-made underground cavities created for various purposes throughout the city's extensive history spanning over two thousand years. They can also be triggered by water leaks from hydraulic pipelines (Ciotoli & Nisio, 2023) and by pluvial flooding occurring during extreme storming events in areas characterized by topographic depressions and/or in proximity to the sewer network (Di Salvo et al., 2017).

The susceptibility map to sinkhole probability in the urban area of Rome was created by using machine learning techniques taking into account various layers (i.e., predictors) including geological, geomorphologic, and anthropogenic data. The susceptibility map categorizes the Rome territory into five distinct classes. The pluvial flood hazard (PFH) map results from an easily replicable procedure applied to the city of Rome. It was developed using the spatial density of observed floods occurring between 2004/2007 and recorded by the Civil Protection of Rome municipality (Comune di Roma, Ufficio Extradipartimentale della Protezione Civile, 2008), and ground morphology factors (i.e. depressions, DTM, fill volume). Available data were processed by weighting depressions by flood density, ranking flooded areas by fill depths and combining these grid layers through a sequence of tools in a GIS environment (Di Salvo et al., 2018).

This work aims to classify and analyze the occurrence of natural multi-hazards, specifically pluvial floods and sinkholes, affecting the urban area of Rome. The procedure is based on a robust geological, geomorphological, and hydrogeological analysis performed using data collected and archived for the scope. The susceptibility is calculated based on geo-hydrological and geomorphological factors, as well as the occurrence of flooding and sinkholes. The two maps have been reclassified and combined to obtain a joint visualization of the multi-hazards. The result shows that there is a strong correlation between sinkholes and flooding, which tends to decrease and eventually disappear moving from the city center towards the Rome ring road.

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Advancing seismic microzonation: integration of deep learning for high-resolution Vs30 mapping in the Central Italy

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Keywords: seismic microzonation, seismic hazard, deep learning.

Seismic hazard assessment in regions prone to significant seismic activity, such as the Umbria-Marche region in Italy, necessitates accurate characterization of local soil conditions. Past seismic events in the area underscore the urgency for improved methodologies in seismic hazard assessment (Vittori et al., 2000; Chiarabba et al., 2009; Chiaraluce et al., 2017). Vs30, representing the distribution of shear waves within the upper 30 meters of the Earth's surface, emerges as a crucial parameter for ground motion prediction.

My research focuses on investigating the role of Vs30 in seismic hazard assessment within the complex geological framework of the Central Italy. Geological units, including carbonate successions, turbiditic siliciclastic deposits, and Plio-Pleistocene sequences (Bucci et al., 2022), contribute to the diverse Vs30 values in these regions.

Access to an extensive dataset from regional seismic microzonation projects facilitates this investigation (https://www.webms.it/). With 15000 shear-wave velocity (Vs) profiles processed to calculate Vs30 values, spatial integration using geographic information systems enhances data interpretation.

Deep Learning and Machine Learning (ML) are employed in this research, correlating Vs30 data with geological units, building upon previous work (Gironelli et al., 2024) and utilizing QGIS for exploration. Concurrently, supervised ML techniques, particularly the Random Forest Regressor, demonstrate promising results but we the use of Deep Neural Networks push the boundary providing better results.

The primary objective is to create high-resolution Vs30 maps tailored to the Central Italy regions, enhancing the accuracy of seismic hazard assessments. This research provides insights into the advancements in investigation methods and product requirements outlined in the Italian Guidelines and Standards for Seismic Microzonation.

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Vittori E. et al. (2000) - Ground effects and surface faulting in the September–October 1997 Umbria–Marche (Central Italy) seismic sequence. Journal of Geodynamics, 29(3-5), 535-564.

S25.

Landslide monitoring, modelling, and prediction: bridging new tools and data to the 'slope-failure model' perspective

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Landslides monitoring for the protection of the territory: the San Vito Romano study case (Rome metropolitan area, central Italy)

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Keywords: landslides monitoring,natural risk, San Vito Romano.

In the metropolitan area of Rome, the high occurrence of low intensity, small-sized landsides represents a critical issue, in terms of risk prevention and territorial government. The 2000 km long provincial road network is often affected by rockfall and topples, shallow landslides, roto-translational/earth slides, or less frequently debris flows, depending on local geological and hydro-geomorphological setting. In some cases, construction features of the transport infrastructures represent predisposing factor for localized instabilities. Conversely, deep-seated gravitational slope deformations are rare. Because of the described framework, the Metropolitan City of Rome Capital (CMRC) promoted in recent years, consistently with its institutional duties, technical/ scientifical projects on such topic: landslides susceptibility analyses; landslide inventory and modelling; periodic monitoring; geophysical investigations (Esposito et al., 2021; Rotella et al., 2022; Seitone et al., 2023). In 2021, CMRC and the University of Torino- Department of Earth Sciences signed an agreement of cooperation, focusing on the San Vito Romano complex landslide, in the eastern sector of the metropolitan area, between the Prenestini Mts. and the Aniene River valley. It is the largest feature (surface about 1 km2) in the metropolitan area, affecting the modern part of the San Vito village and a long segment of the provincial road "Empolitana I", and thus monitored since the late '90s by local authorities. The geomorphological evolution of area indicate a strong structural control, due to the proximity to the southern part of the so-called "Olevano- Antrodoco Line". This regional shear zone controlled, during Upper Miocene, the eastward thrusting of calcareous-marl units of the Sabina transitional domain over the flysch of the Frosinone Formation, in turn superimposed on the Latium-Abruzzi carbonate platform units. Consequently, the arenaceous- pelitic hills are the surface expression of a N-S trending fold system, disrupted by tear faults and east verging thrust ramps (Corrado & Parotto, 1995). Morevover, structural setting strongly influences groundwater circulation. In reliance of the results of the pilot project completed in 2023, CMRC, the University of Torino and the Municipality of S. Vito designed and structured a remote monitoring network, consisting of several inclinometric and piezometric sensors installed in boreholes. The network, supported by web-gis, includes minor landslides along the surrounding segments of road network, one of them controlled also by means of an extensimeter. The applied methodology, which represents an absolute innovation in the metropolitan area, will guide further application in other critical sectors, which is hoped will lead to a high technology system of territorial control for risk prediction and prevention.

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Geodetic-topographical monitoring of landslide affecting the urban area of Motta Sant'Anastasia (CT) Sicily

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Keywords: geodetic-topographical monitoring.

Geodetic-topographical monitoring of active geological processes is a fundamental practice mainly used to define their kinematics and dynamics. The monitoring must be calibrated by the analysis of spatio-temporal factors that characterise the rate of deformation. These factors are analysed through a preliminary stratigraphic and structural geology surveys following by geomorphological, hydrological, and geotechnical study. In this work, the research team of the Geodynamic & Geomatic laboratory (University of Catania), after signing an agreement with the municipality of Motta Sant'Anastasia, has designed and implemented a programme of geodetic measurements to monitor the kinematic of a landslide affecting the north-eastern edge of the Motta Sant 'Anastasia urban centre, located in the lower southern slope of Mount Etna (Catania).

The landslide body is formed by chaotic clayey-sandy materials (Servizio Geologico d'Italia, 2010). It develops to the east direction, affecting part of the urban area. The crown of the landslide is delimited by fractures crop out on low walls, asphalt and buildings.

The shallow geological succession is constituted, from the top to the bottom, by thin alluvial deposits and marly-clay. In the marly-clay, the sandy lenses represent preferential paths of infiltration and storage of water. This horizon has been identified as the sliding surface.

To restore the landslide body, consolidation works were carried out from January 1984 and never fully completed.

From May to July 2023, we have monumented a permanent and a discontinuous GNSS networks. The permanent network consists of one station located outside the landslide area; the other two stations are localised close to the crown, one located within and the one outside the landslide. The discontinuous network consists of 11 benchmarks located transversally to the landslide, above the diaphragm created for the consolidation of the landslide, and now partially damaged since reactivation of landslide.

After 25 surveys, the GNSS stations and the points, outside the landslide, shown no significant movements, while the other stations and points shown an eastward movement of about 8 mm per month, associated to the landslide sliding. GNSS data show the dynamics and kinematics of the landslide above and along the 1984 diaphragm which is no longer effective.

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Stability of terraced slopes accounting for potential hydrological scenarios in the UNESCO World Heritage Site of Cinque Terre, Northen Italy

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Keywords: dry-stone wall, Cinque Terre, stability analysis, hydrological scenarios, terraced slope

In the last decades, the variation in rainfall regimes along with the abandonment of rural areas that affected Cinque Terre's UNESCO World Heritage site (Liguria, Italy) have contributed to a significant degradation of the cultural asset of the area, namely agricultural terraces sustained by dry-stone walls. Indeed, these two factors have played a relevant role in driving landslide and erosion processes, which in turn caused important social and economic damages. In order to better understand mechanisms behind these hydro-geological events and the potential conditions for their initiation, this study presents a stability analysis of terraced slopes that accounts for land-use condition, identified as a key factor for rainfall-induced shallow landslide susceptibility, as well as potential hydrologic scenarios (i.e., combination of initial soil hydrologic conditions and rainfall). Two terraced slope sections located behind the Manarola village and characterized by different land-use (i.e., cultivated and abandoned) and engineering-geologic setting (e.g., different stratigraphy) have been considered for the analysis. Specifically, land-use features have been integrated into a finite elements slope stability analysis implemented into the ADONIS software in the form of soil properties. In this regard, different values of total cohesion, namely resulting from both the effective soil cohesion and the contributions of roots systems, have been considered in the stability analysis according to the following land use settings: (i) cultivated terrace, (ii) abandoned terrace from short-term periods and (iii) abandoned terrace from long-term periods, (iv) absence of root reinforcement. Moreover, hydrologic scenarios in the form of positive pore water pressure have been considered in the stability analysis. In the simulations, the dry-stone wall has been assimilated to a fractured rock mass; namely, the size, arrangement, and mechanical properties of the stone elements and of separating joints, have been taken into account to estimate the slope failure potential through the Mohr-Coulomb criterion. They have been consistently obtained by modelling rainfall scenarios derived by a Gumbel distribution-based statistical modelling of up to 24h cumulative annual maxima derived from the nearest meteorological station of Levanto. Hydrological modelling has been completed through the VS2D code for simulating rainfall infiltration. Soil hydrological monitoring data acquired at the research sites providing potential initial humidity conditions for pore pressure generations have been used. A preliminary model validation has been conducted considering available monitoring data and rainfall data for hydrologic scenarios generation scenarios have been. Significant hydrologic scenarios corresponding to return periods of 100, 300 and 500-years and three different initial soil water content conditions have been considered for the analysis. The results indicate the substantial stability of the selected terraced slope sections in response to rainfall events with return periods of 100, 300 and 500-years and under both different initial hydrological and land use. The first results presented in this study indicated the suitability of the proposed procedure in predicting the stability of terraced slopes in the study area, also providing a basis for evaluating the influence of land-use in slope stability from a physically based point of view. Future improvements of the followed methodology may allow to effectively identify areas require the adoption of adequate risk mitigation strategies.

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A combination of deep learning and InSAR techniques for landslide hazard assessment

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Keywords: InSAR, CNN, LSTM.

Landslides are among the most significant and widespread natural hazards on Earth, which frequently cause victims and huge economic damage. Over time, landslide mapping, susceptibility and hazard assessment have been carried out with physical-numerical methods, but often based on data that cannot be obtained in real time. For this reason, they have been joined in recent decades by methods such as remote sensing and machine learning. These algorithms are a way of quickly tackling problems related to analyzing the spatial distribution of landslides and mitigating their impact on the territory and population. This work contributes to analyze landslide hazard using a combined approach characterized by Differential Interferometry SAR (DInSAR) technique and deep learning algorithms, specifically the integrated model CNN (Convolutional Neural Network) – LSTM (Long Short-Term Memory). The study is conducted at an inter-municipal scale in an area which falls between Umbria and Marche, in Central Italy. This area is affected by several landslides threatening urban settlements and infrastructures, and many of them were triggered by the strong earthquake of magnitude 6.5 with epicentre in Norcia, occurred on 30th October 2016 (Fortunato et al., 2012). The purpose is to assess landslide hazard by analyzing and comparing predisposing factors and cumulative surface deformations, to process spatial and temporal data at the same time and predict future cumulative deformations based on the combination of both. Regarding to spatial data elaboration, predisposing factors such as slope, elevation, aspect, curvature, geology, flow direction, land use, Stream Power Index, Topographic Wetness Index, Normalized Difference Vegetation Index are analyzed with the CNN algorithm. The latter, introduced by LeCun et al. (1998), uses these factors as inputs and considers them separately, creating a multidimensional matrix, in which there are layers that automatically detect landslide susceptibility. On the other hand, as regards temporal data, the analysis refers to the surface cumulative displacements, induced by landslides, which are derived from satellite data and obtained with DInSAR technique. SAR data has been useful for the training of LSTM algorithms (Hochreiter & Schmidhuber, 1997), to model the temporal progression of cumulative ground deformations. They are suitable at storing information for prolonged periods and managing data sets to model cumulative deformations by temporal factor. The integration of the two algorithms allows to grasp the space-time relation existing between predisposing factors and cumulative deformations, to predict future deformations and have a more accurate and complete prediction.

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Large-scale landslide mapping based on deep-learning paradigms

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Keywords: landslides, deep-learning, large-scale mapping.

Landslides pose significant hazards to communities, infrastructure, and the environment, necessitating accurate mapping and monitoring strategies. Traditional methods of landslide mapping often rely on manual interpretation of remote sensing data, which can be time-consuming and subjective. In recent years, there has been a growing interest in leveraging deep learning techniques for automated landslide mapping at large scales. This work explores the advancements in large-scale deep learning-based mapping of landslides. Deep learning models, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs) (Hakim et al., 2022), have demonstrated remarkable capabilities in feature extraction and pattern recognition from various types of remote sensing data, including satellite imagery, LiDAR data, and aerial photography (Azarafza et al., 2021; Ghorbanzadeh et al., 2022). Key components of deep learning-based landslide mapping include data preprocessing, feature extraction, model training, and post-processing. By utilizing large-scale datasets and powerful computing resources, deep learning models can learn complex spatial and spectral patterns associated with landslide-prone areas, leading to more accurate and efficient mapping results (Ngo et al., 2021). Furthermore, the integration of multi-source remote sensing data, such as optical, radar, and topographic data, enhances the robustness and generalization capabilities of deep learning models for landslide mapping across diverse landscapes and environmental conditions. Here the potential of deep learning-based approaches to revolutionize landslide mapping by providing timely and cost-effective solutions for landslide hazard assessment, mitigation, and disaster management on a large scale. Future research directions may focus on improving model interpretability, addressing data scarcity issues in certain regions, and integrating real-time monitoring systems for proactive landslide risk reduction. A proactive policy of management of landslide-prone areas is a key point for their development and preservation. The spatially diffuse availability of medium-high resolution geological, geomorphological and topographic data is boosting the use of artificial intelligence approaches, like deep learners. Deep learners will return a spatial map of points, representing if there is an earthflow or not.

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Nutcracker-like masonry bridges deformation and failure due to slow gravitational deformation

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Keywords: slow landslides, bridge deformations, nutcracker.

Italy is a geologically young territory still subject to tectonic and orogenic action, originating in a relevant and continuous geomorphological evolution (Guerricchio, 2022). The slow deformation of the slopes with landslide expresses this. These are sometimes seemingly imperceptible but may have severe effects in long-term damage to infrastructures (D'Ambrosio et al., 2023; Doglioni, 2024).

It is the case of the Albiano Magra bridge failure or the famous Lagonegro bridge. These are phenomena that are often overlooked, due to the difficulty of grasping slow deformations often attributed to age. This is true especially for some very old masonry bridges, which can be considered real monuments, or even for bridges made of different materials as in the case of the Lagonegro bridge (Southern Italy). Anyway, very small deformations may be detected by modern technologies allowing us to objectively document and monitor the very slow deformations by satellite images. These images, when appropriately analyzed and elaborated, contribute to understanding the dynamics of territory.

The work presents a series of historic arched bridges deformed by slow movements due to gravitational phenomena which generate compressive deformations of the abutments which can give ogivalization and "nutcracker-like" deformations of the arches (Simeone et al., 2024). A roundup of Italian examples shows how slow gravitational slope deformations can lead to severe problems for bridges. A preliminary investigation on bridge deformation based on satellite techniques is also presented. Some case histories of this kind are here introduced: the12-arches railway bridge of the dismissed Paola-Cosenza railway line; the masonry arch bridges in Basilicata along provincial roads 15 and 5 in the province of Matera and the dismissed railway bridge of Cassano allo Ionio in the province of Cosenza. Finally, it is noteworthy to mention the Albiano-Magra bridge failed in 2020, and the Lagonegro bridge still existing by dismissed since 1952. These are all examples of how slow deformations can affect arch bridges creating the condition for the failure or the final compromise of the bridge.

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Multidisciplinary approach on the preparatory effect of wildfires in shallow landslides

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Keywords: wildfires, landslides, RETURN.

Impacts of wildfires in forest areas can lead to new avalanche-prone slopes with a higher risk of landslides (e.g., shallow landslides, debris flows, rock falls), soil erosion, and water quality problems. The scarce maintenance of vegetated lands can increase the risk that fires may affect areas closer to human settlements, raising both the risks associated with the fire and those linked to landslides. Wildfires constitute one of the most relevant preparatory factors for shallow landslides, that are investigated, among other preparatory processes, in PE3 RETURN. Wildfires are responsible for changes in watersheds' hydrologic and geomorphic response, and they also lead to the denudation of hillslopes and the consequent reduction of the root strength, which mainly contributes to the soil cover stability (Abdollahi et al., 2023). Depending on vegetation resistance and resilience, the effects of the wildfires on the territory can last for years, during which heavy rainfall or earthquakes can more likely trigger shallow landslides. The unpredictability of wildfires phenomena is one of the main challenges in studying their characteristics, as on field measurements of its effects are difficult to collect. Future scenarios linked to the effect of climate change predict that forest fire frequency and severity will likely increase, as will the extreme rainfall events. As both probability of occurrence and magnitude of wildfires can change over time in relation with climate changes, more efforts should be made to deepen knowledge of interacting disturbances and to understand how to mitigate the related risks.

In this work, a multidisciplinary approach to quantify time-dependent scenarios of shallow landslides prepared by wildfires is presented, evaluating the environmental conditions before, during, and after the wildfires occurrences. This allows understanding how wildfires can affect slope stability and how long this effect persists over time as well as how the ground reacts. All these aspects are very important to be defined since they constrain the quantification of how the soil can change in its chemical and physical characteristics as well as in evaluating the heat transfer at different depths below the ground (Chicco et al., 2023). The used approach involves specific in-situ and laboratory geotechnical investigations on surface soil layers to determine the physical, hydraulic, and mechanical interactions between soil, vegetation, and fire, together with back-analysis approaches as well as numerical models aimed at reproducing how wildfires can affect soil depth and slope stability. To calibrate these models, controlled burning, simulating a small-scale fire, was used, allowing the evaluation of the relationship between the combustion of biomass on the ground and the heat transfer in the subsoil, its duration, and the thermophysical characteristics of geological materials within which the heat pulse propagates.

Abdollahi M. et al. (2023) - Post–Wildfire Stability of Unsaturated Hillslopes Against Rainfall–Triggered Landslides. Earth's Future, 11(3), e2022EF003213, https://doi.org/10.1029/2022EF003213.

Chicco J.M. & Mandrone G. (2023) - Effects of wildfire on soils: field studies and modelling on induced underground temperature variations. Frontiers in Earth Sciences, Interdisciplinary Climate Studies, 11, https://doi.org/10.3389/feart.2023.1307569.

Survey, data visualization and numerical modelling: An overview about how the new tools and methods of analysis can influence landslide studies

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Keywords: landslide modelling, remote sensing, augmented and mixed reality.

In the last two decades the advent of new tools and methods for landslide analysis has completely changed our approach to study such phenomena. Satellite, aerial and terrestrial remote sensing techniques remarkably improved amount and quality of data while the increasing number of numerical codes made the use of numerical simulations more and more common. However, the combination of remote sensing data and numerical simulations is not an easy task, as well as the definition of geotechnical input parameters for these simulations. In this research we aim to shows advantages and limitations of these new survey and analysis tools with a particular focus on the potential risks associated with the use of numerical simulations without proper and rigorous validation/calibration procedures. Different codes will be used and compared at this purpose. Finally, we will introduce the use of new data visualization and management methods through the use augmented and mixed reality.

Landslide susceptibility, vulnerability, and risk assessment based on remote sensing and GIS data models: a case study at the eastern Hindukush Mountain ranges, Pakistan

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Keywords: landslides, vulnerability, risk.

Landslides are one of the most devastating and frequently occurring natural hazards worldwide, impacting communities, infrastructure, and the environment. The northern regions of Pakistan are characterized by rugged terrain, high seismicity, and complex tectonics structures, making it highly prone to landslides and debris flow events. The only possible way to mitigate the socio-economic impacts of these natural hazards is to assess and evaluate the zones of future events and highlight the landslide risk areas for further planning and development. However, such assessments are frequently deficient in regions characterized by complexity and scarcity of data. This research study suggests an integrated approach for evaluating landslide zonation, vulnerability, and risk utilizing a variety of freely available geospatial data and semi-quantitative techniques in a highly landslides-prone area in the eastern Hindukush Mountain ranges of Pakistan (Shah et al., 2023). Satellite imagery with high spatial and spectral resolution (Spot-5, Worldview) is employed to depict the distribution of landslides and predisposing factors. A bi-variate statistical model is here used to develop a landslide susceptibility map (Shah et al., 2024). A geospatial database containing element-at-risk data, i.e. building footprints, topological data, road network, population, and land cover is acquired using remote sensing tools and field excursion (Abella & Van Westen, 2007). Subsequently, this dataset is evaluated using multi-criteria decision analysis for vulnerability mapping. These analyses are incorporated using a semi-quantitative approach to generate a risk index map in relative classes from very low to very high-risk zones (Althuwaynee & Pradhan, 2017). The risk index map has a significant impact on future urbanization and development, enabling targeted efforts for mitigation and risk reduction.

Shah N.A. et al. (2023) - Integrated Approach for Landslide Risk Assessment Using Geoinformation Tools and Field Data in 574 Hindukush Mountain Ranges, Northern Pakistan. Sustainability, 15(4), 3102.

Shah N.A. et al. (2024) - Regional scale landslide risk assessment using field and remote sensing data in a semi-quantitative approach in Chitral, northern Pakistan. Research Square. https://doi.org//10.21203/rs.3.rs-3860483/v1.

Althuwaynee O.F. & Pradhan B. (2017) - Semi-quantitative landslide risk assessment using GIS-based exposure analysis 572in Kuala Lumpur City. Geomatics, Natural Hazards and Risk, 8(2), 706-732.

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Development and application of an enhanced inversion algorithm for the reconstruction of the basal surface of landslides

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Keywords: landslides, numerical modelling, numerical methods.

Landslides are critical natural hazards that can cause significant impacts in mountainous regions. Their characterization is primarily oriented towards the interpretation of failure mechanisms, controlling factors, and involved volume. To this aim, the combining remote sensing and numerical techniques proved instrumental in investigating the factors controlling the instability evolution. Remote sensing techniques are fundamental tools routinely employed for geological data collection, as well as monitoring slope deformation. Such data can be employed as input or constraint for numerical simulations, to reliably identify the factors and process that control the instability. One of the major challenges is the uncertainty that affects the subsurface configuration of the landslide in terms of material characteristics and morphology of the basal surface. Several methods have been proposed and used to reconstruct the basal surface, which are largely based on geomorphic interpretations or monitoring data processing (Jaboyedoff et al., 2020).

In this work, we present the application of an algorithm that takes advantage of the method of inversion to infer the spatial variations in landslide thickness, based on surface deformation monitoring data. Originally, the technique was developed for the analysis of inland glaciers, before being applied to landslide studies (Booth et al., 2013). We implement significant improvements to the original algorithm, by accelerating the convergence using a faster optimizer and by applying a different criterion for selection of the regularization parameter, which does not require approximations on the noise level. The main advantage compared to earlier versions lies in its improved ability to give an estimate of the depth without imposing extra assumptions in the model. Furthermore, we investigate the role of different regularization functions which incorporate a priori knowledge on the solution.

To evaluate the accuracy of the approach, we first develop a series of conceptual, three-dimensional models, characterized by pre-defined sliding surfaces that are accurately reconstructed by the algorithm using modelled surface deformations as input data. Then, we test the method on selected landslide sites to evaluate the performance of the algorithm in practical applications.

We observe that the algorithms perform well in most conditions, however, some challenges remain to be solved, including the need to constrain the reconstruction with one or more known points, and the inability to investigate the displacement of rigid blocks. Additionally, the correlation between some of the input parameters with landslide rheology has yet to be explored. Despite these limitations and challenges, we show that the inversion method can represent, in some cases, a very important tool in landslide characterization and modelling, providing a means to reduce the uncertainty of numerical model geometry.

Booth A.M. et al. (2013) - Landslide velocity, thickness, and rheology from remote sensing: La Clapière landslide, France. Geophysical Research Letters, 40, 4299-4304, https://doi.org/10.1002/grl.50828.

Jaboyedoff M. et al. (2020) - A review of methods used to estimate initial landslide failure surface depths and volumes. Engineering Geology, 267, 105478, https://doi.org/10.1016/j.enggeo.2020.105478.

Biased landslide inventories and illusory susceptibility model high performances: a test in western Sicily

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Keywords: landslide inventories, susceptibility models, Sicily.

With the aim of producing regional/basin scale landslide susceptibility maps, time/costs effectiveness suggests exploiting the available regional P.A.I. (Piano Assetto Idrogeologico – the Management Plans for hydraulic and geomorphologic risk) landslide inventory (PAI inventory, hereafter), which all the Italian Basin Authorities adopt for their territories having, what is more, a recognition at the administrative level. However, these types of inventories are frequently affected by incompleteness and bias as they are mainly fed by past and reported phenomena which have been associated to damages occurrences rather than being produced down to expert and systematic landslide recognition surveys.

In this contribution, a test was carried out in the Platani river basin (Sicily, Italy) for evaluating the actual quality of landslide susceptibility models which were calibrated by exploiting the PAI inventory prepared by the Basin Authority of the Sicilian hydrographic district.

Starting from the available slide and flow PAI landslide inventories, after a critical review of the mapped landslides, two LIP (landslide identification point) archives (714 slides and 1983 flows) were prepared so to assign stable/unstable status to each of the slope units (SLUs) in which the whole basin was partitioned. By applying multivariate adaptive regression splines (MARS), the SLU status was then regressed on a set of 11 geo-environmental predictors, obtaining the two different (slide and flow) basin-scale susceptibility models. By applying recursive calibration/validation SLUs random partition, excellent values of the Area Under Curve (AUC) were obtained (slide: 0.89; flow: 0.9) together with high values of sensitivity (both: 0.86) and specificity (slide: 0.78; flow: 0.76).

To test the actual prediction skill of the susceptibility models, a new validation subset was prepared through a systematic remote/on-field landslide recognition of a randomly selected set of PAI landslide-free SLUs (11245: ~500 km2). Critical model performances were then observed, especially for the flow model, with a marked lowering of prediction skill for new unstable SLUs, missing 1289 out of the 3132 positive cases (84 out of 334 positive SLUs missing, for slide landslides).

To solve this limits, two new models were prepared by including 70% of the new unstable SLUs in the calibration subset finally obtaining high predictive performance in recalling the whole basin SLUs status (AUC: 0.85 and 0.86, sensitivity: 0.87 and 0.85, specificity: 0.69 and 0.72, respectively for flow and slide) as well as focusing on the blind hidden 30% (sensitivity: 087 and 0.82, specificity: 0.84, 0.73, respectively for flow and slide).

According to the test in the Platani river basin, using biased uncomplete landslide archives, can lead to apparently performing models, which can paradoxically constitute a severe threat in terms of risks if formally adopted as tools for land-use planning and civil protection aims.

Multi-temporal geomorphological analysis and seismic surveys as tools for the investigation of a complex slow-moving landslide: an example from the southern Apennines

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Keywords: landslide, UAV, seismic survey.

Multitemporal geomorphological analysis and mapping of landslide-related landforms of unstable slopes are critical, but frequently underestimated, activities to investigate the spatiotemporal evolution of slow-moving landslides, identify predisposing and triggering factors, and plan mitigation actions. Innovative remote-sensing techniques must be integrated with traditional geomorphological analysis based on multitemporal analysis of historical images and multi-year DEM comparison. This is necessary for a comprehensive investigation of large, slow-moving landslides with a long history of intermittent dormancy and activity, even though recent technological advancements in space and drone platforms have made it easier to quantify the evolution and kinematics of short-term landslides. Through the use of near-surface seismic survey, DEM comparison, and multitemporal geomorphological analysis, the spatial and temporal evolution of a multistage complex landslide has been reconstructed. The impressive complex earthflow identified as the slow-moving Tolve landslide is located in the landslide-prone catchment of the frontal sector of the southern Apennines chain. The study area includes an unstable slope near Tolve, a small town located about 10 kilometres east of Potenza town (Basilicata, southern Italy). The slope is interested in a complex landslide (hereafter Tolve landslide) that shows a high variability of its active sectors in space and time. In order to: i) investigate the multi-decadal spatial and temporal evolution of the landslide; ii) estimate the mobilized volumes during the recent stages of the slope's reactivation; iii) reconstruct the subsurface features of the landslide body and the geometry of the sliding surface; and iv) infer the predisposing and triggering factors of the intermittent activity of the earthflow, we integrated traditional geomorphological analysis with DEM comparison and seismic surveys.

Sentinel-1 SAR-based globally distributed landslide detection by deep neural networks

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Keywords: landslides, neural networks, SAR.

An effective response to widespread multiple landslide events (MLEs) on a large scale requires swift and accurate landslide detection. Despite considerable efforts using optical remote sensing, there are limitations in achieving global coverage, day-and-night operation, and all-weather capabilities. To address these challenges, we propose a method that combines Deep Neural Networks (DNNs) with Synthetic Aperture Radar (SAR) backscatter data. This method is developed by analyzing 11 earthquake-induced MLEs, which involved around 73 thousand landslides globally in various geographical settings. We validate the model's performance on unseen earthquake-induced landslides in Sumatra and Haiti, achieving a test F1-score of 82% in rapid assessment, signifying substantial advancement over previous approaches. Our method utilizes Google Earth Engine for Sentinel-1 SAR image processing and employs local computing resources for advanced DNN-based image classification. Through explainable artificial intelligence, our study highlights the effectiveness of change detection bands in better distinguishing landslide features, surpassing the use of backscatter data alone. Additionally, we demonstrate improved landslide detection using multi-temporal information stacks rather than single post-event SAR images. Finally, we introduce the SAR-LRA Tool in its Beta version, offering a valuable resource for swift and comprehensive all-weather global landslide assessment. The systematic application of this tool promises to enhance timely responses to future MLEs. Our research provides a solid foundation for future endeavors, where SAR and DNNs can be leveraged to identify natural hazards and earth surface changes in mountainous regions. Given the frequent occurrence of MLEs, developing a robust modeling approach is crucial for promptly assessing their spatial distribution. This research sets the stage for efficient rapid assessment of MLEs in the future.

Integrated geophysical and geotechnical investigations of Upper Sarbala Landslide: a case study of Himalayas Mountain ranges, Pakistan

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Keywords: landslide, electrical resistivity tomography, specific gravity.

Landslides are gravitational mass movement that occurs as an effect of some change in the factors controlling the equilibrium of the sliding mass. In this contribution, landslide case study situated in the northwestern Himalayas of Pakistan, located near Sudhan Gali, District Bagh, Azad Jammu and Kashmir, with coordinates ranging from 73°43'31.38" to 73°43'22.04" E longitudes and from 34°5'25.22" to 34°5'25.11"N latitude, is discussed. In mountainous regions such as Pakistan, landslides are the main cause of loss of life, damages to buildings and infrastructure lines, and financial losses (Basharat, 2012). The Himalayan Mountains are among the most dangerous areas in the world for landsliding, due to weak geological components, and seismically very active zones (Khan, 2006). To characterize the Sarbala Landslide, techniques including geological fieldwork, electrical resistivity tomography (ERT), geotechnical laboratory characterizations, and GIS mapping were applied to evaluate the surface and subsurface dynamics of the Sarbala Landslide. In order to understand the geometry and failure mechanism of landslides, the ERT survey is widely used (Perrone et al., 2014). Soil samples were collected during multiple field surveys, and six ERT profiles were acquired using the Schlumberger array in various parts of the Sarbala Landslide. According to the ERT results, the sliding mass of the Sarbala landslide consists mostly of saturated colluvium and debris, which causes low resistivity in tomograms. Saturation of the slope-forming material can be considered as a major factor controlling the instability of the Sarbala Landslide. Based on resistivity contrast, a well-developed slip surface is observed between the unconsolidated landslide mass and the underlying bedrock. Atterberg properties, which have a strong influence on mass movement, include soil texture, porosity and permeability, soil mineral content, and soil water content (Kristyanto et al.,2017; Kitutu., 2009). The Atterberg limits of the landslide material indicate low to medium plastic behavior of the landslide. The reconstruction of the slope lithological setup has indicated that the sand deposit, with large permeability values, in the upper portion of the landslide, works as a water recharge tank for the downslope area, providing a large amount of water for the landslide mass, mainly formed of clayey material, , which then results in slope failure. Therefore, the hydrogeological setup of the slope-forming mass can be considered as a major factor controlling the stability of the Sarbala Landslide. Furthermore, this area is tectonically active, and faults play an important role in the activation of this landslide. Landslide scarps and large-scale tensional cracks show the active nature of the landslide. According to this research, the Sarbala Landslide is an active mass movement. A limit equilibrium back-analysis has been also carried out for the landslide mass in order to derive information on the shear strength parameters mobilized at failure as well as on the whole slope conditions leading to instability.

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Assessing landslide hazards in the Volcanic Crater of Lake Albano, Rome, Italy: feasibility and challenges

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Keywords: landslide susceptibility, prediction modeling, mathematical functions.

This study utilizes mathematical models to assess landslide susceptibility in the vicinity of Lake Albano, a volcanic crater and tourist destination near Rome, Italy. The region has experienced various types of mass movements for over 2,100 years, posing ongoing risks exacerbated by urban expansion and socioeconomic activities.

Spanning 30 km², the study area is represented by a digital raster of 1002 pixels × 1202 lines at 5 m resolution, comprising 975,093 pixels above water and 229,311 below. Within this area, 8,867 pixels denote 150 sub-aerial landslides, and 34,028 pixels denote 65 sub-aqueous landslides, indicating high densities of mass movements.

A comprehensive database compiled information on landslide distributions, types, shapes, and locations, both sub-aerial and sub-aqueous (Patera & Fabbri, 2021; Patera & Fabbri, 2023). Categorical maps of land use classes and lithology units, along with high-resolution topographic elevation data, characterized the physical environment. Utilizing a dense grid of elevation points (Bozzano et al., 2009), continuous value maps at 5 m resolution were generated for aspect, digital elevation model, slope, curvature, planform, and profile.

Prediction modeling employed a fuzzy set membership function and logistic discriminant function, yielding digital images ranking the study area by relative susceptibility levels. Spatial support varied based on landslide types and physiographic conditions, integrating empirical likelihood values to contrast settings with and without landslides for each pixel. Despite overlaps in predictions between models and landslide types, the feasibility of assessing landslide susceptibility with low uncertainty is demonstrated. However, challenges persist due to the volcanic nature of the area and socioeconomic factors, complicating hazard mitigation and risk management efforts.

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Assessment of the risk of shallow landslides integrating InSAR and optical data with a distributed eco-hydrological model

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Keywords: landslides, physically-based deterministic models, remote sensing technology.

Each year, landslides pose significant hazards, causing loss of life, destruction, and financial setbacks. Physically-based models for rainfall-triggered landslides offer advantages over empirical methods by evaluating rainfall, soil hydrology, and shear strength during infiltration. However, their complexity, especially regarding distributed soil parameters, is a major obstacle. To address this, we propose integrating remote sensing, enhancing landslide research. Our methodology integrates remote sensing and InSAR technology with a distributed model, focusing on estimating soil parameters and understanding soil moisture's correlation with deformation history. Accurate assessment of soil thickness is crucial for landslide prediction. We utilized pedotransfer functions and in-situ data to derive additional factor of safety components. The framework integrates the tRIBS-VEGGIE model with a landslide component, utilizing Richard's equation for soil moisture transport. However, the hypothetical failure surface depends on specific soil characteristics and must be constrained. To determine soil thickness, we plan to explore thickness inversion, using displacement rate estimation from InSAR measurements and mass conservation principles (Xu et al., 2019; Xu et al., 2020). Synthetic Aperture Radar Interferometry (InSAR) data from Sentinel-1, via the European Ground Motion Service (EGSM), provides European-scale ground motion information. This dataset will be validated in the Friuli-Venezia Giulia region, focusing on documented alluvial events triggering shallow landslides. Analyzing soil parameters emphasizes the importance of assessing geological characteristics identified through InSAR technology. To document and detect landslides, we use the Italian Landslide Inventory (IFFI), supplemented with open data from the IDROGEO project.

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S26.

Sinkholes vs. land subsidence: assessment of the geological hazards and impacts on environment and society

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Anthropogenic sinkholes' susceptibility assessment in Palermo, Italy, using a machine learning algorithm

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Keywords: Palermo, sinkhole, susceptibility.

Sinkholes are a widespread geohazard related to the subsidence or collapse caused by underground cavities presence. In urban areas, the latter is related to anthropic activities, such as building stone extraction, or subsurface utilities (aqueducts, sewers, cables) installation and leaking. This type of sinkholes, called anthropogenic sinkholes (Parise, 2015), usually cause fewer deaths compared to other geohazards, but their impact on the urban fabric is still relevant. Damage to the road network, for example, can lead to economic loss to the local socioeconomic fabric, especially if repair works require the interdiction of the road. Anthropogenic sinkholes are widespread in the historic city centres of the Italian Peninsula: Palermo, regional capital of Sicily, is among these cities. The machine learning algorithm Maximum Entropy (MaxEnt) (Phillips & Dudìk, 2008) was employed to evaluate the sinkhole susceptibility in the city of Palermo. The presence inventory was obtained by combining the available data from ISPRA, the Universities of Palermo and Siena, and national/local news. As the inventory is limited to 274 events, a k-fold cross-validation technique was employed (with k = 5). This means that the modelization process is iterated using one of the k sets as the validation set (a different one for every iteration), while the remaining data is used as the training set. The final model is a mean of the k models obtained through the algorithm iteration process. The Variance Inflation Factor (VIF) technique has been performed to minimize the influence of multicollinearity during machine learning modelization. The VIF analysis has been executed in R (R Core Team, 2023) using the usdm package (Naimi et al., 2014). The predisposing factors implemented in this analysis describe geological characteristics (land use, slope angle, geological map) and anthropogenic factors (underground cavities, road and underground railroad networks, and areas influenced by the extraction of building materials). The performance of the model is evaluated using the ROC/AUC score. Due to the implementation of the k-fold cross-validation technique, the score obtained is a mean of the iterated models. The good performance achieved for the resulting map makes it a useful new step towards a better understanding of anthropogenic sinkhole susceptibility assessment in urban areas. These tools can be a valid contribution to the work of local administrations and stakeholders aiming at risk mitigation and protection of cultural and monumental heritage.

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A geological-geotechnical approach to analyze the causes of subsidence in the Volturno River plain (northern Campania, Italy)

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Keywords: land subsidence, geological-geotechnical characterization, primary and secondary consolidation.

The areas affected by land subsidence (LS) have become the subject of many studies in recent years. The purpose of this research is to analyze LS and its main natural causes in the Volturno River plain. In this study, the geological and geotechnical characteristics of the subsurface are investigated using subsurface data, i.e. boreholes and cone penetrometric tests (CPT), to interpret the stratigraphic architecture of the plain and assess its susceptibility to subsidence. The Volturno river plain is a peculiar study area for studying LS, due to the presence, in the subsoil of the entire Volturno alluvial plain, of a thick, continuous level of pyroclastic deposit (the Campanian Grey Tuff - CGT - dated 39 ky B.P.). The CGT represents the bedrock surface for the following Holocene deposition and is considered as an incompressible base. A careful geological and depositional reconstruction was carried out combining information from geomorphological evolution and stratigraphic investigations. The spatial arrangement of Holocene depositional facies was reconstructed, as well as that of the different lithologies, which showed the presence and spatial distribution of compressible materials such as clay, silt and peat. These data were spatially superimposed on the present subsidence map reconstructed with InSAR data, highlighting the relationship between the different subsidence rates and the composition of the Holocene fill, suggesting that the greatest subsidence in the lowlands is related to the potential for compressible soft soils affected by both primary and secondary consolidation.

Subsequently, the geological data regarding depositional and lithological characteristics were associated to the penetrometric data from the CPT. This analysis showed that different facies associations may have a similar lithological composition but have surprisingly dissimilar geotechnical behavior. This latter provides valuable input for the evaluation of the paleo-compaction rates for the different lithofacies during their deposition. The results obtained provide a more advanced understanding of the evolution of the floodplain and coastal plain of the Volturno River reconstructed on a purely stratigraphic basis in the previous analyses, providing more information on the main depocentres or processes that occurred following the aggradation and progradation phases that led to the formation of the present day Volturno delta plain. A further study was conducted combining InSAR and subsurface data (CPT) to assess primary and secondary consolidation coefficients and thus understand the relationship between natural and anthropogenic causes and how these contribute to the variability of subsidence rates within the plain.

The study offers a comprehensive and multidisciplinary reading of the various factors that influence the natural behavior of sediment deposition and compaction dynamics in a floodplain and coastal plain. It provides a comprehensive overview of the stratigraphic architecture of the subsurface of the northern Campanian plain and, consequently, its connection to past and ongoing land subsidence, thus providing an important contribution to support the planning of interventions in the Volturno River plain to manage the impacts on the environment and buildings resulting from subsidence.

Storm-induced coastline sinkholes monitored by means of uncrewed aerial systems (UAS) in the gulf of Trieste (NE Italy)

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Keywords: coastline sinkholes, climate changes, UAS monitoring.

In the last decades, there has been a growing discussion within the scientific community regarding extreme events attributed to climate changes, implying the occurrence of increasingly intense and more frequent catastrophic phenomena. The latter do not exempt Italy, which is grappling with severe weather conditions, including torrential rainfalls, intense thunderstorms, alluvial events, strong winds, landslides, forest fires during extreme heat, etc. Among the other, coastal areas, represented by the long shoreline of the Italian peninsula, are one of the most susceptible environments. Here, several interactions occur between natural and anthropogenic inputs, as well as between marine and terrestrial processes, making these areas particularly susceptible to rapid morphological changes. During extreme weather conditions, such as high sea water levels, strong winds, and high waves with crests oriented parallel to the coastline, important natural phenomena such as coastal erosion and landslides can be triggered. This convergence of factors occurred in the Gulf of Trieste (NE Italy) between late October and early November 2023, mimicking an episode that already occurred in the area in November 1969. In particular, four storm surges events with peak winds between 14.3 m/s and 19.5 m/s, blowing from the southwest (from 200 to 240 degrees from the north) hit the area. Among the hardest-hit areas were the Barcola waterfront and the Sistiana Bay (coastline of approximately 4.5 km) counting million euros of estimated damages. The present study focuses on the Sistiana Bay where the occurrence and evolution of 10 sinkholes were monitored since before the onset of the extreme weather. The maximum diameter reached by these features was between 1.4 and 6.86 m (with an average of 4.06 m) corresponding to surface areas between 1.03 and 17.04 m² (8.26 m² in average). The monitoring involved the acquisition of several aerial images using UAS (specifically, a DJI Mavic 3T RTK drone) that were repeated 6 times between September 29 (2023) and February 13 (2024). Each set of images was processed using Agisoft Metashape to generate Structure from Motion-Multi View Stereo (SfM-MVS) photogrammetry-derived products, including 3D models, digital elevation models, and orthophotos. In conclusion, this study contributes to shedding new light on the time-space evolution of these catastrophic geomorphological features in coastal settings under extreme weather conditions, thereby aiding in the formulation of actions toward coastal defence and monitoring.

Anatomy of a small sinkhole near the Adriatic coast

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Keywords: sinkholes, stratigraphy, karst hydrogeology.

Coastal sinkholes characterize many sectors along the Adriatic coastline, with variable size and depth, and involving different lithologies. As regards the mechanisms of formation, they are typically originated as cover-collapse sinkholes (*sensu* Gutierrez et al., 2014; Parise, 2022), involving the Quaternary calcarenite and the calcirudite deposits unconformably lying on the Cretaceous bedrock. This is the case for Puntore Cave (PU 377 in the regional cadastre of caves in Apulia, available at http://www.catasto.fspuglia.it), which connection to the surface consists of two small openings created by collapses. Within the cave, the floor is marked by widespread breakdown deposits, and by a small water lake. In the past, man excavated an artificial gallery to easily reach the subterranean environment, and use the water for irrigation of the surrounding fields. This contribution describes the stratigraphy of the cave, its main speleogenetic characters, the morphometry, and the first phases of monitoring of the water so far carried out, including the preliminary analysis of the stygofauna (Galmarini et al., 2023). Quaternary calcarenites and calcirudites cropping out at Puntore Cave consist of poorly lithified and weathered bioclastic packstones, grainstones and floatstones belonging to the Calcarenite di Gravina Fm. They are classified as soft rocks having complex rock fabrics and diagenetic features (Festa et al., 2017). As a result, their peculiar petrographic features, such as grain-packing, matrix content, pore size and pore-size distribution, type and abundance of sparry cement in pore spaces contribute to define the peculiar physical and mechanical behaviors and the resistance to weathering processes of carbonate rocks. Preliminary data suggest that bioclastic grainstone, having large and interconnected pores partly filled by granular cements, is the most prone lithotype to be affected by weathering processes. Consequently, it is inferred that the subsequent rapid decay of the mechanical properties of this lithotype may have played an important role in triggering the sinkhole formation.

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Ground deformation induced by piezometric levels fluctuations in the plain of the Sarno River (southern Italy)

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Keywords: piezometric level fluctuation, ground deformation, DInSAR.

Ground deformations associated with fluctuations in groundwater levels have been recognized on a global scale, posing georisk to human activities and urban settlements in certain instances (Tang et al., 2022). Mismanagement of groundwater resources exacerbates hydrogeological imbalances, often resulting in overexploitation. Subsidence induced by groundwater extraction is well-documented in the scientific literature (Galloway, 2013). Conversely, uncontrolled cessation of pumping can trigger groundwater rebound phenomena, causing piezometric levels to recover and possible ground uplift (Coda et al., 2019). In this study, the pyroclastic-alluvial plain of the Sarno River, extended over about 170 km2, was investigated through an integrated analysis of meteorological, hydrogeological, and ground deformation data. Firstly, a 3D hydrostratigraphic model of the aquifer was developed using Rockworks 17 (RockWare Inc.), based on 165 stratigraphic logs and 122 well data from open-source databases and a field survey conducted between July and October 2021. Furthermore, at the basin scale, a multitemporal estimate of the water balance and spatio-temporal analysis of piezometric levels was carried out in the period 1978-2021. Radar data from four different satellite constellations, i.e. ERS-1/2 (1993-2000), ENVISAT (2002-2010), COSMO Sky-Med (2011-2014), and SENTINEL-1 (2016-2020), were interpreted and processed using the Differential Interferometry SAR (DInSAR) technique to produce multi-temporal maps and time series of ground vertical deformation. For the investigated period (1978-2021), a significant reduction in groundwater recharge at the basin scale was observed, quantified at approximately 0.57 m^3/s, mainly attributed to the strong increase in urbanized area (from 31% to 76%) and reduction (from 69% to 24%) of rural areas. The spatiotemporal analysis of piezometric levels and soil deformations revealed a clear cause-effect relationship between piezometric lowering and subsidence, and piezometric rising and ground uplift. Fluctuations in piezometric levels were recorded with spatially heterogeneous distribution, ranging from -14.0 m to +16.0 m with rates ranging from -1.0 m/year to +2.0 m/year. The main causes of these processes were attributed, in addition to temporal variations in effective infiltration, to reductions and/or relocation of industrial and drinking water withdrawals. Satellite data showed correspondence in the spatiotemporal distribution between the areas affected by subsidence (up to -1.8 m, period 2003-2010) and piezometric decreases, and between uplift (up to +1.2 m, period 2003-2010) and piezometric increases. The rate of vertical ground displacement appears to be controlled by local hydrogeological and hydrostratigraphic conditions, linked to aquifer type (phreatic or semi-confined), the magnitude of piezometric fluctuation, and the thickness of the most compressible and deformable layers.

Acknowledgements: This work was carried out within the RETURN Extended Partnership and received funding from the European Union Next-GenerationEU (National Recovery and Resilience Plan – NRRP, Mission 4, Component 2, Investment 1.3 – D.D. 1243 2/8/2022, PE0000005).

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Natural risks and protection of the territory: the San Martino Valley case history (Capena, Rome metropolitan area)

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Keywords: Natural Risk, San Martino Valley, sinkhole.

This research pertains to the findings of a study conducted under a Collaboration Agreement between the "Metropolitan City of Rome Capital" (CMRC) and the "National Institute of Geophysics and Volcanology" of Rome (INGV). The study focuses on the geophysical analysis of deformation phenomena observed at a selected test site within a *sinkholes-prone* area in the metropolitan area of Rome (Central Italy). The study area corresponds to the San Martino Valley (near the Capena village, about 30 km North of Rome), where the "Lago Puzzo" sinkhole-lake (classified with ID 58009 in the national database; https://sgi.isprambiente.it/sinkholeweb) occurs; it showed a multiphase evolution well documented in historical times, coupled with the presence of similar morphologies along the valley (Nisio, 2008, and references therein). The study area is located close to the middle Tiber River valley, south of the on Mt. Soratte carbonate horst, belonging to the Sabina tectonic units and bounded by extensional faults. The San Martino Valley, a depressed area where a thick plio-quaternary sedimentary cover overlays the tectonically lowered carbonate bedrock, is interpreted as the surface expression of a N20° striking high-angle transtensional fault (Faccenna, 1994).

In October 2020, a low intensity earthquake, characterized by a shallow hypocentre, occurred in this area; moreover, roars have been clearly perceived by resident population several times in the following months. The site, located in correspondence of relevant infrastructures (a high-speed railway line, an overhead power line, provincial roads and urbanized areas), deserved thus a particular attention. The investigation, based on an interdisciplinary approach, is aimed to evaluate the geo-structural model of the occurrence and to decipher its evolutionary stages. The remote sensing data (SAR) allowed outlining and quantifying the movements (InSAR analysis). The seismological spectral analysis techniques have characterized the recent seismic event occurring in the Capena area, whereas the geophysical investigations (e.g., ERT, magnetic and gravimetric surveying) have illuminated the subsurface structure. These latter have highlighted a clear connection among the regional and local tectonic framework, a shallow and fractured carbonate bedrock and the overlaying Plio-Pleistocene cover. This connection is also clearly testified by geomorphological and geochemical marks. The results offer valuable insights into understanding the mechanisms of deformation, predicting the future evolution of the phenomena, and potentially forecasting their spatial migration. Consequently, this study represents a significant step towards the refinement of hazard evaluation methodologies.

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Subsidence in the Po Plain (Northern Italy) during the last 500 ky

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Keywords: subsidence, Pleistocene, Po Plain.

Subsidence controls the evolution of alluvial and coastal plains, the most densely populated areas of the planet. Recent high-resolution technologies, such as satellite interferometry (INSAR) and GPS surveys, permit the precise measurement of subsidence over yearly to decadal scales. The values obtained with these techniques include the contribution of natural and anthropogenic subsidence. The calculation of natural subsidence is based on the recognition and dating of key marker horizons in the geological record. Seismic profiles typically provide information about subsidence over millions of years. In contrast, relatively poor information is available on subsidence over intermediate time scales (thousands of years).

The Po Plain, the most populated alluvial and coastal plain in Italy, is a rapidly subsiding foreland basin that preserves a thick record of Quaternary deposits. In this area, we calculated subsidence rates (SR) over different time intervals since the Middle Pleistocene. SR calculations relied on a detailed stratigraphic framework obtained through sediment core correlation, constrained by pollen data and absolute ages (14C, IRSL and ESR). Coastal and lagoon deposits, reflecting chronologically constrained marine ingressions related to the Middle Pleistocene interglacials, were selected as stratigraphic markers (paleo-sea level indicators) for SR calculations. SR were calculated by dividing the elevation of the stratigraphic markers (referred at sea-level at the time of accumulation), by their age of deposition.

The results show minimum SR above the main tectonic structures (thrust-related folds) in the subsurface of the Po Plain, and maximum values away from the buried anticlines, beneath the Adriatic coastal plain. This particular SR distribution likely reflects the combination of two controlling factors: (i) tectonic activity of the buried structures, (ii) enhanced compaction of highly compressible sediments in distal settings.

The approach used in this work can potentially be applied to other subsiding basins with a well-preserved sedimentary record, and provides data on subsidence over intermediate time scales.

Sinkhole development along the Apulian coastlines, within the framework of the project Fu.Co.Ka. (Future scenarios in Coastal Karst)

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Keywords: sinkholes, coast, karst.

This abstract is dedicated to studying coastal karst areas in Apulia focusing on the effects deriving from the dissolution processes acting at the interface between freshwater and saltwater, within the framework of the PRIN project "Future scenarios in coastal karst: saltwater intrusion, loss of water resources and sinkhole development as effects of climate changes (Fu.Co.Ka.)". Apulia is among the most remarkable karst regions in the Mediterranean Basin, with over 80% of its territory constituted of soluble carbonate rocks outcropping, and about 900 km of coastlines. It represents therefore an ideal place where to study the climate change impacts on coastal karst, and which outcomes might be useful for other coastal areas, in the Mediterranean as well as in other parts of the world.

The high fragility of coastal karst is related to its hydrogeological peculiar characteristics, the direct link between the surface and the underground, and the facility in contaminating the groundwater and in favoring the development of sinkhole processes. In this latter regard, the presence of karst voids poses the need to investigate the instability processes, and their effects at the surface. Within caves, the rock materials are strongly susceptible to water-induced weathering processes, which are responsible, first, of local failures, and, through progressive stopping, may later reach the ground surface in the form of different types of sinkholes (Gutierrez et al., 2014; Parise, 2019, 2022). Assessing the stability of underground karst caves is a complex task, due to the variety of involved factors, the many uncertainties in predicting the cave evolution, and the likely interaction of the instability features with the overlying infrastructures at the surface. This latter is a very important issue in highly attractive tourist sites such as the coasts of Apulia.

The main driving factors for sinkhole occurrence in coastal settings are detected through investigations with DTMs and detailed mapping, characterization of local geology and geomorphology, and geo-structural surveys. Detailed surveys are being carried out using advanced laser scanning devices, integrated by drone flights for the outside environments, aimed at searching for correlations between surface features, evidences of instability (subsidence, flooded areas, erosion, sinkholes), cave levels and underground morphologies. This activity may also contribute to reconstruct the evolution of the water table, and its relationship with the landscape evolution, both at the surface and underground. A specific focus is further given to documentation of some of the precursory signs of likely failures in cave systems, such as extrusion wedges and bulging from the walls, that may represent the first warning signs for future sinkholes. Given the relevant role of seastorms in the triggering of cliff failures and coastal sinkholes, this aspect, too, is taken into account for a full understanding of the driving forces acting on the examined coastal stretches.

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Artificial cavities and risk assessment: the case study of the Cloister of Sant'Agostino (Caserta, Italy)

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Keywords: underground artificial cavities, ERT, stability assessment.

The presence of underground voids represents a serious problem that affects many urban centers in Italy and that often compromises the stability of urban structures. In order to keep people safe and reduce economic losses, it is necessary to accurately identify the presence of these underground spaces and to monitor their behaviour, to manage the risks related to the unpredictable trigger of sinkholes or soil subsidence. This is even more dramatic when it happens underneath buildings of historical and cultural interest.

The research presented herein refers to the study case of the Cloister of Sant'Agostino (XVI century), located in the historic center of the city of Caserta, very close to the the Royal Palace Garden (Damiano et al., 2023). The whole structure has recently been the subject of a restoration project, for its inclusion in a tourist circuit, which required investigations inside the cloister. The cloister presents phenomena of instability in the flooring and on some portions of the portico that surround it. Underlying the uncovered area of the cloister - and for approximately 2/5 of the corresponding surface area - there is an underground cavity of anthropic origin which includes a cistern for rainwater storage.

For the accessible part of the cavity, a laser scanner survey was conducted in order to highlight the spatial relationships that exist between the void in the subsoil and the elevated structures that insist on it. In addition, to understand the true extention of the cavity, electric tomography (ERT) investigations were carried out. To define the geological and geotechnical model of subsoil, numerical methods were applied to estimate potential crisis areas, with preliminary assessments of the influence of the presence of the cavity on the stability of the subsoil.

This study was carried out by integrating research between applied disciplines (geology, geotechnics, speleology, cultural heritage) and provide indispensable support both for the management and mitigation of geological risks in urban areas and for the sustainable reuse of hypogea thus contributing to enhancing the cultural and tourist promotion of a territory.

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Building a database for the analysis of sinkholes related to artificial cavities: the case study of Altamura (Apulia, Southern Italy)

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Keywords: sinkholes, susceptibility, database.

The Altamura town (Apulia, Southern Italy) has been severely affected by collapse sinkholes during the last decades, particularly at some new urbanized areas around the outskirts of the historic part of town. The ground failures occurred in correspondence of the extensive network of man-made underground galleries, used as mines and calcarenite quarries. Weathering, water infiltration, pipeline leakages and anthropogenic actions such as ground vibrations due to traffic, as well as additional loads of new buildings, triggered failures in the cavities below the urban area, causing the sinkhole formation.

This study aims at evaluating the sinkholes susceptibility at Altamura, in collaboration with the local municipality. Specifically, the probability of future collapse events occurrence will be investigated. The analysis proceeds throughout various phases: first, the construction of a dedicated database in GIS system, containing all the relevant information about geology, hydrogeology, and rock geotechnics parameters. This geodatabase will be integrated with data related to the underground galleries, as their geometry (cave maps and sections, as surveyed by cavers) and stability conditions, as the presence or absence of failures and/or damages within the subterranean systems. To proper assess the stability conditions of the system, the outcomes from periodic interferometric surveys will also be included in the analyses. Eventually, some information about past occurred sinkholes will be considered, like location and occurrence time. The database will therefore represent an archive from which to extrapolate additional data of scientific interest to perform new analyses, also based on quantitative approaches. The final goal will be the realization of a sinkhole susceptibility map, a useful tool for authorities and planners in charge of the management of the territory.

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GNCA database for stability assessment of artificial cavities

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Keywords: artificial cavities, GNCA, stability assessment.

Dealing with territorial planning, the complexity of subsoil setting represents both a resource and a constraint. For this reason, the collection, the standardization and the sharing of information about the conditions of the cavities are recognized as crucial elements for the assessment of the risk of collapse and, consequently, to implement mitigation interventions.

From this perspective, the Italian National Geodatabase of Artificial Cavities (GNCA) represents a free access digital tool (ISPRA & SSI, 2023) which contains a set of information such as the location of the cavity and, for many of them their underground configuration. Specifically, the database provides plan maps, sections and field survey reports of the artificial cavities documenting the geological and geometrical features.

The present work highlights, on the one hand, the usefulness of the GNCA to share available data on cavities' features for researchers, technicians and stakeholders to manage the risk associated with them.

On the other hand, a comparative study on the assessment of roof stability is analysed to evaluate the safety of cavities collected in GNCA.

To this aim the stability charts adopted and proposed by de Silva et al. (2023) and by Mevoli et al. (2024) have been considered. The farther evaluates the stability of the roof by considering the uncertainties of geotechnical properties of the rock in terms of spatial variability and discontinuities. The latter provides a preliminary safety margin evaluation based on the quantitative assessment of the geometrical features and taking in account the strength parameters of the rock material of cavities.

The salient ingredients accounted, in both methods, used are the characteristic length of the cavities, the thickness of the roofs, the strength parameters of the rock and the field stress affecting the roof. A major part of the above data was retrieved from the GNCA set of attributes searching, for each cavity in the database, the suitable two-dimensional sections on which to apply the mentioned stability charts. Finally, the results are represented in terms of stable/unstable conditions.

Summarizing, the conjunction of GNCA data and the application of such tools let outline the stability frame at the urban scale. Nevertheless, to refine a proper judgement for decision makers, the analyses should be delved deeper by downscaling the focus and by detailing the cases, especially, considered critical by the preliminary assessment.

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A multidisciplinary approach for sinkhole mitigation strategies: the case of the urban area of Altamura (southern Italy)

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Keywords: sinkhole susceptibility, social vulnerability, mitigation strategies.

Sinkholes have to be considered one of the most typical features in karst settings, given the soluble nature of rocks. Since their attitude to be carved by man to build artificial cavities, collapse sinkholes (Gutierrez et al.,2014) may also occur in no karst areas, like volcanic soils or soft carbonate rocks. In both cases, the rapid kinematics of collapse sinkholes is associated with the absence of clear precursory signals, representing a serious issue in terms of hazard for local communities. In this context, underground quarries within soft calcarenite rocks are one of the most relevant and diffused artificial cavities prone to collapse. Altamura (Apulia Region) is one of the Apulian municipalities showing an extended network of underground voids that have been dug in the past to extract calcarenites. In recent years, sinkholes occurred at some galleries of the underground quarry net (Parise et al., 2013), generating fear and discomfort in the population. For this reason, investigating the social vulnerability of the population living above the void network becomes of primary importance to understand the main factors influencing the capacity of a specific community to anticipate, cope with, and recover from a disaster (Frigerio & De Amicis, 2016). In particular, the interaction between the sinkhole susceptibility and the socio-economic environment can provide a first detailed map of the sinkhole risk context that can be used as a tool for emergency planning and that can play a crucial role in the mitigation strategies to prevent loss of life and infrastructure damage. Our work investigates the correlation between the sinkhole susceptibility and the social vulnerability in the urban area of the Altamura town through a multidisciplinary approach. Based upon the evaluation of different integration levels, which includes the sinkhole susceptibility and the social vulnerability, a set of engineering mitigation strategies (grouting, local reinforcements or piled foundations), coupled with cost assessment, is also analyzed to help local authorities and inhabitants to deal with sinkhole hazard.

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Sinkholes in the Campo Soriano karst plain (Central Italy)

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Keywords: Campo Soriano, karst, sinkhole.

The karst plain of Campo Soriano extends for approximately 1km2 in the southern sector of the Ausoni Mountains (Central Italy), in the territory of the municipalities of Sonnino and Terracina.

This area was declared a Natural Monument in 1985, because of its significant landscape and geomorphological uniqueness due to the presence of numerous types of epigean (karren, hum, sinkholes) and hypogeal karst morphologies.

Indeed, the Campo Soriano area is a karst plain located at an average altitude of 300 m above sea level, delimited by reliefs a few hundred meters higher. The subsoil of the plateau is made up of Cretaceous limestones and dolomitic limestones, covered by a residual deposit (*terra rossa)* with a thickness varying from a few tens of cm to just over 1 m, in the areas of greatest accumulation.

The area has still active karst phenomena highlighted by recent sinkholes. The surface waters are drained from the numerous ponors and cavities that develop along the main fractures, with a predominantly vertical trend, such as the two locally called "Chiavica di Zì Checca" and the "Chiavica del Cervaro", as well as many other minor cavities.

The superficial development of the sinking phenomena under study are linked to the network of cavities surveyed over decades by speleological associations (Bellatreccia et al., 2020).

In this work, the analysis and census of sinkholes phenomena was carried out, through field surveys, cartographic analysis, and the study of aerial photos. For some sectors, the processing of images taken through photogrammetric surveys with drone has allowed the development of 3D models. Some corrosion grooves on the walls of the hums are also described, interpreted as signs of ancient ground surfaces and witnesses of the evolution of the plain through subsequent sinkings.

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A user-friendly and mechanically-based method to assess the stability of underground caves: the iSUMM abaci

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Keywords: sinkhole hazard, numerical modelling, abaci, safety factor.

In the recent years, an increasing number of sinkhole events related to man-made underground caves has been observed in several contexts of urban and peri-urban areas of the Italian territory, which induce significant risk conditions in terms of human lives as well as damages to the anthropogenic environment. Frequently, such caves have been dug within very soft porous rock formations, as for example the calcarenite deposits, even at shallow depths, and later on, after some decades, abandoned. The low values of the mechanical strength of such rocks, along with their proneness to weathering and consequent degradation of the strength, represent an important controlling factor of the instability processes leading to the sinkhole development. It follows that developing quantitative methods that can be considered as reliable for the assessment of the cave stability conditions is urgent for planning and management policies of the territory.

Based on a previous scientific work presented by these authors, which proposes abaci for the assessment of proneness to instability of underground caves according to the cave geometrical features and rock mechanical properties (Perrotti et al., 2018), the present contribution discusses a recent enhanced formulation of the abaci (iSUMM, innovative, Straightforward, User-friendly, Mechanically-based Method) that introduces the opportunity to evaluate the range of the safety factor values with respect to a potential failure mechanism. Such an advanced version of the abaci has been derived from the results of a wide set of parametrical finite element analyses and, therefore, allows to calculate in a fast way a mechanically-based indication on the safety margin against the rock mass failure. It follows that the application of the abaci can be used as a quantitative tool to assess sinkhole hazard in a preliminary way, to be used in analyses at wide scale, and, eventually, followed by detailed studies developed with more advanced methods at the local scale. This work presents the numerical procedure that has been adopted to derive the enhanced version of the abaci and the validation performed based on a large set of underground cave case studies.

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Natural and anthropogenic sinkholes in volcanic areas an underestimated hazard

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Keywords: natural and anthropogenic sinkholes, volcanic areas, nuclear waste.

In Italy, volcanic regions are susceptible to sinkhole hazards due to the unique interplay of volcanic activity, hydrogeological dynamics, the rise of geothermal fluids, and human activities. The new sinkhole census databases that ISPRA is developing as part of the PNNR Geosciences-IR project (WP.3.2) highlight the widespread of this natural or anthropogenic phenomenon. Despite this evidence, the possibility of developing natural sinkholes in volcanic areas is still little considered. Even a part of the scientific community tends to confine the sinkhole phenomenon only to the forms that develop on karst and pseudokarst lithologies. A striking case of this trend is, for example, the exclusion of sinkholes that can develop in volcanic areas in the guidelines designed for identifying nuclear waste storage sites. This omission has contributed to considering the plateaux of Latium inactive volcanic districts as particularly suitable sites for that purpose. This study utilises geological surveys, remote sensing data, UAVs, and historical records to map and analyse the distribution of some particularly significant sinkholes that have opened on volcanic rocks in the Latium region and correlate their occurrences with geological, geomorphological and hydrological conditions. The aim is to highlight the complex dynamics of sinkhole formation in Italian volcanic areas and provide a framework for risk assessment and management of volcanic plateaux, which are often considered stable areas in terms of geomorphology. For this reason, it is essential to define the types, sizes, and mechanisms that trigger these phenomena, which can affect not only large urban areas such as Rome or Naples but also rural or suburban areas. The sinkhole risk is widely underestimated, especially in these areas, because they are less populated and urbanised. Still, it can become very high where high-risk industrial installations, special or nuclear waste dumps, strategic infrastructure, motorways, and railways occur. In the Latium volcanic plateaux, millennia of anthropic activity have shaped and flattened the relief forms and tend to obliterate the recent tectonics. The sinkhole distribution associated with the presence of hydrothermal vents and structures such as fissure ridges in travertine can help redefine an overall picture of the complex dynamic evolution of these areas and could provide clues about neotectonics activities. Anthropogenic factors, both in urban and suburban areas, indirectly increase the sinkhole's hazard by changes in the hydraulic and hydrogeological regimes and directly through the excavation of anthropogenic cavities, underground hydraulic works, or diverting and channelling water streams. Mitigation strategies are essential for minimising sinkhole impacts in these vulnerable regions. This research advocates for integrated sinkhole hazard management approaches combining geological assessments, land-use planning, and public awareness programs.

Collapse sinkholes at Palude del Capitano (Nardò, Italy)

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Keywords: coast, sinkhole, karst.

Coastal zone can be described as highly dynamic environments given the simultaneous action of marine and terrestrial processes. This is particularly true in coastal karst, due to the soluble nature of rocks and the wide presence of underground voids, likely prone to sudden collapses also in consequence of wave actions. Sinkholes (Gutierrez et al., 2014) widely characterize coastal karst environments, especially along low-topography and flat coastlines. The mixing between freshwater-saltwater enhances the carbonate dissolution making faster their evolution, and leading to a rapid geomorphological evolution of coast, as well (Liso & Parise, 2023).

This is widely the case in Apulia (SE Italy), an almost entirely karst peninsula with more than 850 km of coastline. Along its Ionian side, Palude del Capitano represents the perfect example to observe and study such collapse phenomena. It is a wide wetland showing several collapse sinkholes flooded by brackish water. There, a detailed survey of the sinkholes recognizable from the surface has been carried out. The activity highlighted the importance to characterize the overall karst systems, including also the minor sinkholes and the main sets of fractures and conduits within the calcarenite rock mass. These, as a matter of fact, seem to exert a strong control on the future evolution and enlargement of the wetlands. Furthermore, diver surveys show the presence of extensive systems of flooded galleries and passages where it is also possible to recognize water bubbles coming from the bottom of the wetlands. The aim of this research is the comprehensive characterization of predisposing, preparatories and triggering factors that influence the sinkholes occurrence. To reach such a goal, many activities have been planned and will be performed at the study area. These include geophysical surveys to assess the spatial distribution and development of underground karst voids, not accessible to man; drone flights to provide the morphometric parameters of sinkholes, the current distribution of collapses, and monitor through multi-temporal surveys their likely evolution; traditional geological surveys at the surface; hydrogeological monitoring of the water within the wetland system; and, eventually, biological investigations through sampling and analysis of biotic and abiotic parameters using multiparametric probes .

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Diapiric uplift and ground-instability processes in the Cardona salt extrusion (NE Spain) analysed by geomorphological mapping and satellite interferometry

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Keywords: Cardona, geomorphology, remote sensing.

The Cardona Diapir in the NE sector of the Ebro Cenozoic Basin (Spain) is an actively rising salt extrusion initiated by the unroofing of the crest of a salt anticline by the entrenchment of the Cardener River. Here, the potash-bearing Cardona Saline Formation (late Eocene) flows towards the diapir driven by both erosional unloading and overburden loading (Pérez-Villar et al., 2024). The diapir has been subjected to intense halite and potash mining since Neolithic times (Weller, 2002), involving the creation of extensive underground galleries, and drastic hydrological changes, including the flooding of the mines by the Cardener River in 1998. An in-depth geomorphological study was carried out combining detailed mapping and remote sensing techniques. The interpretation of orthoimages and LiDAR-derived terrain models together with thorough field surveys allowed the production of cartographic sinkhole and landslide inventories, as well as the detection of subsidence damage on human structures. A Differential Interferometry SAR (DInSAR) analysis was carried out to map and assess the kinematics of the ground instabilities. These products were confidently interpreted thanks to the detailed maps based on direct field observations. Additional analyses were performed by decomposing the DInSAR data in horizontal and vertical components (Cascini et al., 2010). The latter reveals five sectors with different behaviour within the area: i) the floor of the river valley dominated by dissolution-induced subsidence; ii) the central sector of the extrusion with prevailing diapiric uplift at ca. 2 cm/yr; iii) the Old Slag Heap with incomplete data due to artificial surface changes; iv) the NE sector of the Salt Mountain, characterized by surface lowering related to rapid dissolution at salt outcrops; and v) the Bofia Gran karst depression with uplift rates of around 0.5 cm/yr. Displacement time series were compared with daily precipitation data, highlighting that the uplift related to salt flow shows a rainfall-independent steady behaviour, whereas dissolution-induced subsidence and especially solutional lowering at salt outcrops show unsteady patterns and positive correlation with the precipitation. This work shows that the Cardona Diapir is a highly dynamic and complex area with the superposition of localized hazardous processes on general and continuous diapiric uplift. The integration of DInSAR and detailed field mapping is essential to resolve these complex ground displacement patterns and to produce the basis for preventing the associated hazards and risks.

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Coastal sinkhole mapping and evolution along the Taranto coastline

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Keywords: coast, sinkhole, karst.

The coastlines of Apulia (southern Italy) are intensely affected by development of sinkholes, favoured by a variety of predisposing and preparatory factors, that also include the saline intrusion due to mixing of fresh and saltwater along the coast (Liso & Parise, 2023). They represent sites from unique morphodynamic and environmental value (Mastronuzzi et al., 2015). In low coastal settings, such as those characterizing long stretches in the Gulf of Taranto and its surroundings, there is therefore a high number of sinkhole phenomena, showing different stages of evolution: from incipient sinkholes, with initial but still not fully developed failures, to collapse sinkholes partly dismantled by the successive action of seastorms and waves. Sinkholes have been mapped and analyzed, as concerns their stages of evolution, in the stretch south of Taranto, and this contribution illustrates the present situation, also taking into account the vulnerability of infrastructures. These latter, given the high tourist attraction of the area, include houses, communication routes, beach resorts, but also several sites of interest as concerns the cultural heritage, with archaeological sites and remains located along the coast, and directly threatened by the occurrence of instability and sinkhole processes.

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Liso I.S. & Parise M. (2023) - Sinkhole development at the freshwater-saltwater interface in Apulia (southern Italy). In: Land L., Kromhout C. & Suter S. (Eds.), Proceedings of the 17th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Tampa (Florida, USA), 27-31 March 2023, NCKRI Symposium no. 9, 229-238.

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Land subsidence in the Italian coastal plains: an overview

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Keywords: land subsidence, Italian coastal plains, Late Pleistocene-Holocene stratigraphy.

Land subsidence (LS) is the gradual or sudden sinking of the ground surface, due to a variety of processes amog which the consolidation of sediments and thus the rearrangement of earth materials in the subsurface as a result of increasing effective stress.

Although LS occurs in different geographical settings, this phenomenon poses a major threat to low-lying coastal plains that are already facing the effects of climate change, i.e. sea-level rise and extreme rainfall events. LS increases the vulnerability of low-lying coastal areas to flooding and storm surges and causes severe damage to infrastructures and natural and historical heritages, which in turn harms economic production and coastal ecosystems.

The causes of LS are multiple, both natural and induced. Those of anthropogenic origin are fairly well known and well documented. The natural ones, slow and silent (few mm/yr), are harmless but uncontrollable.

With this contribution, we provide an overview of the LS affecting the coastal plain systems of the Italian peninsula.

Coastal plains were considered by selecting the maximum land elevations of 10 m above mean sea level. For this purpose, we used TanDEM-X 30m Edited Digital Elevation Model (German TanDEM-X mission) acquired between 2010 and 2015. Then, land subsidence was investigated over the periods 2015-2021 and 2018-2022 using the European Ground Motion Service (EGMS) from Copernicus, which provides ground movement data obtained by SAR Interferometry on Sentinel-1 images. Purely vertical displacements obtained by combining ascending and descending acquisition geometries were used.

Subsequently, the Italian coastal areas most subject to LS were highlighted and the potential mechanisms driving the phenomenon have been reported. Particular attention was paid to the lithological and stratigraphic characteristics of the Late Pleistocene-Holocene successions. The overlay of the main trends of subsidence with the litho-stratigraphic data suggests that the vertical ground deformation is partly controlled by the lithology and stratigraphic architecture of the geological units and, in particular, by the presence of compressible materials (such as peat and organic-rich clay), which are subject to primary and secondary consolidation. Obviously, discriminating the main driver requires more in-depth on-site analyses and the characterization of the geotechnical properties of the sediments are required, as compaction does not occur simultaneously for each layer, depending on the stratigraphic position (i.e. age and depth) and spatial distribution. In this regard, it appears of paramount importance a detailed reconstruction of the vertical stacking of the sedimentary units and their variation over short distances.

While these results are still preliminary, they provide a basis for a better understanding of LS drivers in the coastal-deltaic plains and have the potential to support the management of impacts caused by this phenomenon.

Artificial cavities and sinkholes in the hydrographic district of the Southern Apennines of Italy: findings, architectural variability and risk assessment

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Keywords: artificial cavities, hazard, sinkholes.

The territory managed by the Hydrographic District of Southern Apennine (Autorità di Bacino Distrettuale dell'Appennino Meridionale - ADAM), in southern Italy, is subject to highly critical situations of the physical-environmental system and risk induced by natural and anthropogenic phenomena; the geological hazards include those connected to the presence of cavities in the subsoil. These represents a serious problem, especially in intensely urbanized areas where the stability of urban structures is often compromised by the presence of underground voids, locally forming a well developed network of cavities , produced by decades of excavation activities. Aimed at developing a District Basin Plan and the related Management Plan relating to the topic of Cavities, a scientific collaboration agreement was signed between the ADAM, the Department of Earth and Environmental Sciences of the University of Bari Aldo Moro (DiSTeGeo) and the Engineering Department of the University of Campania Luigi Vanvitelli (DI). Objectives of the research project are the census, analysis and evaluation of the cavity system on the territory of the district. An accurate research was conducted as regards all documentary sources that could provide information on the presence of cavities. The great heterogeneity of the data acquired made it necessary to identify a homogenization and cataloguing system to be connected to the classification provided by the National Commission on Artificial Cavities of the Italian Speleological Society (Galeazzi, 2013; Parise et al., 2013), which takes into account the construction typologies and those structural elements susceptible to trigger sinkholes. Since the municipalities included in the District are 1632, a "top-down" approach was chosen for the identification of the presence of possible artificial cavities, starting from the analysis of the Lithological Map of Italy and selecting those lithologies potentially affected by activities of excavations. The data were managed in a GIS environment; through the creation of queries, information was obtained about the spatial distribution of cavities of anthropogenic origin by municipal area. In parallel with the activities described above, data relating to documented sinkholes that occurred in the ADAM territory were collected, deriving from previous studies (above all the DiSTeGeo chronological catalogue; Vennari & Parise, 2022) and research commissioned by the Civil Protection Service of Apulia. By analyzing the available data, the spatial distribution of the documented sinkholes connected to artificial cavities was obtained throughout the territory considered. The work is still in progress and many portions of the territory are still without data, or need to verify what has been identified with the survey framework set out herein. However, the acquired data is populating a DB which will constitute a unique document in Italy, including all aspects relating to artificial cavities which will form the basis for subsequent analyses, aimed at defining procedures for preliminary evaluation of the stability conditions of artificial cavities, detailed assessment at two pilot areas within the ADAM territory, including modeling analyses, and to establishment of actions addressed toward mitigation of the risk related to sinkholes.

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Mapping sinkhole susceptibility in Italy: a machine-learning approach for risk assessment and management

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Keywords: natural sinkholes, mapping techniques, machine learning.

Sinkholes, often underestimated geological hazards due to their localized nature, present a direct threat to the vulnerability of aquifers, resulting in fatalities and property damage. Civil protection officials and urban planners encounter difficulties in forecasting the timing and locations of these sudden collapses. Developing a sinkhole susceptibility map becomes very important, necessitating an understanding of the controlling factors and spatial distribution patterns to mitigate adverse effects and implement strategic land use changes. This study aims to produce an initial sinkhole susceptibility map for the Italian region using a machine-learning modeling algorithm. Drawing on over 2900 cases from the ISPRA sinkhole inventory, we modeled sinkhole occurrences based on known presence locations. A conceptual model was devised, incorporating 10 conditioning variables (predictors), comprising seven continuous and three categorical variables. Dummy variables were derived from categorical ones, and the Variance Inflation Factor (VIF) was utilized to identify and eliminate predictors with minimal impacts on prediction quality, such as redundancy. Model accuracy was evaluated using receiver operating characteristic curves (ROC). SHAP diagrams were employed to spotlight factors strongly associated with sinkhole formation, encompassing the presence of CO_2 emissions, low elevation areas, clastic-alluvial sedimentary cover, seismicity, and high fault density. The resulting probability map for sinkhole occurrence delineated areas with very high and high susceptibility, notably the Padana Plain (northern Italy), the Thyrrhenian coast area from northern Tuscany to southern Campania, and the Umbria region. Integration with shape files of Italian municipalities facilitated the identification of areas with higher susceptibility, estimating the extent covered by different susceptibility classes. This comprehensive approach enhances comprehension and proactive management of sinkhole risks in Italy.

Autocompaction as a main driver of coastal depositional environments

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Keywords: natural land subsidence, coastal depositional environments.

Natural environments such as coastal wetlands, lowland river floodplains, and deltas are formed by sediment, transported by watercourses and the sea, and deposited over century to millennium timescales. These dynamic environments host vulnerable ecosystems with an essential role for biodiversity conservation, coastal protection and human activities. The body of these landforms consists of unconsolidated sediments with high porosity and compressibility. Consequently, they often experience significant compaction due to their own weight, that is, autocompaction, which creates an important feedback within the geomorphological evolution of the landform. This work aims to provide a comprehensive 4D (i.e., 3D, including time) perspective to address this issue, incorporating data interpretation techniques and novel numerical modeling tools that account for the dynamic interplay of sedimentation and compaction. The novel NATSUB3D finite element model (Xotta et al., 2022) is used to simulate the evolution of two main case studies: the Mekong Delta in Vietnam (HIETE Project, funded by CaRiPaRo) and the salt-marshes of the Venice Lagoon in Italy (RESTORE Project, funded by PRIN PNRR 2022). To address the complexity of sedimentation-compaction history, we explored alternative methods for combining lithologic bore logs with sediment geochronological data. Through advanced interpolation techniques we derive delta-specific 3D sedimentation rate history that goes beyond the available spatial and temporal measurements. This new information, coupled with the geomechanical properties, forms the primary input to NATSUB3D. The simulator combines a 3D groundwater flow module with a 1D compressibility module to reproduce the Holocene delta evolution of a 3D domain using an adaptive finite-element mesh, properly simulating accretion and natural consolidation which govern the dynamic elevation evolution. The models are calibrated to match the present-day surface elevation and provide estimates of current natural compaction rates resulting from Holocene evolution. Furthermore, they can be used as tools to evaluate future compaction and consequent relative sea-level rise following ongoing sedimentation, sediment enhancing strategies, or sediment decrease following engineering intervention as the MoSE gate in the Venice Lagoon. The modeling procedure can be easily adapted to different deltaic/coastal environments with only minor modifications to accommodate site-specific data.

Xotta R. et al. (2022) - Modelling the role of compaction in the three-dimensional evolution of depositional environments, J. Geophys. Res. - Earth Surface, 127, e2022JF006590, https://doi:org/10.1029/2022JF006590.

Updated inventory of anthropogenic sinkholes in Naples (Italy)

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Keywords: inventory, cavities, triggering factors.

Anthropogenic sinkholes, due to their spatial and temporal distribution, are among the most relevant issues in the densely urbanized municipality of Naples (Italy). Between October 2023 and March 2024, more than 15 events occurred in the city of Naples: among them the high-magnitude (i.e., high diameter and depth) event that occurred on 21 February 2024, while not resulting in any fatalities, once again drew attention to the importance for the municipality to have an adequate mitigation plan for such kind of geological hazard. For a comprehensive susceptibility analysis that aims to predict the spatial probability of the process, the inventory of anthropogenic sinkholes in the city of Naples has been updated including 316 new events in the period February 2010–March 2024. Considering the previous inventory of sinkholes in the city of Naples (Tufano et al., 2022), collecting events up to June 2021, the final consistency of the updated inventory is 504 sinkholes between 1880 and 2024. A systematic procedure based on i) analysis of media sources to identify the event, ii) field survey to define the correct location, iii) detection of size (i.e. diameter and depth), and where possible the triggering mechanisms, was carried out to catalog the most recent sinkholes. Based on such procedure, in the period July 2021-March 2024, 15 events have been collected through the examination of online newspapers and 28 from local daily reports. Including the information about these newly inventoried events, the triggering factor analysis reveals that 41.6% of sinkholes were triggered by rainfall, 13.9% by aqueduct and sewer leaks, 1.9% by maintenance works, while in 42.6% of cases the trigger remains undetermined.

The morphological analysis indicates a diameter median value of 1.5 m, and a depth median value again of 1.5 m, according to the data of previous inventory. However, although no variation was observed in the magnitude of the events, the spatial analysis reveals a migration of sinkholes occurrence in the western sector of the city (i.e. municipality 10 - Bagnoli, Fuorigrotta, and western sector of municipality 1 - Chiaia, Posillipo, S. Ferdinando) previously less affected by these instabilities. In this area, the network of underground cavities is less developed, so the increase in sinkholes can be mainly related to the progressive degradation of mechanical properties of tuff bedrock coupled with water infiltration action occurring during intense rainfall.

Therefore, it is important to continue with the inventory of these phenomena because, as highlighted by the number of the latest events, other sectors of the city are showing an increase in susceptibility for such phenomena.

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Tufano R. et al. (2022) - Anthropogenic sinkholes of the city of Naples, Italy: an update. Natural Hazards, ISSN: 0921-030X, https://doi.org/10.1007/s11069-022-05279-x.

Quinis: a small hamlet in the Alta Val Tagliamento valley (NE Italy), example of resilience to sinkhole geohazard

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Keywords: sinkholes, machine learning, GNSS monitoring.

A sinkhole, a naturally formed circular depression often linked to a complex underground drainage system, is a distinctive feature of karst landscapes. Our research focuses on the North-Western mountainous sector of FVG Region in NE Italy, specifically in the Alta Val Tagliamento Valley within the Enemonzo municipality, in the hamlet of Quinis. The study site rests upon alluvial fan deposits extending over the fluvial terraces of the Tagliamento River, with dissolution and subsidence processes favoured by the presence of Triassic and Permian evaporites, notably from the Carnian period, distributed throughout the valley. The Quinis area features a significant phreatic aquifer with substantial water table fluctuations, influenced by both effective infiltration and seepage from streams and rivers, exacerbating the phenomena.

Hydrological studies indicate high annual rainfall (1600-2000mm/y), contributing to subsidence risk. Even if it is a small village, within the years, Quinis experienced different types of collapse events. A slow surface subsidence pattern attributed to the gradual settling of surface materials through natural fissures and conduits within the bedrock, take to the formation of cover suffosion processes.

Sometimes sinkholes developed also as abrupt collapses as in 1960s when two impressive phenomena took place in correspondence of the Tagliamento riverbed. The dimensions were 15m in diameter and 10m depth for the first one occurred in 1962 and 45m in diameter and 15m in depth for the second one, occurred in 1964.

Several geophysical methods like ERT, 2D GPR, 3D GPR, Reflection Seismic, PS-InSAR, as well as hydrogeological investigations are previously used to study the phenomenon in this region. Currently, thanks to the GeosciencesIR PNRR project, further researches are ongoing in the area. A total station, equipped with a GNSS antenna, installed in the centre of the Quinis village will allow to record indirect data regarding ground displacements (vertical movements) by monitoring the benchmarks present on selected buildings. Inductive electromagnetic methods in the frequency domain will provide information on the presence of sinkholes in poorly urbanized areas by means of electrical conductivity maps at various depths down to about 10 m from the topographic surface.

The use of CTD divers (which record electrical conductivity, water level and temperature) allowed in the past and continue to give information about the groundwater fluctuations which are the engine of this type of phenomena in this area.

Finally, an attempt to construct a susceptibility map focusing on the inhabited area is realised by using machine learning techniques.

S27.

Caves, mines and other underground spaces as field laboratories in environmental geology

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A research to study the unstoppable subterranean journey of microplastics

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Keywords: microplastics, caves, pollution.

Microplastics (MPs) are a global problem, contaminating remote areas too. However, different environments are poorly studied, such as subterranean ones and karst areas, despite the global drinking water sources and the environmental heritages. MPs can endanger the fragile subterranean ecosystems, be consumed or assimilated by animals, damage speleothems, and pollute karst aquifers.

The aim of this multidisciplinary research is to investigate MP pollution in waters and sediments in karst surface and subterranean environments from a geological, biological and environmental point of view, in order to monitor the state of ecosystems.

Samples from different European karst areas were collected and investigated, from show caves to unexplored caves, from surface watercourses to groundwaters. The sediments of three Italian show caves (Bossea, Borgio Verezzi and Toirano caves, Piedmont and Liguria. Italy) were analyzed, highlighting the presence of high amount of MPs along tourist paths and in speleological areas. Surface and subterranean waters of Bossea karst system showed MP pollution in all examined samples, underlining the importance of the entire aquifer karst systems monitoring, even susceptible to contamination by surface pollutants. Different protected aquatic surface (spring) and subterranean (caves) environments of the Classical Karst were analyzed in order to verify micropollution in habitats hosting particularly protected species such as the olm *Proteus anguinus*. All samples highlighted high values of MPs and anthropogenic microfibers. Sediment samples in not jet explored caves of Abruzzo region, Italy, were collected to verify MPs pollution even in underground environments not directly affected by human presence, showing still little threatened habitats by MP pollution. Samples from different caves in Herzegovina and Slovenia, and from Italian springs with different karst characterizations will be analyzed too, in order to understand MP transport in active karst systems and deposition in vadose zones. Other micropollutants linked to MPs will be analyzed too. Alongside, specialized hypogean crustaceans from Bossea karst system were analyzed in order to understand micropollutants ingestion even in subterranean habitats (Sforzi et al., 2024).

Karst areas and caves are one of the most important and well-known geological features in the world, fragile and unique ecosystems with an exceptional scientific, cultural and environmental value, as well as an important economic resource. Monitoring of these environments is fundamental for their conservation and to propose new strategies for the protection and conservation of karst habitats.

Sforzi L. et al. (2021) - (Micro-)Plastics in Saturated and Unsaturated Groundwater Bodies: First Evidence of Presence in Groundwater Fauna and Habitats. Sustainability, 2024, 16(6), 2532, https://doi.org/10.3390/su16062532.

Monitoring of lampenflora growth on speleothems exposed to LED lights in show caves

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Keywords: show caves, lampenflora, LED lights.

Speleothems, geological formations by mineral deposits that accumulate over time, are the major show caves attractions. However, they are often subjected to alterations linked to tourism, including the so-called "lampenflora". Lampenflora is a community of photosynthetic microorganisms, mainly diatoms, cyanobacteria, and green algae, which sometimes also include mosses, ferns and higher plants, carried into the cave by tourists, water, gravity, air circulation and animals.

Lampenflora development on speleothems in show caves is due to the installation of artificial lights, which allow the photosynthetic activity in an otherwise dark environment. The lampenflora growth causes physico-chemical and aesthetic damage to speleothems, and changes the subterranean ecosystem modifying the food chain and damaging the autochthonous organisms. Moreover, microorganisms activities can release acid substances that lead to the deterioration of the formations surface.

Although in recent years lampenflora presence has been increasingly monitored in show caves from a biological point of view, geological modifications on surface of speleothems are less studied, such as the impact of the new LED lamps. This work aimed to give operational indications after two-year of sutdies to verify lampenflora growth after the installation of LED lights systems, and evaluate changes in calcite crystal habits over time, due to lampenflora growing. Homogeneous speleothems slabs without lampenflora were used for the test, as natural substrate, totally compatible with the formations in the examined cavity. Different slabs were positioned in several points of the cave along the tourist paths, at different distances and angles from the LED lamps. In this work, first results applied to Bossea cave, Italy, were reported such as example of application of this protocol. The results of this preliminary study can be the starting point for future and more complete monitoring in show caves, useful for the protection of the geological and environmental heritages.

Technological innovation and environmental monitoring for the evaluation of the bearing capacity in tourist caves

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Keywords: showcave, carrying capacity, monitoring.

Environmental assets can be important economic resources for territories, but their management should be focused on the maintainance of the natural heritage, through adequate control procedures, which would allow keeping the impacts that may derive from their use within reversibility thresholds. In tourist caves, impacts are connected both to preliminar infrastructure interventions and to the ordinary attendance of visitors, which can potentially induce a modification of the natural conditions of the internal atmosphere, with several potential effects deriving from it, due to the introduction of warm air and in particular CO_2, emitted by tourists into the cave. Monitoring of this gas therefore becomes an indispensable measure to quantify such modifications and, together with a scientific approach that combines several applications provided by information technology, can allow the development of site-specific anthropogenic carrying capacity thresholds.

As part of the environmental monitoring actions carried out by the Showcave project in Sardinia, the volumes of cave atmospheres were estimated using 3D laser scanners. This data, together with other parameters related to CO_2, such as its natural background concentration in the atmosphere, the average human hourly production, and concentration thresholds preliminarily defined, for example using the EU indoor air quality guideline values (0.15%) and the recommended guideline values to preserve the geological component and for safeguar visitors (1%), allowed the assessment of site-specific anthropogenic loads in the project caves open to tourism (Nettuno, Bue Marino, and Su Marmuri caves).

The results of the analysis of the collected data and the estimates of carrying capacity illustrate a situation that may be critical for the Nettuno cave, with exceeding of both the daily (1,500 ppm) and seasonal (10,000 ppm) carrying capacities. However, monitoring data do not show critical levels of carbon dioxide for Nettuno and Bue Marino caves, as when the tourist flow stops at the end of the day, CO_2 levels return to natural values. Su Marmuri cave deserves greater attention instead, where, although flows remain below carrying capacity thresholds, the particular characteristics of the cave do not allow CO_2 to naturally flow out of the system; therefore any potential increase in tourist visits will need to be carefully evaluated in terms of carrying capacity thresholds. The work highlighted the capabilities of environmental monitoring tools and technologies, that can enable the objective assessment of several parameters useful for the sustainable management of caves.

Sustainable speleology and cave conservation

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Keywords: speleology, conservation, collaboration.

Caves, with their complex and intricate nature, are not only geological marvels but also delicate ecosystems teeming with life and can constitute cultural heritages susceptible to protection. However, human interaction with caves, driven by tourism, exploration, cultural and scientific interest, has brought forth a myriad of challenges for their conservation. This overview aims to dissect such challenges, explore the methodologies devised to mitigate human impact, and delve into the collaborative efforts, involving various stakeholders in safeguarding these unique environments. The challenges in cave conservation are manifold, stemming primarily from the detrimental effects of careless human activities. Graffiti, vandalism, littering, and inadvertent damage to geological formations pose significant threats to the delicate equilibrium of cave ecosystems, finely tuned over millennia. To address these challenges, the philosophy of minimal impact speleology is the guiding principle for cave conservation (Gillieson et al., 2022); it emphasizes responsible exploration practices aimed at minimizing anthropogenic disturbances (Capitanio et al., 2022). Techniques such as gentle cleaning, graffiti removal, and substrate-specific restoration methods may be employed to mitigate the impact of human activities while preserving the integrity of cave ecosystems (Werker & Hildreth-Werker, 2006). Additionally, promoting awareness among speleological communities and tourists is crucial for fostering a culture of environmental stewardship and responsible cave exploration. The recognition of caves as unique habitats supporting diverse flora and fauna is critical to cave conservation. Cave-dwelling species, adapted to the subterranean environment, are particularly vulnerable to disturbance caused by human activities. Thus, conservation efforts must prioritize the protection of these species, employing measures to minimize habitat disruption and mitigate the introduction of alien/invasive species. Collaboration among various stakeholders is essential for the success of cave conservation efforts. Speleologists, environmental conservation groups, local authorities, and local communities all play crucial roles in safeguarding these fragile environments. By pooling their expertise and resources, these stakeholders can develop conservation strategies tailored to the specific needs of each cave system.

In conclusion, cave conservation requires a holistic approach encompassing scientific research, community engagement, and sustainable tourism practices. By adhering to the principles of minimal impact speleology and fostering collaboration among stakeholders, we can ensure the preservation of these extraordinary environments for future generations. This overview underscores the urgency of prioritizing cave conservation and highlights the collective responsibility we all share in protecting these natural wonders.

Capitanio R. et al. (2022) - Speleologia ad impatto minimo: caso di studio della Grotta Sant'Angelo di Ostuni. Atti XXIII Congresso Nazionale di Speleologia "La melodia delle grotte", 2-5 June, Ormea (CN), Memorie dell'Istituto Italiano di Speleologia, s. II, 42, 509-510, https://www.congressospeleo2020.it/wp-content/uploads/2023/11/ormea2.pdf.

Gillieson D.S. et al. (Eds) (2022) - Guidelines for Cave and Karst Protection, 2nd Edition. International Union of Speleology (UIS) and International Union for Conservation of Nature (IUCN), Switzerland, 112pp.

Werker J.C. & Hildreth-Werker V. (2006) - Cave Conservation and Restoration. KIP Monographs, 7. https://digitalcommons.usf.edu/cgi/viewcontent.cgi?article=1006&context=kip_monographs.

Speleogenesis and hydrostructure development in conglomerate-dominated sedimentary sequences: the “Castel Sotterra” Cave

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Keywords: speleogenesis, karst hydrogeology, conglomerate karst.

The Montello Hill is located in the south-alpine fold and thrust belt, which evolved from a foreland basin in Oligocene-Miocene to fluvial plain in the Neogene passing through an intense and rapid landscape evolution. The Montello hill represents an isolated low-elevation plateau, uplifted by the active Montello Thrust. The outcropping substrate is composed mainly by a succession of Pleistocene conglomerate beds alternated to sandstone and siltite layers. The relief has been sculpted by erosion of the Piave river, attested by the incisions of Biadene and Nervesa, and modified by karst processes. These latter are widely recognized in the epikarst, dominated by solution sinkholes and karst valleys, and underground. Well-developed multi-level caves form hydrological connections between the summit plateau and springs along Montello border.

The “Castel Sotterra” Cave is the most extended cave in the Montello Hill, ~ 7 km long and 125 m deep. The cave is the fourth largest cave in conglomerate in the world and its importance is related both to the possibility to investigate the bedrock geology and the speleogenetical processes in non-carbonate rocks. Along with exploration and topographic survey of speleological purpose, a sedimentological-structural investigation of the bedrock and underground climate data acquisition have been conducted.

The speleogenesis is primarily controlled by the lithology, due to different strength and the compositional heterogeneities of Pleistocene conglomerate’s matrix and pebbles, and by the presence of fracture networks. Multiple series of sub-horizontal inception horizons developed in meandering proto-conduit in fractured conglomerate beds. The enlargement of phreatic conduits and the successive entrenchment forming steep canyons is directly related to the interplay between landscape evolution and tectonic uplift. Large meandering conduits developed along fine-grained beds may contribute to the failure of large portions of the rock mass. Underground collapses are one of the most distinctive features in the evolution of conglomerate karst. Diffuse failures can intercept different cave levels and lead to the formation of new cave passages.

The cave is active in terms of geomorphological processes and neotectonics. Meander entrenchment, rock failure and offset along strike-slip faults are recognized. The bottom of the cave reaches the expected water table level, nevertheless the hydrologic connection with the main springs is yet to be proven. The presence of a karst phreatic zone is documented only at Forame and Casselon Springs, reaching about 20 meters of depth, but appears poorly developed elsewhere probably due to the high rate of tectonic uplift. The “Castel Sotterra” Cave represents an example of extremely fast landscape evolution, where Pleistocene fluvial deposits went through diagenesis and karstification in a short time due to Piave river incision and uplift by thrusting, impacting on groundwater circulation.

CALIGOLA: a project for enhancing the knowledge of underground archaeological sites in the Palatine Hill through the integration of geological and geophysical data with new technologies

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Keywords: 3D model, virtual vs real, underground cultural heritage.

This work illustrates the activities carried out within the CALIGOLA Project, a research program funded by the Lazio Region and MUR (Minister of University and Research) with the goal of improving the set of skills and technologies dedicated to the protection and fruition of Cultural Heritage. Situated at the top the Palatine hill in Rome, the Central *Cryptoporticus* comprises hypogea structures that are the object of this investigation. They are part of a complex underground archeological site pertaining to the Domus Tiberiana, the first dynastic palace re-built by Nerone after the fire of 64 AD. To address the collapse and subsidence risk affecting the examined area, stabilization measures are necessary. These measures aim to consolidate underground anthropogenic and natural cavities, including water drainage tunnels and voids resulting from the extraction of building materials. In order to enhance our understanding of the geological risks faced by the monument, a 3D geological model of the superficial and shallow subsoil portion of the area, comprising the man-made structures and caves, was created. This model is based on the analysis and elaboration of a large amount of geological data, such as geological cross-sections, geological map and boreholes. Additionally, it incorporates the 3D model of the underground Central Cryptoporticus, obtained through laser scanning, along with geophysical data, such as new Ground Penetrating Radar (GPR) prospections, Electrical Resistivity Tomographies (ERT) and ambient noise measurements carried out during field work in 2023-2024. The 3D model also comprises geophysical and geotechnical data acquired over time on the Palatin hill (Mancini et al., 2014; Moscatelli et al., 2014). This novel methodological approach combines subsoil and laser scanning data for reconstructing precise, realistic, high-resolution, small-scale 3D models, beneficial for studying historically and\or archeological sites. In this case, it aids identifying instability factors concerning the structures and detecting new, unexplored underground cavities. The information derived from the use of velocimetric sensors capable of detecting the three components of motion in a wide range of frequencies and with high dynamics enrich this approach. Concepts from dynamic buildings identification have been adapted to characterize the dynamic response of the three excavated sections of the Cryptoporticus. Simultaneously, the digital representation of this Cultural Heritage has facilitated the development of a virtual model and game-based learning experience. This activity addressed a prestigious case study in the direction of disseminating knowledge of mitigation measures aimed at reducing the impact of disasters on Cultural Heritages (Gaudiosi et al., 2022). It may be meant as a new way to encourage the preservation and conservation of historical and archeological sites, aligning with the principles of the Nara declaration (NDWG, 1994).

Gaudiosi I. et al. (2022) - From the Institute of Environmental Geology and Geoengineering of the National Research Council (CNR IGAG) to schools: introducing cultural heritage into classrooms to foster awareness about natural risk prevention", Rendiconti Online Societa Geologica Italiana, 58, 9-15.

Mancini M. et al. (2014) - A physical stratigraphy model for seismic microzonation of the Central Archaeological Area of Rome (Italy). Bulletin of Earthquake Engineering, 12, 1339-1363.

Moscatelli M. et al. (2014) Integrated geological and geophysical investigations to characterize the anthropic layer of the Palatine hill and Roman Forum (Rome, Italy). Bulletin of Earthquake Engineering, 12, 1319-1338.

NDWG (1994) - The NARA document on authenticity, https://www.icomos.org/en/386-the-nara-document-on-authenticity-1994.

Metals discharge from underground mine drainage of Argentiera Pb-Zn-Ag mine, NW Sardinia, Italy

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Keywords: acid mine drainage, CRM recovery, environmental mineralogy.

Mining activities have affected, even in ancient times, numerous areas of the national territory. The footprints of its presence are often evident and sometimes visually impactful, as exploitation of underground georesources implies the modification of the original environmental configurations. These changes can be both superficial and underground and involve a series of hazards that remain even when the activity ends. Among the risks associated with mining work, the pollution of superficial and/or deep aquifers stands out.

This study focuses on assessing the metal load discharged from the abandoned mineral district of the Argentiera (NW Sardinia, Italy). During the last century, this mine was one of the most important Italian silver ore body, associated with Pb-Zn-Ag-Sb sulphide mineralization. After the Roman open air mining works, the ore exploitation extended into several kilometres of interconnected underground tunnels. Its drainage is discharged through a gallery at 4 m asl along the coast into the Mediterranean Sea. From this artificial spring, currently partially occluded, a small stream characterised by water with a red colour with abundant precipitation of amorphous Fe(III)-(oxy)hydroxides flows out with a significant metal load.

At the sampling site, the physico-chemical parameters (pH, temperature, total dissolved solid) were measured with a portable Hanna HI 991301 probe. Water samples were collected in pre-cleaned bottles after 0.4-µm filtering and fractions for cation analysis were acidified with suprapure-grade 1% v:v of nitric acid 65%. Mine drainage has a temperature higher compared to the annual average air temperature (21.0 °C for water), conductivity (TDS) >4 mS/cm and the pH is <6.0. For metals composition, diluted water were analysed by inductively coupled plasma-optical emission spectrometry (ICP-OES) (Varian 710-ES). Among the major dissolved components, calcium (Ca) is the dominant cation, exceeding sodium (Na) concentration. Minor elements such as potassium (K), and silicon (Si) were detected. Results show that the mine drainage of Argentiera contains high concentrations of (Fe), magnesium (Mg), manganese (Mn), chromium (Cr), cadmium (Cd), arsenic (As) and very high concentrations of zinc (Zn). All these metals are potentially toxic elements and pose a serious risk of ecosystem contamination. On the other hand, Mn-Cr-Cd and As are recognised as Critical Raw Materials by the European Commission because of their strategic importance in green-transition technologies. Further investigation should be addressed to understand the environmental impact and to explore the viability of CRM recovering from this Acid Mine Drainage (AMD).

Karst and cave environment conservation in the Alta Murgia National Park

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Keywords: karst, cave, conservation.

The karst environment, among the most fragile and vulnerable on Planet Earth, often hosts remarkable natural resources, thanks to the widespread network of caves that acts as a very special treasure chest where it is possible to preserve sediments, deposits, fossils and human remains that at the surface have been eroded or buried by weathering and the action of atmospheric agents. High fragility of karst is at the origin of severe impacts occurring on such environment, due to a variety of natural and anthropogenic processes (Gutierrez et al., 2014). Karst caves are therefore a precious place, to which explorers, cavers and scientists should approach only keeping well in mind their uniqueness, and the need to preserve as much as possible such delicate settings.

The Alta Murgia National Park, located in inland Apulia, covers a wide sector of Apulia region, entirely developing in karst settings, and hosts extraordinary sites of geological, palaeontological and anthropological interests. Among these, the limestone surface with thousands of dinosaur footprints at the Pontrelli quarry; the whole skeleton remains of a Neanderthal within the Lamalunga Cave, entirely covered by, and embedded into, calcite speleothems; and the Altamura Pulo, a huge collapse sinkhole that has become one of the symbol of the Park. Karst plays therefore a fundamental role in the geological relevance of Alta Murgia, and should be worth of particular care in the park management action, especially as concerns the need to protect the geological heritage. This is particularly true in the case of the Lamalunga Cave, since in recent years many attempts have been carried out, aimed at extracting from the cave part, if not all, of the skeleton. Even though such attempts were made in the name of "Science", and the need to fully study the remains outside of their environment, many doubts arise on the effective possibility to successfully carry out such actions, which inevitably will produce irreversible damage to the cave environment, and with high probability the destruction of the remains themselves. As scientists, geologists, cavers, and managers, we present in this contribution our clear position against such actions, and toward the need to preserve the cave system and the deposits therein preserved by nature, also taking into account the need to safeguard them for future generations.

Gillieson D.S. et al. (Eds) (2022) - Guidelines for Cave and Karst Protection, 2nd Edition. International Union of Speleology and Gland, Switzerland, IUCN, 112pp.

Gutierrez F. et al. (2014) - A review on natural and human-induced geohazards and impacts in karst. Earth Science Reviews, 138, 61-88, https://doi.org/10.1016/j.earscirev.2014.08.002.

Teaching sustainable planning of show caves

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Keywords: underground tourism, professional education, show cave management.

Tourist caves are among the most important geotourism resources in the world, attracting nearly 80 million visitors a year to more than 1200 sites. Some estimates of their economic importance report revenue of around 2 billion euros. Among the 50,000 natural Italian caves, several are suitable for touristic use and today over sixty natural cavities can be visited, attracting more than 2 million visitors every year. Despite these numbers, the management of tourist caves is currently not regulated and for this reason the International Union of Speleology (UIS) and the International Show Cave Association (ISCA) have drawn up guidelines on appropriate standards for the sustainable development of show caves. However, small local communities and public and private caves' managers have difficulty in applying these good practices.

Aware of this limitation, the training of qualified planners was tested within the doctoral school in Architecture and Environment of the University of Sassari with a course in "Tourist management of underground environments" offered to students of the master's degree in Urban, Environmental and Landscape Planning/Policy Development. This educational activity had the objective of providing essential environmental knowledge for the sustainable design and planning of show caves, giving students the opportunity to extend their skills on the cave habitat and its dynamics, as a cognitive tool for correct development of an underground tourist environment.

The course lasted 20 hours for 2 CFU divided into theoretical (14 hours in classroom) and field lessons (4 hours in a show cave). The course program discussed topics related to the origin and the physical features of the underground habitat and its ecology to give an environmental background to the students. The anthropic impacts linked to the tourist use of underground environments and how these must be monitored to prevent permanent damages of the landscape were addressed. Particular attention was given to the choice of the materials that must be used for both internal and external infrastructures (lighting systems, pathways, etc) and to the Italian legislation regarding the workers/visitors health in underground environment. Furthermore, the experience in a show cave provided the students with the opportunity to verify their acquired knowledge and to stimulate the in-depth analysis of the topics for the final examination that took place through a written report or slideshow presented for the suitability assessment.

This university course pursued the objective of show caves sustainability as educational contribution to the ecological transition in which the conservation of georesources is a necessary and transversal condition for the pursuit of the prosperity and well-being goals identified by the European Green Deal, with which this course shares the strategy aimed at protecting, conserving and improve the EU's Natural Capital.

Radon monitoring in underground workplaces. The case of Sardinia region (Italy)

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Keywords: radon survey, underground workspaces, indoor radon.

Among the main geological factors affecting human health there is the geogenic release of radon from soil and rocks that poses a serious risk of ionizing radiation exposure to the population. This natural radioactive gas can quickly diffuse underground and dissipate into the atmosphere or enter through cracks or open spots inside buildings, where it can be accumulated. In Italy, the indoor concentration of radon is regulated by Law 101/2020, which establishes a reference level of 300 Bq/m3 (200 Bq/m3 for dwellings constructed after 2024), expressed as the annual average value of radon activity concentration in the air. This regulation applies to indoor workplaces, specifically to all underground spaces. Measurements on the ground floor and in the basement are carried out only in the areas defined as at risk (the reference level is exceeded in 15% of buildings) by the Italian national and regional radon action plans. Currently, three Italian regions have an action plan in place to reduce the population's radon exposure. Since 2019, Sardinia has identified the radon priority areas with Dgr n. 7/49 including municipalities where the probability of exceeding the 300 Bq/m3 level exceeds 30% of the buildings, recently updated with the requirements of the national reference level (Dgr n. 20/71 of 2022).

Considering that the distribution of financial services over a region depends on population density and economic activities, in this study data from radon concentration measurements in some underground workplaces of different bank companies in Sardinia were analysed as a possible criteria for radon risk assessment. Radon activity measurements from 36 bank buildings located in 17 municipalities spread throughout the island were collected. The CR-39 detectors were exposed in a total of 262 indoor spaces, used by employees and/or accessible to the public. The duration of the monitoring was two or more consecutive periods (e.g., two semesters) to cover an entire solar year of exposure, otherwise, the dosimeter was directly exposed for an entire year. In some cases, multiple data were recorded for a single room, depending on its volume, and a weighted average of the different measurements was determined. The annual concentrations recorded in the last 10 years range from 8 to 1,630 Bq/m3. The analyses show that only approximately 6% of the monitored rooms exceed the limit set by Italian regulations. Among those underground workspaces that exceed the reference level, not all are located into Sardinian priority areas. Furthermore, data exploration shows that in some buildings there is high variability between rooms belonging to the same floor. These results hint at the difficulty of accurately predicting indoor radon concentrations and highlight the importance of performing radon monitoring to protect workers' and public's health.

Moisture on underground walls in abandoned mines as source of acid drainage

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Keywords: mine drainage, sulphate dissolution-precipitation, condensation water.

The mining exploitation over the centuries has led to several kilometres-long networks of underground tunnels dug into the rocks at different levels that now are an environmental challenge in remediation of abandoned mining sites. In fact, the interaction of groundwater with exposed mineralization could produce water pollution, one of the most important issue associated with mines' closure. The nucleation of secondary minerals over gangue and host rocks and the discharge of acid drainages are clear evidence of this process, that could have negative effects on terrestrial and marine ecosystems. Moreover, in metals sulphide ore bodies, mine drainages generally have a sulphate-dominated composition and are heavily contaminated with toxic elements that can persist for long periods. This latent environmental risk is to be expected for the abandoned mineral district of the Argentiera mine (NW Sardinia, Italy). Its Pb-Zn-Ag sulphide ore mineralization consists mainly of galena and blenda-bearing hydrothermal veins hosted in Palaeozoic phyllites, exploited up to 360 meters below sea level. Currently, the mine drainage outflows along the coast with a significant metals load discharging into the Mediterranean Sea. Within the ancient underground mining works secondary minerals cover seasonally mine walls as crusts, coatings and minethems. Their minerogenesis is related to precipitation from metals-bearing solutions by evaporation-driven oxidation of the polysulphides dispersed in the host rock and in dump materials that fill the mine voids. Most of the detected crystalline phases are ephemeral sulphates and the typical paragenesis is copiapite-melanterite-epsomite. The occurrence of secondary sulphates over mine walls and their dissolution-precipitation cycles were investigated by micrometeorological techniques. Continuous measurements of the underground temperature and relative humidity were compared with data of the external atmosphere. The sulphate minerals occurrence were detected by monthly field-work during winter that coincides with the time of relative humidity decrease. On the other hands, these salt efflorescence disappeared since the late spring, during the whole summer, and until November. For this period the underground atmosphere is over saturated in air water vapour and water droplets were observed on the mine walls. This rock moisture is related to vapour condensation brought by external air masses entering into the shallow part of the mine. As the interaction between condensation water and sulphide materials generates acid drainages that potentially increase the solubility of toxic elements, these results contribute to understand contamination pathways occurring at abandoned mining sites.

Disentangling natural signal from anthropogenic contribution in the temperature dynamics within show caves

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Keywords: cave monitoring, sustainable management, cave microclimate.

Caves are natural underground spaces in the Earth Critical Zone with complete dark environment developed in rock. These confined habitats are characterized by a reduction in fluctuation amplitude of environmental parameters (such as temperature, relative humidity, air currents, food availability, water level, and so on), compared with surface landscapes. This feature makes karst systems a vulnerable environment where even minuscule differences can be a significant factor negatively impacting subterranean ecosystems. A baseline parameter for all studies related to evaluation of cave's vulnerability is the observation of cave air temperature trend, that thanks to the availability of better continuous monitoring devices with high frequency sampling and high accuracy and resolution can detect even low variability. Moreover, understanding cave temperature dynamics is of major importance for the improvement of sustainable management of show caves, in which anthropogenic thermal influences linked to tourism due to the heat brought into by the lighting system and human body can noticeably affect cave microclimate.

The aim of this study was to understand the impacts of both visitation and external atmosphere in Su Mannau, a show cave receiving around 15,000 visitors per year, in the Geomineral, Historical and Environmental Park of Sardinia (Italy). This cave system develops in Cambrian carbonates with large rooms and long tunnels for more than 8 km in length, with mostly horizontal profile and only few vertical drops. The first 600 m of the cave is equipped with tourist path for visits, opens seasonally from April to October. The underground air temperature was measured at 10-minutes intervals with HOBO U23 Temp/RH datalogger (accuracy: ±0.25°C; resolution: 0.04°C) at three different locations, two along the tour route and one in the wild part of the karst system, 800 m distant from the cave entrance. Data from cave atmosphere were compared to hourly air temperature from surface, measured within 100 m outside of the cave opening. Year-around monitoring at all cave sites shows both daily and annual temperature fluctuations that decrease increasing the distance from entrance. Daily temperature variations are less than 1 °C, a stable regime compared to nearby surface locations that in summer vary daily by more than 15 °C. Results show a direct correlation of cave and external temperatures during the warm season when the modification of the ventilation regime due to cave morphology causes the entrance of external air into the cave. This micrometeorological condition leads to a rhythmic daily oscillations in cave temperature, even in remote passages, strongly associated to the outside atmosphere but with a hourly delay. No anthropogenic source of temperature rise attribute to visitation was detected, except for a single occurrence in spring when tourist presence reached more than 500 units in only a day. Fortunately, the cave recovered during night closure.

A long-term analysis of mining-induced sinkhole activity in Gavorrano (Tuscany, Italy) by remote sensing and field data

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Keywords: mining-induced sinkholes, remote sensing, subsidence.

The failure of underground cavities and the formation of sinkholes is a major hazard at both active and dismissed mining areas that may cause important social and economic losses for the communities leaving nearby. Monitoring ground motions at mining area has been proved to successfully reduce the occurrence and the consequences of sudden sinkhole collapses. However, while most active mines are constantly monitored today, the ground instabilities around historical and dismissed mining areas often remain disregarded. In Italy, more than 2400 abandoned mines have been reported. In southern Tuscany (Italy), the Gavorrano area is a well-known mining district that was exploited during the 19th century for pyrite (FeS2) extraction. According to mining reports, the pyrite extraction was accompanied by underground failures of cavities, sometime followed by the formation of fractures at the surface. Today the area shows important evidence of sinkhole activity, with the major Monte Calvo sinkhole dominating the landscape of Gavorrano. However, the spatio-temporal evolution of the sinkhole phenomena, the relationship with mining, and the potential ongoing sinkhole activity in the area remained unclear. In this study, we used a multidisciplinary dataset of historical mining reports and maps, aerial images, high-resolution Digital Surface Models (DSMs), field measurements and InSAR observations to conduct a long-term spatial and temporal reconstruction of ground deformation around the sinkhole prone area in the mining district of Gavorrano. We identified the three sinkholes of Monte Calvo, Valsecchi, and Ravi, with the latter two never reported in literature. The three sinkholes have a spatial correlation with the underground cavities and galleries of major mines. InSAR observations between 2016-2022 also revealed that an area of ~ 700 m × 400 m around the Monte Calvo sinkhole is still subsiding with rates of ~5 mm/yr. Conversely, no clear evidence of deformation is observed at Valsecchi, Ravi, and the nearby city of Gavorrano. Our observations suggest that the sinkhole activity in Gavorrano has been induced by the mining activity in the area and that subsidence is still ongoing at Monte Calvo. The comparison between long-term and short-term deformation indicate that surface velocities are slowing down in Gavorrano and that the sinkhole is stabilizing. However, the occurrence of future sinking episodes cannot be ruled out if the underground stability conditions change for example after further cavities failures.

Relationship between air-rock-water temperatures in karst caves and surface temperatures

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Keywords: karst caves, monitoring, air-water-rock temperatures.

In karst caves air-rock-water temperatures are rather constant over time compared to the surface considerable thermal variations. The significant differences between the outside air temperatures and the in-depth ones, environmental parameters and karst system morphology, trigger the air circulation in the fracture networks. Air has a very low thermal inertia, therefore, if still, it quickly reaches a sort of equilibrium condition with the rock, assuming the rock temperature in absence of significant circulations. The greater thermal exchanges take place near the cave entrances, conditioned mainly by the speed of the incoming air flows. Into depth, temperature of the infiltration waters plays a dominant role in subtracting heat from the limestone masses, which have a lower temperature than the other rocks.

To better understand these processes, the Paleolab of Politecnico di Torino began a series of research through the installation of data loggers for air-rock-water temperatures monitoring in karst caves of southern Piedmont, Italy, characterized by very different environmental conditions. Almemo multiple-channel sensors with temperature probe (accuracy: 0,01; resolution 0,001°C) are used in Bossea cave, TinyTag sensors with temperature probe (accuracy: 0,02; resolution 0,001°C) are used in other caves. In collaboration with Arpa Piemonte, part of the project concerned the monitoring of cavities characterized by the presence of underground glaciers showed a rapid reduction in the last decade, linked to the increase in surface temperatures. In collaboration with S.O. Bossea C.A.I., another part of the project involved the installation of over 50 air-rock-water temperature probes at the "Giovanni Badino" Climatological Research Centre to examine the relationships between surface and in-depth temperature variations. Finally, in collaboration with the Speleo Club Tanaro, the third project concerns the temperatures monitoring of caves characterized by considerable air flows, for examine at different distances from the entrances the relationships between the air and the rock temperatures induced by these air circulations.

Anthropogenic impact assessment in show caves through environmental parameters monitoring

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Keywords: showcaves, monitoring, environmental impact assessment.

As part of the national project PRIN SHOWCAVE, aimed at the study of the anthropogenic impact in show caves, environmental parameters were monitored in three important cavities (Toirano and Borgio Verezzi caves in Liguria, and Bossea cave in Piedmont, Italy). Air-water-rock temperatures and CO_2 air concentrations were detected every 10 minutes, groundwater level variations with hourly intervals.

Air temperature variations are significant not only to assess the tourist passage and light impacts, but also because they allow to understand the air circulation in the cavities. By placing temperature probes outside and at the entrances of the caves it is easy to observe periods with evident variations related to daily thermal fluctuations (intake phase). In the blowing phase, air temperature values remain rather constant over time, flowing air coming from deep areas of the cavity, characterized by a remarkable constant thermal values.

The three examined caves showed different situations. Bossea cave has a unique entrance (one-entrance circulation), and is characterized by several convective cells related to the cave morphology and the air cooling due to the inner collector. Toirano caves are two cavities (Bàsura and S. Lucia Inf. caves) connected through an artificial tunnel. The difference between the high and low entrances is about 20 m with a mild air circulation (multi-entrance cave), highlighted by the different temperature values detected at the two entrances. Borgio Verezzi cave has four entrances with an elevation gain of few meters which guarantees a mild air circulation (multi-entrance cave).

The monitoring of the CO_2 values carried out in the cavities showed a daily impact linked to the tourist passage, with an obvious temporary increases related to the number of visitors. However, the air circulation inside all monitored cavities allowes a decrease in CO_2 concentrations. Moreover, collected data highlighted a significant CO_2 air concentration of natural origin in each monitored cave. In Toirano caves, about 8,000 ppm of CO_2 were detected in a not-touristic area, coming from the deep karst networks. In the other two cavities, part of the CO_2 come from the depressurization of the waters circulating in the saturated network of the karst system, near the tourist paths.

Thanks to the data collected in three consecutive years, it was possible to evaluate a rather reduced anthropogenic impact in the three show caves.

List of endangered caves and karst, an initiative from the International Union of Speleology

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Keywords: karst, cave, conservation.

Karst systems and caves are very precious places, hosting remarkable natural resources and historical and cultural heritage sites and remains. All people exploring such settings, including cavers and scientists, should therefore approach karst keeping well in mind the uniqueness of these sites, and the need to preserve as much as possible such delicate settings. Since many years the International Union of Speleology (UIS) has released a Speleological Code of Ethics, aimed at protecting caves and karst, that provides the basic information for responsible caving and scientific sampling. As a further action, UIS in collaboration with the International Union for Conservation of Nature (IUCN) recently released the second edition of the Guidelines for Cave and Karst Protection (Gillieson et al., 2022), furthermore reinforcing the issues above. In detail, as reported by the UIS-IUCN guidelines, any person wishing to undertake research in caves should be able to either demonstrate they are familiar with cave environments and the local Minimal Impact Caving Code, or that they are working with experienced cave scientists who will ensure adherence to the code, with an emphasis on minimal sampling methods for fauna, speleothems and sediments. All of this is especially true for caves located within reserves or national parks.

Preservation of caves, and of the karst environment as well, must be stressed also as concerns scientific research, which actions should always be carried out with extreme care, considering as main priority the conservation of the karst environment, and the fact that destruction of remains is an irreversible action, resulting in loss of part of the human and cultural heritage.

The UIS Bureau has recently created a working group dedicated to develop a list of endangered caves and karst, aimed at increasing the awareness about the necessity to safeguard the delicate and fragile karst setting, both at the surface and underground. Through information coming from the UIS Delegates in the many countries within UIS, we are collecting a variety of indication about karst sites worldwide that are in danger, or threatened, by human actions. These latter are often being carried out irrespectively of the peculiar nature of karst terrains, and of the remarkable importance of the resources therein contained, starting from groundwater. The main goal of such an activity is raising awareness about fragility of karst among the communities living in karst, and to carry out actions to inform people, and force land planners and managers to take into the due account the geological and hydrogeological peculiarity of karst.

Gillieson D.S. et al. (2022) - Guidelines for Cave and Karst Protection, 2nd Edition. International Union of Speleology and Gland, Switzerland, IUCN, 112pp.

S28.

Experiences of data sharing and use in the frame of Research Data Infrastructures

CONVENERS & CHAIRPERSONS

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Sharing seismological data related to historical earthquakes in Italy

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Keywords: historical seismology, open data, open science.

Historical earthquake investigation in Italy has produced a huge amount of data on the seismic history of its territory. These data are collected and organised in ASMI, the Italian Archive of Historical Earthquake Data (Rovida et al., 2017), which today grants access to information on more than 6500 earthquakes that occurred in Italy and surrounding areas from 461 BCE to 2021 CE. ASMI collects and provides instrumental and macroseismic earthquake parameters from current and previous catalogues and macroseismic intensity data from different historical studies, together with their bibliographic metadata, with a total of 459 data sources. The multiple datasets provided for each earthquake can be easily compared for the compilation of the Italian Macroseismic Database DBMI and the Italian Parametric Earthquake Catalogue CPTI. ASMI represents the Italian node of the European Archive of Historical Earthquake Data AHEAD (Rovida & Locati, 2015), which in turn is the European node for the collection and distribution of historical earthquake data within the Seismology Thematic Core Service (Haslinger et al., 2022) in the framework of the European Plate Observing System EPOS. ASMI is accessible through a dedicated web portal that allows querying its content by either earthquake or data source. Through the query by earthquake, it is possible to select a single earthquake from a list. Once an earthquake is selected, all available information, in terms of parameters from earthquake catalogues and macroseismic intensities from archived studies, is displayed. Data from various external databases (i.e. Euro-Mediterranean Tsunami Catalogue EMTC, Italian ACcelerometric Archive ITACA) is also provided thanks to extensive use of DOIs identifiers and APIs (Application Programming Interfaces) allowing direct access to their content. The query by data source lists all bibliographic citations and grants access to the study as a PDF file, a link pointing to the original document, and a list of the investigated earthquakes. An alternative way for directly accessing ASMI data is through different web services according to the specific type of data (i.e. parameters, intensities, bibliography). Detailed earthquake parameters can be accessed using three distinct API standards: fdsnws-event, OGC WFS (Open Geospatial Consortium Web Feature Service), and OGC WMS (Web Map Service). Macroseismic intensity data can be accessed using a RESTful service providing a QuakeML 2.0 output. The bibliographic citation of data sources can be accessed using another dedicated RESTful service to output JSON, XML, and plain text format. In addition, a QGIS plug-in (QQuake; Locati et al., 2021) was developed to provide easy access to ASMI data when working with the QGIS software. Most features of ASMI were designed with the FAIR data principles, a step required for the adoption of the Open Science paradigm.

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GeoChem: structure and tools of a database for geochemical data of volcanic areas

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Keywords: geochemical metadata, volcano monitoring, open science.

In the last decades, the advances in analytical chemistry and the development of techniques of sampling and measurements in the different geochemical spheres (lithosphere, atmosphere, hydrosphere, pedosphere), have significantly increased the amount of data (Jochum et al., 2005).

New additional information is required, first to make geochemical data reproducible and reusable (as requested by the FAIR principles) and, second, to broaden the use of applied methodologies of data collection and analysis. This work describes the design principles employed in creating a comprehensive conceptual scheme for a geochemistry database, fitting the wide range of geochemical data on fluid and rocks, obtained by in situ measurements and/or laboratory analyses. The main objective is to define a standard model for rock and fluid geochemistry, by introducing specific metadata, which consists of different macro levels, containing the sample information, different types of materials and a list of possible analyzed parameters organized in different category (Corsaro & Miraglia, 2020).

In the implemented database, the representation of gas and rock samples differs, principally, for types of materials and categories of the analyzed parameters. The implemented metadata model makes easier the scientific data integration and FAIR data management; furthermore, it contributes to Open Science using fields which have been already standardized by the scientific community (e.g. IGSN sample code). Finally, the model allows a fruitful organization of multidisciplinary data acquired for monitoring activity of volcanic areas (Puglisi et al., 2022).

The main effort of this work is focused in developing a data structure able to provide an efficient geochemical data management framework, available through web services (e.g. RESTful API). This structure gives access to a diverse range of geochemical data and products, and it is also compliant with the EPOS Data Portal requirements.

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The CARG Project's experience in sharing geological data

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Keywords: CARG project, PNRR, geological data.

The Geological Survey of Italy, through the CARG Project, produces the Geological Map of Italy at a scale of 1:50,000 and has so far produced about 280 geological maps and 30 geothematic maps, covering 45 percent of the national territory. Thanks to new funding, a new phase of activity has begun that will lead to the realization of geological coverage of about 60 percent of the Italian territory.

The products related to each geological map consist of Rasters, Explanatory Notes and Databases (Artioli et al., 1997; Battaglini et al., 2009). As part of the activities of WP2 - Geological and geothematic mapping and modeling within the PNRR - GeoSciences IR, it is planned to create services and app that make these data accessible according to FAIR principles. Geological Sheets and related Explanatory Notes will be identified through the assignment of Digital Object Identifier - DOI.

The geological databases of the single Geological Sheet, through data transformation and decoding procedures to make them interoperable in the context of different applications and uses, will be provided in open source formats, such as GeoPackage format, and for each of them the metadata will be filled in according to the RNDT standards, which will be followed by the assignment of the Digital Object Identifier - DOI.

The three products of CARG Project are then findable, downloadable and viewable, and through their identifiers it is possible to highlight their relationships with each other. Currently the Geological Database at the scale 1:25,000 is published on the Geological Survey Portal as a WMS service; after INSPIRE harmonization process, WFS and Atom download services, defined according to international standards (OGC), will be implemented.

Another of the products provided within PNRR - GeoSciences IR project is the app for viewing and querying the CARG geological maps. This is an application for Android and iOS mobile devices through which it is possible to view the Geological Sheets and consult the information contained in the databases. Contents related to geological and geomorphological elements and resources and prospecting are displayed.

In order to make this data more available, a new website is being developed to increase the accessibility of CARG data by users. These new web pages within ISPRA's institutional website, will provide access to the Geological and Geothematic Sheets of the CARG Project, the related Explanatory Notes and Databases, allowing visualization through map browsing, and downloading of products indexed through the DOI.

The geological knowledge, accessible through these platforms, provides an immediate and comprehensive view of the existing data in specific area, enabling further planning where necessary or filling information gaps and providing a fundamental tool for land use planning and actions.

Artioli G.P. et al. (1997) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, Banca dati geologici - Linee guida per l'informatizzazione e per l'allestimento per la stampa dalla banca dati. Quaderni del Servizio Geologico Nazionale, serie III, 6, 142 pp.

Battaglini L. et al. (2009) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, Progetto CARG: modifiche ed integrazioni ai Quaderni n. 2/1996 e n. 6/1997. Quaderni del Servizio Geologico d'Italia, serie III, 12(I), 166 pp.

Harmonization of the new release of Earthquake Environmental Effects Catalogue (EEE Catalogue) in the context of Research Data Infrastructures

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Keywords: EEE Catalogue, geopackage format, data harmonization.

The purpose of this work is the implementation of the new release of the EEE Catalogue (a database of Earthquake Environmental Effects), which will be accessible through the GeoSciences IR and MEET Research Infrastructures. In this regard, for the data that become part of such Research Data Infrastructures the harmonization in accordance with the INSPIRE Directive and FAIR (Findability, Accessibility, Interoperability, Reuse) principles is mandatory.

The EEE Catalogue is a database compiled at global level, collecting information about environmental and geological effects induced by recent, historical and paleoearthquakes, including primary effects (e.g., surface faulting, tectonic uplift), as well as secondary effects (e.g., ground subsidence, ground cracks, slope movements, liquefaction, tsunamis, hydrogeological anomalies). The observed relevance of EEEs as a major source of damage, in addition to vibratory ground motion, corroborates how the knowledge of these types of effects can be fundamental for seismic hazard and intensity assessment. Therefore, the EEE Catalogue can be regarded as an useful source of information for land planning, especially in areas of high seismicity.

The first version of EEE Catalogue was launched in 2011 and was designed in PHP (Hypertext Preprocessor) format. The structure of this catalogue is based on collecting data at three different levels of increasing detail, corresponding to three different layers: Earthquake, Locality, Site. The Earthquake features contain general information on the seismic event. The Locality features provide information on a specific locality where some coseismic effects have occurred. The Site features contain information at the site of each earthquake environmental effect. The structure of the catalogue is completed by Country features, consisting of point geometry. At present, the EEE Catalogue contains information on EEEs associated to 202 earthquakes, 1553 localities, and 4605 sites.

In order to facilitate worldwide compilation, the GeoPackage structure was planned to be used for the new version of EEE Catalogue. This structure represents an open and standards-based format for transferring geospatial information developed by the Open Geospatial Consortium (OGC). This format presents several advantages including platform independence, versatile data support, large storage capacity, and maintenance of relations between database tables.

Due to unchecked data entry the database underwent an initial review. Because of the requirement to enter new records into the database, new code lists were implemented, through which a specific database field is filled by a list of predefined attributes. The main challenge of the new release consists in the semantic standardization on the basis of standard vocabularies (e.g., INSPIRE, GeoSciML). The attributes which are not present in any standard vocabularies will be written and proposed on the INSPIRE Register Federation.

Advancing seismological and geodetic data management at the OGS

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Keywords: data management, seismology, geodesy.

The Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS houses a large amount of seismological and geodetic data, some of which gathered digitally since the mid-1990s. Within our archives lie diverse data types, including time series data, station metadata, and event metadata (bulletins), sourced from both permanent and temporary networks (Bragato et al., 2021; Priolo et al., 2015) . Currently, these data are accessible via various internal (e.g., Real-time Antelope, Oasis, http://oasis.crs.inogs.it, Rts, https://rts.crs.inogs.it, Frednet, http: //frednet.crs.ogs.it) and external services (e.g., EIDA https://eida.ingv.it).

The need to optimize internal data usage and improve user-friendliness, alongside our dedication to upholding FAIR principles in data sharing and preservation, has led us to develop a roadmap for data governance that we are ready to implement. This effort aligns with our strategy to leverage the capabilities of European Research Data Infrastructures (RDIs) to organize our databases systematically.

Our seismological data service is facilitated through the SeisComp Suite and embodies innovation and accessibility, marking a stride forward in seismological data management and dissemination. In this presentation, we introduce the state-of-the-art of seismological data services, which have been realized in alignment with the WebServices standards outlined by the International Federation of Digital Seismograph Networks (FDSN).

Additionally, we present the service related to the GNSS data and products (Tunini et al., 2024), which are recorded by the Friuli Regional Deformation Network and are distributed through a dedicated repository housed within our Institute. The repository is made accessible through the GNSS Linkage Advanced Software System (GLASS Fernandes et al., 2022), developed as part of the European Plate Observing System (EPOS) project. GLASS serves to collect, validate, and distribute GNSS data and associated metadata across Europe.

It is noteworthy that within this framework, our organization, OGS, oversees the Central and East European GNSS Node within EPOS (CEGNxEPOS), presently in a pre-operational stage (https://gnss-metadata.eu/site/distributor). Although still in progress, partial dataset retrieval is feasible. Completion of the full sharing procedure with CEGNxEPOS is anticipated by the end of 2025. Access to the node is currently available at http://gnssdata-epos.ogs.it.

Bragato P.L. et al. (2021) - The OGS–Northeastern Italy seismic and deformation network: current status and outlook. Seismol. Res. Lett., 92(3), 1704-1716, https://doi.org/10.1785/0220200372.

Fernandes R. et al. (2022) - A new European service to share GNSS Data and Products. Ann. Geophys., 65(3), p. DM317, https://doi.org/doi:10.4401/ag-8776

Priolo E. et al. (2015) - The OGS Archive System of Instrumental Seismology. Seism. Res. Lett., 86. 978-984, https://doi.org/10.1785/0220140175.

Tunini L. et al. (2024) - Global Navigation Satellite System (GNSS) time series and velocities about a slowly convergent margin processed on high-performance computing (HPC) clusters: products and robustness evaluation. Earth Syst. Sci. Data, 16(2), 1083-1106, https://essd.copernicus.org/articles/16/1083/2024.

The CARG project towards 3D geology: definition of standards for the construction, consultation, and distribution of three-dimensional geological models

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Keywords: 3D geological models, CARG project, FAIR principles.

The Servizio Geologico d'Italia (SGdI), alongside traditional geological sheets and subsurface geological maps, is strongly promoting the production of 3D geological models. Indeed, in the framework of the CARG Project (Geological map of Italy at 1: 50,000 scale) and other projects participated by the SGdI, more than 35 geological 3D models will be produced in the coming years. To collect and distribute these models according to FAIR principles (Findability, Accessibility, Interoperability, Reusability), the SGdI is implementing the "Geological 3D subsurface models database" and the dedicated 3D web viewer "GEO-IT3D – Modelli geologici 3D in Italia". A three-dimensional model is a complex set of geometric, parametric, descriptive information, and their relational schemas. The challenge has been to define the model data structure to make it as simplified as possible, but at the same time comprehensive, well-constrained, and interoperable, to be adaptable to a wide range of users varying from professionals to local government agencies, to researchers. Furthermore, the web viewer extends also to non-geologists the possibility to navigate and interact with the geological models through tools for user-defined spatial queries (i.e. cross-sections, maps, and virtual boreholes). Here we present the data schema and file structure of 3D geological models that will be hosted on the SGdI database. The geological model consists of textual description files, geometry files (points, surfaces, volumes), and data tables with descriptive attributes, geometric and kinematic parameters gathered in a single archive. Parameters description adopts and possibly extends INSPIRE and GeoSciML Geology-based data model and codelists. The data schema and file structure, together with the implementation of controlled vocabulary, will benefit from the activities carried out in the Next Generation EU-funded projects GeoSciences IR and MEET. Dedicated ISOstandards-compliant metadata and DOI persistent identifier will guarantee the findability of the 3D geological models. Finally, the "GEO-IT3D" web viewer (https://geo-it3d.isprambiente.it/), developed in the framework of the CARG Project, will allow to access, navigate and query the 3D geological models in real-time, as well to carry out complex spatial queries by the users (i.e., synthetic borehole, vertical and horizontal sections). Models are also available for download through OGC APIs and are released under CC-BY open license.

How to organise a rock repository of volcanic samples: a proposal of metadata model

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Keywords: rock repository, volcanic samples, metadata model.

Volcanological community manages different types of data which consist of continuous or discrete measurements and observations acquired by ground based networks and remote sensing instruments, or during field surveys and laboratory analyses. In particular, one of the activities performed during the fieldwork is the sampling of rocks.

A sample is a "physical object" which deserves to be archived before a part of it will be addressed to laboratory analyses. Therefore, the use of an international system, as the IGSN (International Geo Sample Number), which uniquely and globally identifies rock samples, is progressively spreading in last years. Here we design the structure of metadata for a rock repository of volcanic samples, which include most of the IGSN metadata, but integrate them with supplementary information thought for monitoring and research activities of the volcanological community.

The metadata structure that we propose comprises two types of descriptors. The "General Metadata" include the basic information of a sample, and the "Specific Metadata" deal additional details essential to characterise the volcanic context.

"General metadata" comprise information on the sample's identification, geolocation, collection and archiving.

"Specific metadata" encompass all the volcanological facets associated with various conditions and methodology of sampling. In particular, we treat: i) Syn-eruptive sampling: samples are collected during an eruption (or soon thereafter) and primarily consist of lava flows and pyroclasts; their study is crucial particularly for volcano observatories and Institutions in charge of the volcanological/petrological monitoring. ii) Stratigraphic sections: samples are from stratigraphic sections, which are vertical sequences formed by the accumulation of volcanic products. iii) Dredge: samples are collected during dredging operations, which are fundamental for characterising submarine volcanic structures and related products. iv) Boreholes: boreholes are drilled into the Earth's crust, penetrating the sedimentary cover to extract core samples, allowing the investigation of layers up to hundreds of metres below the surface.

The long-term curation of collected materials is an important investment for the future. As a matter of fact, it guarantees the possibility to preserve rocks in order to avoid repeated sampling, uses rocks that could be no longer sampleable, and allows to reproduce science by repeating laboratory analyses.

The aim of this work, based on discussion within the EUROVOLC project, is to provide the basic information for populating in the future a relational database for the description of different volcanic samples, physically located in different rock repositories and Institutions, in order to facilitate future sharing between different groups of scientists and more complete volcanological studies.

The Isotope Virtual Research Environment developed within ITINERIS Project: example of mixing modelling

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Keywords: virtual research environment, isotopes, mixing modelling.

Applications of conventional (e.g., H, O, C, N, and S), as well as non-conventional stable (e.g., B, Li, Fe, Cu, Zn, and Mg) and radiogenic (Sr, Nd, and Pb) isotopes provide unique opportunities to evaluate deep geology and critical zone processes. One of the most important environmental issues affecting human development in the twenty-first century are represented by human-induced climate change, which can be successfully addressed using isotope compositions. A considerable number of studies have been published on isotope geochemistry applied to geological and critical zone processes, and their number is ever-growing. In the light of this, an inventory of stable and radiogenic isotopes becomes a fundamental tool to track processes involving fluids, minerals and rock evolution and origin, as well investigations on soils and plants and other pools.

A national database on environmental isotopes is still missing so far, and data and information still unfaire and scattered across various sources and institutions, generating difficulties in data and information recovery. In the framework of the ITINERIS Project (PNRR), the Work Package 8.9 is aimed at building the ISOTOPE Virtual Research Environment (VRE), which will pioneer the establishment of Italy's first comprehensive national VRE service encompassing the national database on stable isotopes. The new Isotope VRE incorporates tools for analysis, interpretation, and modelling services allowing researchers and Stakeholders to retrieve coordinated information and analysis tools.

One of the most common model to unravel biogeochemical processes consists of quantifying the contributions of multiple sources to a mixture, using isotope data along with chemical compositions. Given the isotopic compositions of diverse sources, isotopic mixing models can be used to calculate the relative source proportions. Here, we present a new application capable of calculating, quantifying, and showing the outcomes of two- and three-component mixing dynamics.

The first results demonstrate the great usefulness that the creation of the Isotope VRE can have in understanding processes occurring on Earth Systems such as mixing. Other mathematical approaches will became available soon. For this reason, the creation of the Isotope VRE is aimed to provide to the scientific community an isotopic data sharing set in a virtual research environment able to offer a series of powerful tools to understand and interpret environmental processes.

EIDA Italian node: seismic data curation preservation e dissemination

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Keywords: quality, fairness, data life cycle.

The EIDA (European Integrated Data Archive) node hosted at Istituto Nazionale di Geofisica e Vulcanologia (INGV) holds more than 140 TB of seismological waveform data. A set of data curation practices are in place as a guarantee of a robust and reliable preservation and dissemination of quality data.

Archived data originates from a seismic network inventory and requires a continuous update of all station and network related metadata.

Our system has a modular design by leveraging, whenever possible, existing open-source solutions. Tasks are managed by adopting a customised ticketing system, for injecting and tracking the changes and managing any station's faults. The station metadata and channel responses are managed using an XML database to store StationXML documents natively and an implementation of the fdsnws-station web service standard is based on it. Our GUI leverages Grafana creating an intuitive dashboard to present an overview of the system status of all components.

We have deployed a Policy Enforcement Point in order to apply our policies and quality assessment before archiving any data.

Our preservation policy is also based on a replication (synchronised copy) at a long-distance storage (~200 Km) and a backup copy in a tape library.

The EIDA node run by INGV disseminates data through websites and webservices (https://eida.ingv.it/, https://webservices.ingv.it/).

To enhance our services for users we are adding significant computational resources and an adequate processing and analysis framework combining the open source Apache Spark and ObsPy, creating a "computational archive" where storage and computational resources converge.

MUDA: the dynamic geophysical and geochemical MUltiparametric DAtabase

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Keywords: multiparametric monitoring, open data.

Nowadays increasingly consciousness on the interaction between tectonics and crustal fluids dynamics is lacking simultaneous monitoring of the relative key factors. Changes in water chemistry and levels, spring discharges, soil flux regimes (e.g., CO_2, CH_4, radon) and compositions of dissolved gases in water are well documented in the literature (e.g., Chiodini et al., 2020; Wang & Manga, 2021; Gori & Barberio, 2022), as being pre-, co- and post-seismic modifications as well as being markers of the local tectonic stress acting in the crust. However, geological differences among sites require specific knowledge of crustal fluids response to seismicity.

In this framework arose MUDA (geophysical and geochemical MUltiparametric DAtabase, https://muda.mi.ingv.it), a new infrastructure of the National Institute of Geophysics and Volcanology (INGV, www.ingv.it) serving geophysical and geochemical multiparametric data, designed and developed in the framework of Dynamic Planet-Working Earth project (https://progetti.ingv.it/it/pian-din).

MUDA is a dynamic and relational database based on MySQL with a web interface realized in php using a responsive design technique. The multiparametric data are stored and organized using a table-structure able of correlating different types of data that allow possible future integration with new type of data acquired through both real-time and off-line transmission vectors.

MUDA collects information from different types of sensors, such as seismometers, accelerometers, hydrogeochemical sensors, sensors for measuring the flux of carbon dioxide on the ground (CO_2), sensors for detecting the concentration of Radon gas and weather stations with the aim of making possible correlations between seismic phenomena and variations in environmental parameters.

MUDA daily publishes multiparametric data updated to the previous day and offers the chance to view and download dynamic time series for all available data and for different periods, up to a maximum of 30 days. For longer periods, users can request data to muda@ingv.it.

Chiodini G. et al. (2020) - Correlation between tectonic CO_2 Earth degassing and seismicity is revealed by a 10-year record in the Apennines, Italy. Sci. Adv., 6(35), eabc2938, https://www.science.org/doi/10.1126/sciadv.abc2938.

Gori F. & Barberio M.D. (2022) - Hydrogeochemical changes before and during the 2019 Benevento seismic swarm in central-southern Italy. J. Hydrol., 604, 127250, https://doi.org/10.1016/j.jhydrol.2021.127250.

Wang C.-Y. & Manga M. (2021) - Water and Earthquakes. Lecture Notes in Earth System Sciences, Springer Cham, 387 pp., https://doi.org/10.1007/978-3-030-64308-9.

The research infrastructure of GeoSciences: from datasets analysis to harmonization process

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Keywords: inspire, fair, harmonization.

Nowadays, the relevance of open data is growing widely as a consequence that their benefits and value are largely recognized. In this regard, research data infastructures have a key role for the assumption of the Open Science paradigm.

In this context, the GeoSciences IR project aims at creating a research infrastructure for the Italian Geological Surveys Network (RISG), which represents the coordination network between the Geological Survey of Italy, part of the Italian Institute for Environmental Protection and Research (ISPRA), and the Regional Geological Surveys. Different types of products will managed into the research infrastructure: datasets, metadata, services, vocabularies, publications, software, and applications. These products cover several issues: geological and geothematic mapping and modeling, landslides, sinkholes, hydrogeological risk mitigation, satellite and in-situ monitoring, active and capable faults, sustainable mining, and land use and consumption. For all the products that will become part of the GeoSciences IR the harmonization in accordance with INSPIRE Directive 2007/2/EC and FAIR (findable, accessible, interoperable, reusable) data principles is mandatory. Within the project workflow the work package 6 (WP6) is responsible for open data and data harmonization.

The WP6 purpose is collecting and analyzing all the datasets produced by the operating units of thematic WPs. All these datasets are subjected to an analysis to define process of semantic and geometric harmonization.

In order to achieve its objectives, the WP6 group is pursuising different actions: source data model and information content analysis, target data model analysis, mapping tables creation. The result is the final data model design (by going through semantic enrichment), dataset transformation, validation (INSPIRE validator) and sharing. Dataset and services metadata fallows same validation flow. Moreover, one of the major challenges of GeoSciences IR is represented by the semantic standardization on the basis of standard vocabularies (e.g., INSPIRE, GeoSciML). The dataset attributes which are not currently available in any standard vocabularies will be written and subsequently proposed to the Agency for Digital Italy (AgID), which maintains the INSPIRE Italia Registry.

This step is of crucial importance in order to provide users with homogeneous datasets having the same minimal information content at any level.

New tools for geo-scientific data management in the framework of the ITINERIS project leveraging D4Science e-infrastructure capabilities

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Keywords: D4Science infrastructure, VREs, data sharing.

Open Science is a cultural movement based on transparency, inclusion, research integrity, collaboration, and cooperative work, promoting an enhancing approach to science. Benefits are expected from this approach, although doing open science can entail a contrast with several barriers, including: (i) cultural factors (e.g., the fear of the loss of control of the datasets); (ii) cost-base factors; and (iii) disincentive factors (Assante et al., 2019; 2023). The effectiveness of the Open Science approach of a project can be enhanced by using the D4Science infrastructure. This infrastructure promotes collaboration and cooperative work with Virtual Research Environments (VREs).

As part of the ITINERIS Project, a comprehensive Italian Research Infrastructures (RDIs) hub in the geo-scientific and environmental fields is under development, in which teams with a high level of trans-disciplinarity are working on the development of thematic VREs for topics that includes: (i) Critical Zone (CZ) VRE; (ii) Aquatic Biomass services (BIOMASS) VRE; (iii) Crops, Plants and Pests services (CPP VRE); (iv) Essential Variables (EV VRE); (v) Aerosol-biosphere (AERO VRE); (vi) Carbon Cycle services (CARBON VRE); (vii) Indicators and Impacts of Climate Change (CLIMA VRE); (viii) Downstream Effects of Environmental Change (DOWNSTREAM VRE); (ix) Isotope Database (ISOTOPE VRE). VREs are based on the D4Science infrastructure, and their development is based on the needs of the scientific communities and the specific stakeholders identified by the researcher.

VREs are new eScience facilities that address scientifically and socially relevant topics, especially through the sharing of information and data produced. Research data and results products following international standards are managed and shared with the members of the VREs.

In this context, these D4Science enabled VREs will become tools supporting the entire spectrum of the research lifecycle. Specifically, for data collection (i) the Collaborative Storage Framework promotes teamwork among users and offers a collaborative space to share digital objects. For data analytics, (ii) the Analytics Engine Framework equips VREs with Cloud Computing Platforms. For data publishing, (iii) the Publishing Framework facilitates the dissemination of research outcomes by means of the Metadata Catalogue and the Spatial Data Catalogue, which help organise and make research results available to the broader scientific community.

Moreover, VREs are planned with a modular structure with semantic services for data discovery, harmonization and interoperability, and will contribute to share workflows, procedures and analysis tools which could be applied to analyse new datasets by the members of the VRE. Data from multiple sources, analysis and modelling tools will be integrated into the VREs, allowing users to gain insights into the problems at hand and add their data and analysis methods to respond to the changing scientific and practical needs.

Assante M. et al. (2019) - Enacting open science by D4Science. Future Gener. Comput. Syst., 101, 555-563, https://doi.org/10.1016/j.future.2019.05.063.

Assante M. et al. (2023) - Virtual research environments co-creation: The D4Science experience. Concurr. Comput. Pract. Exp., 35(18), e6925, https://doi.org/10.1002/cpe.6925.

GeoSciences IR: a cloud research infrastructure for regional geological surveys

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Keywords: geosciences, research infrastructure, data harmonization.

GeoSciences IR is a data research infrastructure in the geological domain supported by PNRR recovery funds (M4C2 line 3.1), under implementation by a large consortium composed by 13 Italian universities and 3 research institutes, coordinated by ISPRA, Geological Survey of Italy.

The infrastructure aims at supporting Regional Geological Surveys (RGS), i.e. the local technical offices having a specific mandate on geological topics at regional and local level.

Through the GeoSciences IR Cloud Research Infrastructure (CRI), it will be possible to access to about 50 datasets and services, developed in accordance with the FAIR principles and the INSPIRE Directive, which require fully open accessibility, interoperability, and reusability. Users will be able to access also to innovative tools based on specific algorithms available for cloud data processing. A specific section of GeoSciences IR will be dedicated to e-learning modules built to increase the transfer of knowledge from scientists to target users.

The priority topics of GeoSciences IR have been identified by RGS and encompass various geological topics, including 2D and 3D geological mapping, marine geology, geoheritage conservation, geohazard mapping and monitoring, sustainable mining, and land consumption.

The infrastructure architecture has been designed based on the Agile methodology by selecting the most innovative system architecture solutions fitting with the users' needs.

Several cloud computing components and tools are being deployed, including virtual machines, containers, virtual labs for scientific development and collaboration, geospatial databases, integrated machine learning development, servers for providing network services for spatial datasets, and metadata; as well as a framework for managing semantic resources and easy access to APIs.

The implementation of a pre-operational version of the infrastructure including a prototype of the management software will be followed by the final version of the CRI ready for testing and validation procedures.

The hybrid architecture will allow the provision of data access services and analysis functions in the various GeoSciencesIR topics, as well as the permanent availability of virtual laboratory rooms that will facilitate the collaboration among researchers. Furthermore, through the platform, it will be possible to build FAIR products (metadata, data, scientific vocabularies, software codes for tools, open access publications).

The infrastructure will open in 2025 and will be maintained for at least 10 years. In this long-term perspective, a dialogue with external stakeholders has already started with the aim of building a reference infrastructure for geological data in Italy. Meanwhile, a constant interaction has been established with other existing research infrastructures available at European (e.g. EPOS ERIC, EGDI), and national level (e.g. MEET) to ensure their complementarity and identify eventual gaps and overlaps.

Fostering the Open Science paradigm and strengthening the European volcanology community: contributions of the Volcano Observations Thematic Core Service to EPOS ERIC

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Keywords: data management, EPOS research infrastructure, volcano community building.

The European Plate Observing System (EPOS) is a Research Infrastructure committed to enabling excellent science through the integration, accessibility, use and re-use of solid Earth science data, research products and services, as well as by promoting physical access to research facilities. EPOS represents a unique example of a federated approach to integrating scientific data and fostering FAIR data management in the European solid Earth sciences contributing to Open Science. High-quality data require an effective and sustainable management over the entire data lifecycle. With this perspective, EPOS has foreseen the Thematic Core Services (TCSs), of which the 'Volcano Observations' TCS (VOLC-TCS) is one of the ten formally established. The main objective of the VOLC-TCS is the implementation of a technical, financial, and legal framework compliant with EPOS, to strengthen the European volcanology community. A community including Volcano Observatories and Volcano Research Institutions providing virtual and physical access to data, data products and services from volcanoes in Europe and European overseas territories. Over time the VOLC-TCS has consolidated a wide number of multidisciplinary services and granted access to a diverse range of data, products, and services via the EPOS Data Portal. VOLC-TCS thus contributes to fostering the paradigm of Open Science and to promoting FAIR principles within the European volcanology community by providing tools and resources that facilitate access, integration, and analysis of geoscientific data. The intrinsic heterogeneity of volcanological data, which has represented the richness of the TCS's offer, has also been one of the main challenges in the management of the service provision. Since some of the services used in volcanology are in common with other communities, (e.g. seismology, GNSS, geomagnetic, geochemistry, geology, etc.) a huge work effort has been performed to harmonise the VOLC-TCS's services with those standardised by the other TCSs. An additional important task has consisted of implementing the VOLC-TCS Gateway. Unlike the EPOS Data Portal, the Gateway also enables access to services not fully compliant with EPOS, or services provided by institutions outside the EPOS boundaries. This initiative aims to ensure the visibility of these services within EPOS and to set the stage for potentially integrating the VOLC-TCS with global-scale data infrastructures, such as WOVOdat.

The new version of ITHACA Catalogue supported by GeoSciences IR and MEET projects

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Keywords: active and capable faults, paleosites, geopackage.

The ITaly HAzard from CApable faults (ITHACA) Catalogue gathers information on capable faults affecting Italian territory. Capable faults are active faults able to produce significant and permanent dislocation and deformation at or near the topographic surface during strong or moderate earthquakes (e.g., IAEA, 2015; 2022). The dislocation (i.e., surface faulting) and deformation of the ground surface represent a geological hazard to be taken into consideration at the local scale, particularly in the most densely populated and industrialized areas. Consequently, the knowledge and precise spatial location of capable faults are crucial issues for seismic risk mitigation. ITHACA implementation started in the nineties, taking advantage of the knowledge derived from siting studies of critical infrastructure (i.e., nuclear power plants, gas and oil pipelines, chemical plants, etc.). The first version of the ITHACA Catalogue was launched in 2000, representing the starting point for continuous updating and implementing up to the present-day version, accessible through the following link: https://sgi.isprambiente.it/ithaca/viewer/index.html.

The focus of this work is to present the new release of the ITHACA Catalogue, developed in the framework of the GeoSciencesIR and MEET projects, both aimed at contributing to the creation of research infrastructure on a national and European scale. Following the goals of the projects and in agreement with the INSPIRE Directive, the new version of ITHACA has been implemented to be more compliant with FAIR (Findability, Accessibility, Interoperability, and Reuse) principles. The structure of the ITHACA database has been revised and improved, with the introduction of new sections and layers and the implementation of new and more complete code lists based on the semantic standardization of attributes following standard vocabularies (e.g., INSPIRE, GeoSCiML). A specific section dedicated to paleoseismological studies (paleosites), crucial and already present in the Catalogue but poorly populated, has been invigorated and enhanced. Finally, interoperability and data sharing are ensured through the publication of OGC standard services (WMS, WFS, and OFAPI). To simplify resource reuse, the dataset is also made available in GeoPackage format with open license attribution (CC BY 4.0).

IAEA (2015) - The Contribution of Paleoseismology to Seismic Hazard Assessment in Site Evaluation for Nuclear Installations. IAEA-TECDOC-1767, http://www.pub.iaea.org/MTCD/Publications/PDF/TE-1767_web.pdf.

IAEA (2022) - Seismic Hazards in Site Evaluation for Nuclear Installations. Specific Safety Guide. IAEA Safety Standards. Series SSG-9 (Rev.1), http://www.iaea.or/publications/14665/seismic-hazards-in-site-evaluation-for-nuclear-inallations.

The EPOS research infrastructure and its FAIR data management approach

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Keywords: fair, research infrastructure, data management.

The European Plate Observing System (EPOS, https://www.epos-eu.org/) is a research infrastructure that harmonizes and integrates multidisciplinary solid Earth data acquired through diverse scientific systems across several disciplines in the solid Earth domain.

In 2018, EPOS obtained the legal status of ERIC (European Research Infrastructure Consortium) from the European Commission (https://www.epos-eu.org/epos-eric) and it is currently integrating around 300 national research organizations from 26 European countries into a single distributed Research Infrastructure.

The EPOS Platform (https://www.epos-eu.org/dataportal), officially launched in April 2023, provides access to high quality-controlled data and services from ten different disciplines: Seismology, Near-Fault Observatories, GNSS Data and Products, Volcano Observations, Satellite Data, Geomagnetic Observations, Anthropogenic Hazards, Geological Information and Modeling, Multi-Scale Laboratories, and Tsunami.

To date, the EPOS Platform was visited by over 20,000 users, showcasing its ability to cross geographical barriers and attract a diverse international audience. Researchers spanning the globe converge on this platform to access scientific data and products, thereby fostering collaboration and facilitating knowledge exchange on a global scale.

The Platform is the result of a collective work carried out with a co-development approach. Over the last decade, an international team of about 600 experts has worked in synergy on the integration and harmonization of over 60 types of metadata from the various solid Earth science disciplines, thus enabling interoperability.

The Platform was developed by following a FAIR data management approach and using a combination of open-source technologies and standards. Based on the EPOS experience, in this contribution we present that approach, which by defining a clear roadmap for compliance with the FAIR principles, produced several best practices and technical approaches for sharing multidisciplinary solid Earth data and products to foster research and innovation.

Geological data from submerged areas: a national standardised and harmonised database

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Keywords: submerged areas, PNRR, database.

Many Italian local administrations have among their main tasks the mitigation of impacts of natural events on the territory through land planning and management, such as: (1) land use, focusing on natural and environmental landscapes, (2) georesources, in particular sand and mineral deposits, and (3) coastal hazards, focusing on erosion and tsunami phenomena.

The main information relating to submerged areas requested by local administrations is morphobathymetric data, obtained through the acquisition, processing and interpretation of geophysical data concerning the seabed obtained from multibeam and side scan sonar surveys. Moreover, additional information can be obtained by seismic and gravimetric surveys, by samplings and well logging.

A database for submerged areas was created also according to the needs expressed by local administrations. It is structured as the set of investigations that might be carried out during an oceanographic campaign. The information acquired is represented by vector data and is organised in relation to the three geometric primitives to be visualised in a GIS environment: (1) punctual, for the collected samples, (2) linear, for the navigation lines, and (3) polygonal, for the areas investigated. Furthermore, one or more tables with selected attributes have been associated with each vector type to better describe and characterise all possible information.

The relational database was developed within the QGis software, where it is possible to set and report the information within a geopackage, also defining the relationships between the "parent" tables (those specific to the spatial characteristics of a GIS software) and the "child" tables.

The final product is a shared national database, standardised and harmonised, with the possibility to look for information through a single access point, avoiding long and expensive searches for each type of dataset, which will comply with FAIR principles as well as, above all, with the INSPIRE directive.

Instrumental enhancement to study Mt Etna ecosystem: Carbon dioxide measurements using Eddy Covariance and flux chambers (PON-GRINT project)

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Keywords: CO_2 fluxes, soil-atmosphere interaction, Mt Etna.

The PON-GRINT project, led by INGV, is aimed at strengthening the Research Infrastructures and Italian facilities involved in the EPOS implementation plan and defining possible expansions of data, products and services. IGG-CNR was involved in the project with the goal to investigate CO_2 fluxes at the soil-vegetation-atmosphere interface in the Mt Etna environment and assess the balance between volcanic and biological CO_2. Two fixed stations for measuring CO_2 soil emission and an Eddy Covariance system for measuring net CO_2 exchange in the Mt Etna ecosystem have been installed since december 2021 and April 2022, respectively. These installations are located in the Valle del Bove (Piano Bello, Milo) at 1100 m above sea level in a relatively flat area. The main wind direction is W-E, and permanent outgassing occurs from the four summit craters that are upwind to the stations. The area is dominated by the endemic Genista aetenensis.

Fixed CO_2 accumulation chambers are dedicated to the measurements of ecosystem respiration and consist of opaque automatic chambers with a diffusion infrared Vaisala sensors for CO_2 measurement, a data-logger and a sensor for the measure of soil moisture and temperature. Data on CO_2 flux are acquired at an hourly sampling interval (length of a single measurement = 4 minutes).The Eddy Covariance station allows to measure the net ecosystem exchange, and includes an enclosed path gas analyzer for the measurements of CO_2, H_2O, latent and sensible heat, a sonic anemometer for the measurements of wind and turbulence parameters, sensors for both the total and photosintetically active radiance, a thermohygrometer, a set of probes for atmospheric pressure, soil humidity and temperature. All the Eddy Covariance sensors record raw data at a sampling rate of 10 Hz, while final eddy covariance turbulent fluxes are computed as 30 minutes averages. Data are trasmitted by West Systems to the IGG-CNR server. In addition, field campaigns performed at both sampling sites by a mobile accumulation chamber in light and dark configurations allow to measure both gross primary production and ecosystem respiration, thus integrating previous techniques measurements. Data acquired from the new stations allow high temporal and spatial resolution of CO_2, H_2O, latent and sensible heatfluxes at Piano Bello. Moreover, since few Eddy Covariance towers are reported in the literature for active volcanic contex due to the harshness of the environment (Werner et al., 2003; Lewicki et al., 2012), the new installation at Mt Etna will represent a new innovative challenge in the national panorama.

The data will be of interest to the international community dedicated to the study of natural CO_2 emissions at the soil-vegetation-atmosphere interface, and will be integrated in EPOS. Our long-term goal is an interdisciplinary study of volcanic, biological, ecological, biogeochemical, climatic, and biogeographic aspects, including anthropogenic impact on the environment. The new activities on Mt Etna benefit from collaboration the Etna Park Authority and the Regional Department of Rural and Territorial Development in Catania.

Lewicki J. L. et al. (2012) - Eddy Covariance imaging of diffusive volcanic CO_2 emissions at Mammoth Mountain, CA, USA. Bull. Volcanol., 74, 135-141.

Werner C. et al. (2003) - Monitoring volcanic hazard using eddy covariance at Solfatare volcano, Naples, Italy. Earth Planet. Sc. Lett., 210, 561-577.

The ISOTOPE Virtual Research Environment (ITINERIS project, PNRR)

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Keywords: isotope vre, database, stable isotopes.

Over time, isotopic data have gained increasing significance in Earth Sciences, and their numerous applications have proved valuable across diverse research areas, mainly in Geology, Environmental Science and other disciplines belonging to Earth System Sciences.

The importance of understanding natural processes using isotope ratios points out the need of data sharing. Consequently, the Italian Integrated Environmental Research Infrastructures System (ITINERIS) Project started to build the Italian Hub of Research Infrastructures (Ris) in the environmental scientific domain with the aim to facilitate access to data and services while aiding the nation in addressing current and future environmental challenges.

The Isotope Virtual Research Environment (ISOTOPE VRE) represents the first Italian VRE that aims filling the gap of a national database on environmental stable isotopes. The final scope is to build the first Italian isotope database, wherein isotopic data will be collected and harmonized to promote and facilitate data sharing within the scientific community. Moreover, the ISOTOPE VRE initiative will encompass tools for analysis, interpretation, and modelling services allowing researchers and environmental managers to interpreting and modelling biogeochemical processes in the area of Environmental Sciences.

At present, the national database on environmental stable isotopes is integrated into a web application deployed within a dedicated D4science VRE. The web application is accessible via any web browser. The software architecture under development is based on three main tiers: (i) a relational database, which is designed for heterogeneous data collection, supported by a dedicated access software; (ii) a web services API (Application Programming Interface) designed to allow automatic interactions with other applications in a “Service Oriented” perspective; (iii) a single page web application providing end-users with an intuitive, friendly, responsive, and robust interface allowing them to easily access the main functionalities of the application, such as, for instance, data retrieving and processing. The software architecture relies only on open source technologies, featuring PostgreSQL as relational database, Java 11 as language for developing data access and the REST APIs, and Angular 14.3.0 with Bootstrap as development platform for the web user interface.

Sharing data on seismogenic faulting in Europe: the EDSF platform

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Keywords: seismogenic faults, IT infrastructure, Europe.

The European Databases of Seismogenic Faults (EDSF; https://seismofaults.eu) provides a centralised platform, initially designed in 2016, for accessing and utilising datasets on European seismogenic faults proposed and elaborated by the scientific community in dedicated research projects. This platform contributes to improved earthquake hazard analyses across the Euro-Mediterranean region in the framework of the European Facilities for Earthquake Hazard and Risk (EFEHR), one of the three pillars of the Thematic Core Services (TCS) Seismology (Haslinger et al., 2022) within the European Plate Observing System (EPOS). The current data resource at the European scale is the European Fault-Source Model 2020 (EFSM20) (Basili et al., 2022), alongside its predecessor and regional-scale products.

The EDSF platform leverages a robust IT infrastructure - named SEISMOFAULTS.EU - for data storage, dissemination, and discovery (Vallone & Basili, 2023). Open Geospatial Consortium (OGC) compliant web services facilitate seamless integration with almost all Geographic Information Systems (GIS) software. In addition, EDSF adheres to FAIR data principles, while a Data Quality Assurance (DQA) procedure guarantees data accuracy and consistency. A comprehensive Data Management Plan (DMP) outlines the data lifecycle management practices at the level of the platform and of the individual datasets. Detailed metadata following international standards is stored in the official Open Data Portal of INGV (https://data.ingv.it), ensuring data discovery, retrieval, and understanding. Each dataset is assigned a unique Digital Object Identifier (DOI). Licenses, typically Creative Commons Attribution 4.0 International, govern data use.

The SEISMOFAULTS.EU infrastructure also guarantees that the EDSF datasets are distributed through the EPOS multi-disciplinary Data Portal (Bailo et al., 2023), fostering interoperability and integrated access to solid Earth science datasets. At the Italian level, EDSF is integrated with and supported by the EPOS Italia Joint Research Unit.

Overall, EDSF is vital for researchers, engineers, and policymakers working on earthquake hazard analyses. The platform's maturity acquired over the years, commitment to FAIR data principles, capabilities of a robust IT infrastructure, and integration with EPOS promote the further integration of additional datasets stemming from current (e.g., MEET) and future projects.

Bailo D. et al. (2023) - The EPOS multi-disciplinary Data Portal for integrated access to solid Earth science datasets. Sci. Data, 10, 784, https://doi.org/10.1038/s41597-023-02697-9.

Basili R. et al. (2022) - European Fault-Source Model 2020 (EFSM20): online data on fault geometry and activity parameters. Istituto Nazionale di Geofisica e Vulcanologia (INGV), 1248, 4, https://doi.org/10.13127/EFSM20.

Haslinger F. et al. (2022) - Coordinated and Interoperable Seismological Data and Product Services in Europe: the EPOS Thematic Core Service for Seismology. Ann. Geophys., 65, DM213, https://doi.org/10.4401/ag-8767.

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S29.

Multidisciplinarity and numerical modelling: a comprehensive approach for upcoming Geosciences

CONVENERS & CHAIRPERSONS

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Integrating geophysical models and numerical simulations to study the dynamics of the active geothermal system of Vulcano island (Italy)

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Keywords: geothermal degassing systems, geophysical models, numerical simulations.

The island of Vulcano (Italy) is the exposed summit of an active composite volcano in the southernmost sector of the Aeolian archipelago. It has experienced many eruptions in historical times, including at least three phreatic events. Since the last eruption between 1888 and 1890 AD, Vulcano has been characterized by periodic episodes of unrest. In September 2021, significant variations in geochemical and geophysical parameters, routinely monitored by the INGV, indicated an increased influx of magmatic fluids into the shallow geothermal system. These changes included variations in the chemical and isotopic composition of gases, rising temperatures in fumaroles and increased soil gas emissions in the La Fossa crater area, as well as associated ground deformation and micro-seismicity (Federico et al., 2023). Consequently, the alert level for Vulcano was raised to yellow.

This study aims to elucidate the fluid dynamics and the mechanisms driving Vulcano's active geothermal system. To achieve this goal, we propose integrating geophysical models with geological and geochemical constraints to construct an accurate three-dimensional petrophysical model of the study area. Specifically, a 2.5 km depth magnetotelluric tomography (MT) carried out in 2022 (Di Giuseppe et al., 2023) provided us with the fundamental information regarding the main volcano-tectonic structures of the caldera and the circulation of the geothermal fluid. By adopting a conceptual model of the island derived from the MT results, integrated with geochemical and geological data, we reconstructed the thermodynamic steady state of the system through the use of the TOUGH2 numerical code (Pruess et al., 1999), highlighting the physical processes occurring in the system and their temporal evolution. This approach allowed for estimating fluid distribution in terms of pressure, temperature, and vapour phase saturation, describing the volcano's current state.

Di Giuseppe M.G. et al. (2023) - Three-dimensional magnetotelluric modelling of Vulcano Island (Eolie, Italy) and its implications for understanding recent volcanic unrest. Sci. Rep., 13, 16458, https://doi.org/10.1038/s41598-023-43828-x.

Federico C. et al. (2023) - Inferences on the 2021 ongoing volcanic unrest at Vulcano Island (Italy) through a comprehensive multidisciplinary surveillance network. Remote Sens., 15, 1405.

Pruess K. et al. (1999) - TOUGH2 USER'S GUIDE, VERSION 2.0. Earth Sciences Division, Lawrence Berkeley National Laboratory University of California, Berkeley, California 94720.

Vegetation cover dynamics in the Mediterranean region: a spectral-based assessment of the riparian vegetation patterns

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Keywords: Riparian vegetation, ecological dynamics, environmental changes.

Riparian areas worldwide are valuable ecosystems whose dynamics are strongly related to socioeconomic context. Riparian vegetation represents an extremely important ecosystem component, which ensure water supply, erosion prevention, riverbank strengthening and ensuring biodiversity protection and restoration (Dufour et al., 2019). In the last decades, climate changes and extreme drought events have particularly affected Mediterranean regions, inducing marked alterations in wetlands and threatening their functioning. The multitemporal analysis of riparian vegetation patterns provides a better understanding of riparian ecosystem resistance or vulnerability (Mahdianpari et al., 2020). We assess the spatio-temporal evolutionary trends in riparian vegetation cover in the Mediterranean Bioregion using 20 years of Landsat based Normalized Difference Vegetation Index (NDVI), analysed in Google Earth Engine (GEE). Non-parametric Mann-Kendall and Theil Sen tests were performed to assess statistically significant NDVI trends. Results showed a constant and significant increase in NDVI values over time on 57% of the study area (@ 900.000 ha). Growth trends, evenly distributed throughout the study area, could be driven by several factors including: reduction in river flow and flooding; local land management practices and policies (dams, water extraction facilities for agriculture or humans uses); establishment of biodiversity reserves and increased environmental protection measures; post-fire recolonization; socio-economic changes and land abandonment of marginal areas and demographic decline. Almost 700.000 ha shown non-significant changes, represented by riparian zones with full vegetation cover falling in narrow areas and high slope classes, interfaces zone subject to flood, artificial embankments, or areas that underwent urbanization during the period covered by the analysis. Here positive or negative trends detected are not significant over time. Decreasing trends were detected in area characterised by deviations or slight displacements of the river course, near anthropic activities linked to riverbed mining or to new management practices related to agriculture (greenhouses, farming installations) or to river management (bridges, dams, new riverbanks). Climate change is certainly one of the driving factors of increasing NDVI trends; the widespread increase in temperatures and drought conditions, contributes to changes in hydrological regimes and decreases in water surface availability and thus generating favourable conditions for vegetation expansion and colonization. Riparian vegetation cover patterns represent an interesting example of ecological feedback to environmental and socio-economic drivers within a climate changing scenario. More in depth analysis will investigate the impacts of hydrographic, climatic, topographic and socio-economic variables affecting riparian vegetation patterns and ecosystem resilience.

Dufour S. et al. (2019) - Tracciare la traiettoria scientifica degli studi sulla vegetazione ripariale: argomenti principali, approcci ed esigenze in un mondo in cambiamento globale. Scienza dell'ambiente totale, 653, 1168-1185, https://doi.org/10.1016/j.scitotenv.2018.10.383.

Mahdianpari M. et al.(2020) - Monitoraggio dei cambiamenti su larga scala delle zone umide utilizzando serie temporali di immagini Landsat su Google Earth Engine: un caso di studio a Terranova . GIScience e telerilevamento, 57(8), 1102-1124, https://doi.org/10.1080/15481603.2020.1846948.

Probabilistic hazard modelling of the non-volcanic gas emissions of Mefite d'Ansanto, Southern Italy

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Keywords: probabilistic hazard modelling, atmospheric gas dispersion, natural gas emission.

The emission of gas species dangerous for human health and life is a widespread source of hazard in various natural contexts. These mainly include volcanic areas but also non-volcanic geological contexts. One of the most notable examples of non-volcanic gas emissions is the Mefite d'Ansanto area in the Southern Apennines in Italy. Here, significant emissions of carbon dioxide (CO_2) occur at rates that make this the largest non-volcanic CO_2 gas emission in Italy and probably of the Earth. Given the morphology of the area, in low-wind conditions a cold gas stream forms and spreads in the valleys surrounding the emission zone. This process proved to be potentially lethal for humans and animals in the past. In this study we present a gas hazard modelling study that considers the main specie, that is CO_2, and the potential effect of the most dangerous one, which is hydrogen sulphide (H_2S). For these purposes we used VIGIL, a tool that manages the workflow of gas dispersion simulations specifically optimised for probabilistic hazard applications. We produced maps of CO_2 and H_2S concentration and persistence at various exceedance probabilities considering the gas emission rates, their possible range of variation defined in previous studies and the seasonal control.

Enhancing the assessment of underground cave stability through machine learning-driven mechanically-based methods

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Keywords: machine learnig, undergruond cavitiese, numerial.

In the recent years, sinkhole hazard related to man-made underground caves has increased in the Italian territory, with important consequences in terms of human lives as well as damages to the anthropogenic environment. Such man-made caves have been generally dug within very soft porous rock formations, as for example the calcarenite deposits, even at shallow depths, and later on abandoned. The low values of the mechanical strength of such rocks, along with their susceptibility to weathering and consequent strength degradation, make these rock masses prone to the sinkhole development. In order to develop a speditive but mechanically-based method to assess the stability of man-made caves based on the cave geometrical features and rock mechanical properties, an enhanced formulation of the abaci initially proposed by Perrotti et al. (2018) has been recently proposed by Mevoli et al. (2024), which introduces the feature to evaluate also the range of the cave safety factor. In this perspective, the application of the abaci can be used as a quantitative tool to assess sinkhole hazard in a preliminary way, to be used in analyses at wide scale, and, eventually, followed by detailed and advanced studies at the local scale.

Based on this newly-developed version of the abaci, a data-driven approach was employed to compare and discuss the results obtained from the direct application of the abaci. The selected method, proposed by Giustolisi & Savic (2006), and known as 'Evolutionary Polynomial Regression', is based on the paradigm of genetic programming and returns simple functional relationships, namely polynomials of elementary functions, among the considered physical parameters. In particular, it generates a Pareto front of expressions that considers simplicity and accuracy. This allows the results of the data modelling approach to be interpreted, thereby maintaining focus on the physics of the phenomenon under investigation, as outlined by Fazio et al. (2024). The results will also show how these machine learning techniques can be used to provide mathematical formulations that can be easily used in the field by experts involved in assessing the stability of underground cavities.

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3D limit equilibrium analyses for landslide susceptibility analyses at the urban area scale

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Keywords: urban scale landslide susceptibility, slope stability, 3D limit equilibrium method.

As detailed in the 2021 Report on Hydrogeological Instability in Italy (Trigila et al., 2021), a significant proportion of Italian municipalities are vulnerable to natural hazards such as landslides, floods and coastal erosion. In particular, the region of Puglia in south-east Italy, and in particular the north-western sector of the Daunia Apennines, faces various geohydrological threats, with landslides being a prominent concern. This widespread risk highlights the need for the development of reliable quantitative methods for the assessment of landslide hazard at different scales, in order to allow the establishment of effective land use planning and risk mitigation strategies.

This study presents a physically based method for assessing landslide susceptibility at the urban area scale, taking into account both shallow and deep instability processes that affect almost all urban areas in the Daunia Apennines. The approach was tested in the municipality of Carlantino (FG), where geological and geomorphological maps, together with soil physical and mechanical data, were used to construct a comprehensive three-dimensional geotechnical model. This model, covering an area of 2.5 km², includes both the urban area of Carlantino and the surrounding slopes.

A subsequent three-dimensional limit equilibrium analysis considered equilibrium conditions in both slip and transverse directions, leading to the production of a map showing safety factors for the area. By analysing three different scenarios based on different assumed groundwater table depths, the study identified zones of increased landslide risk, characterised by lower safety factors.

The results, validated by comparisons with field and remote sensing data, demonstrate the effectiveness of this methodology in supporting landslide hazard assessments. This technique not only facilitates immediate and informed land use decisions, but is also adaptable to similar geological settings, increasing its applicability to broader regional planning.

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Comparative soil-to-plant fractionation of Rare Earth Elements in chlorophyll-deficient wheat mutants

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Keywords: REEs, soil to plant, ICP-MS.

The concentrations of Rare Earth Elements (REEs) in soils reflect those of the geological substrate of origin, and their bioavailability depends on soil pH, organic matter and weathering conditions, as well as on relatively low mobility of REEs as compared to other elements. Although some beneficial effects of REEs have been reported in plants, the REEs do not play any known specific role (Gonçalves Egler et al., 2022). Accordingly, plants do not have specific root absorption systems for lanthanides, which are absorbed approximately proportional to their concentration in the soil, likely using calcium channels (Tao et al., 2022). With the exception of Eu, for which plants tend to show a low affinity, it is generally assumed that the different REEs do not undergo element-specific fractionations from soil to leaves, but all merely decrease in concentration. Consequently, the relative proportion of REEs in leaves is expected to be almost the same as in the soil, i.e., the leaf/soil concentration ratio should be very similar for each REE. In this work, the REEs concentrations have been analysed in a soil parcel of the Botanical Garden of Ferrara and compared with that in leaves of a minipanel of four bread and four durum wheat lines, each comprising the wild-type cultivar and three chlorophyll-deficient mutants (Colpo et al., 2023). The mutation affects with variable severity the absorption of Mg, which is promoted in the mutants, the element being required for the chlorophyll synthesis. Analysis was conducted by inductively-coupled triple-quadrupole plasma-mass spectrometry (QQQ-ICP-MS) with special reference to REEs. As expected, it was found that in the soil samples the lanthanides with even atomic numbers were more represented than the adjacent odd atomic numbers, and the overall concentrations decreased according to increasing atomic numbers. In wild-type leaves, the same general trends were also found, but with two noticeable anomalies: selective absorption of Eu and selective exclusion of Tm. In general, the mutants tended to accumulate more REEs in relation to the severity of chlorophyll depletion. Concerning Eu, there were no consistent changes in the mutants, while the selective exclusion of Tm was instead completely lost. At the extreme, the most severe mutant absorbed REEs without any selectivity. These results indicate that the common assumption about the absence of element-specific fractionation of REEs during plant absorption and translocation cannot always be met, and therefore should be verified case by case.

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Gonçalves Egler S.et al. (2022) - Effects of rare earth elements (REE) on terrestrial organisms: current status and future directions. Ecotoxicol., 31(5), 689-699.

Tao Y. et al. (2022) - Distribution of rare earth elements (REEs) and their roles in plant growth: A review. Environ. Pollut., 298, 118540.

Giasone: a method to assess sustainability of georesources cultivation

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Keywords: sustainability, mining industry, research infrastructure.

European policies such as the Green Deal, Agenda 2030, and Next Generation EU mark the transition of European countries towards a new economy based on fostering growth according to sustainability, circularity, and energy transition criteria. In this context, the mining industry, which significantly alters the landscape, can be considered sustainable if the concept of transforming to enhance initial conditions is integrated. Since the modern technological industries require several raw materials that are difficult to recover through recycling, Mining activity plays a role in energy transition. A series of tools and certifications have been proposed for supporting the sustainability of industrial processes, for monitoring the social and economic impact of product life cycles and to guarantee consumers regarding greenwashing practices. The mining industry has also embraced this trend and create a Sustainable Development Goals systems and research projects for the enhancement of convenient and eco-friendly solutions (such as Smart Exploration, PACIFIC, and NEXT, etc.).

The problem of the sustainability of the mining industry focuses on the implementation of mining plans. The sustainability challenge of the mining industry focuses on the implementation of mining plans that which concern deposits covering a very large areal extension and are framed in specific Mining Activity Plans managed at regional level. These plans are designed based on urban planning criteria committed to restoration, change of land use, and preservation of the landscape context. However, if planning is aligned with the directives of the Green Deal, which introduces the concept of "acting to improve," the extractive activity plan must be able to assess the correct balance between transforming the territory for national or international economic purposes, within the framework of actual interactions with the industrial production fabric, the pre-operational level regarding environmental, social, and economic degradation of the territory. Giasone is a multiparametric method integrated within a GIS environment with which it is possible, using overlay mapping systems, to propose a series of scenarios to asses the sustainability degree of a project as indicated by the Green Deal directives. It was born as an ideal practical application within the GEOSCIENCES IR research infrastructure. The evaluation is based on a quantitative analysis of the geological, naturalistic, and environmental characteristics of the territory, determining the "naturalness" status of places. Based on this premise, territorial planning will be designed, at the scale of the Extractive Activity Plan, to mitigate degradation and achieve improvement in the context of the broader area, in terms of environmental recovery and/or socio-economic conditions. The use of the GIS system as a multidisciplinary analysis tool, based on geographical and socio-economic data, allows for a dynamic approach in identifying the intricate relationships of selected themes, modeling the territorial reality with the aim of proposing multiple scenarios to evaluate, distribute, and evenly mitigate the benefits and negative impacts on the entire territory. The "sustainability" index obtained by applying the Giasone method will utilize the following data categories, the initials of which form the acronym of the name: G (geology, geography, hydraulics, hydrogeology...), I (mining industry data), SO (socio-demographic data), N (Nature, environment, agricultural and forestry resources), E (economic data). For each territorial segment derived from the comparison of indicators, a "sustainability" index - the GIASONE index - is calculated by summing the indices related to each indicator, multiplied by the weights associated with their respective categories.

Shallow subsurface stratigraphy of the Mirandola Area (central Po Plain) reconstructed through combined sedimentological and geotechnical analysis

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Keywords: subsurface stratigraphy, quaternary, geotechnical analysis.

Reconstructing the geometry of shallowly buried late Quaternary alluvial successions can be carried out through the integration of facies analysis and geotechnical investigations, including drill cores, piezocone penetration tests (CPTU) and groundwater wells. Under the realization of CARG Sheet 184, we present a high-resolution reconstruction of the Middle Pleistocene to Holocene subsurface stratigraphy of the Mirandola Area (central Po Plain, Italy). Based on the sedimentological analysis of 16 new continuous cores, interpretation of 100 new piezocone penetration tests (CPTU), and stratigraphic correlation of 16313 available data, we demonstrate that CPTU tests, a tool that is commonly used in engineering geology, following calibration with core data may play a key role in subsurface stratigraphic analysis, as they can provide crucial information about the sedimentary facies. Furthermore, CPTU tests enable the identification of prominent stratigraphic markers in the geological record, such as peat layers and paleosols; these latter represent key markers of basin-wide extent that are typically neglected in conventional stratigraphic descriptions. Using eight stratigraphic cross-sections (four with N-S orientation and four running W-E), we identified a series of laterally extensive, fluvial channel-belt sand-bodies and performed high-resolution correlations with their genetically related paleosols. From proximal to distal locations, the Quaternary succession was divided in two distinct portions: i) a mud-dominated sector, close to the Apennines foothills, characterized by floodplain deposits, with laterally continuous paleosols and ribbon-shaped sand bodies; ii) a sand-dominated part, beneath and south of the modern Po River, with thick, vertically amalgamated channel belts that can be mapped individually. In this study, we point out how the combination of multiple data sources into stratigraphic analysis enhances the reliability and effectiveness of subsurface mapping efforts.

Multiparameter markers of territoriality: geochemical-isotopic and fluorometric analysis for asparagus characterization

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Keywords: isotope, soil, geochemistry.

The coastal environment of the Eastern area of the Emilia-Romagna Region is characterized by sandy soils, typically dry and exposed to salinization phenomena. These challenging conditions, usually critical for plant life, are worsening due to climate change, making it a priority to strengthen territorial resilience by characterizing and enhancing local crops that ensure a better response to saline and drought stress. The "Asparagus of Altedo PGI" demonstrates remarkable adaptability to the local soils making it a cornerstone product of this region, important for both economic valorization and territorial uniqueness and heritage. Sandy-based terrains offer ideal conditions for the emergence of asparagus turions; however, notable variations spanning from sandy-clayey loam soils to lean sandy soils delineate a gradient from inland to coast.

By conducting the multi-parametric analyses of the soil-plant system, we unveil the intrinsic connection between agricultural products and their native terroir. Leveraging geochemical-isotopic techniques alongside advanced plant phenotyping methods it is possible to discern opportunities to detect potential asparagus diversification driven by soil and environmental characteristics.

Soil samples were subjected to XRF analysis for major elements; soil and plant samples underwent ICP-MS-QQQ compositional analysis down to ultra-trace elements and EA-IRMS analysis (Marrocchino et al., 2023). The stable isotopes of light elements present in crops, such as carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), offer a unique form of 'isotopic signature' reflective of both the geochemical conditions of the soil (D'Archivio et al., 2014) and the metabolic specificity of the plants, including processes such as photosynthesis and nitrogen assimilation. PCA analysis revealed a remarkable differentiation of soils based on geochemical factors achieving resolution even at scales of just a few tens of kilometres. Notably, the abundance of Na2O effectively delineated the coastal fields from the inland ones, while soil samples from the close-to-town Malborghetto field exhibited distinctiveness through elevated concentrations of specific heavy metals (Cr, Ni, Pb), setting them apart from their counterparts. In addition, the turions were subjected to fluorometric analysis by fast chlorophyll *a* fluorescence induction (OJIP) (Ferroni et al., 2022), a non-destructive near-instantaneous method for physiological plant assessment. An interesting correlation emerged between soil diversity and chlorophyll fluorometric parameters. Despite the uniformly excellent photosynthetic functionality of the plants observed across all fields, it was possible to distinguish the asparagus samples based on their geographical origin.

Work is still in progress to achieve a comprehensive understanding of the seamless continuity between soil and plant dynamics in correlation with the environmental attributes of the surveyed fields.

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Model calibration and validation of carbon dioxide dispersion in the Atmospheric Surface Layer using data from La Solfatara crater (Campi Flegrei, Italy)

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Keywords: eddy diffusion coefficient, volcanic gas dispersion, numerical modelling.

The development of efficient methods to monitor gas concentrations in volcanic areas and to evaluate the related hazard is pivotal for developing strategies for risk mitigation. Numerical models are commonly used nowadays together with gas concentration measurements in order to quantify local emission sources. However, large uncertainties can derive from approximations associated with the physics and formulation used to reproduce the natural phenomena. In this study, we present the validation of a passive gas transport atmospheric model using local CO_2 concentration and wind measurements acquired at La Solfatara crater (Campi Flegrei Italy), during an ad hoc campaign from 4 to 10 May 2023. We simulated gas dispersion using the DIGAS v.2.5.1 model and calibrated it against the observations. Our results indicate that in order to avoid systematic overestimations of the gas concentrations during stable atmospheric conditions, a minimum value of the eddy diffusivity coefficient has to be set at 1.5 m2 s-1. Such a correction drastically improved the agreement between model results and observations. The performance of the corrected model allows us to use it in an integrated way with the periodic measurements in order to retrieve the gas source conditions.

Eroding edges: exploring the tectonic forcing on submarine canyon evolution

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Keywords: submarine landscape evolution, machine learning in geoscience, coastal hazards.

High rates of tectonic driven differential vertical movements along coastal areas, act as both time-independent predisposing conditions and time-dependent preparatory factors for submarine gravitational processes, leading to the retreat of submarine canyon heads. This retrogressive erosion is a significant driver of submarine landscape evolution in outer shelf and slope areas and may represent the source of major coastal natural hazards due to its tsunamigenic potential and the associated risk of coastal erosion and subsidence. Although the link between the retrogressive erosion of canyon heads and active tectonics has been explored through individual case studies, a comprehensive study addressing a statistically significant number of cases has yet to be conducted. This research aims to fill this knowledge gap by employing a machine learning approach that utilizes clustering and regression analyses to investigate correlations between active deformation and the retreat rates of canyon heads, thereby enhancing our understanding of active crustal deformation as a non-climatic driver of such offshore natural ground instabilities.

For this purpose, we have developed a new dataset comprising over 2700 canyon heads along almost the entire Italian offshore using the freely available MaGIC bathymetric data (https://github.com/pcm-dpc/MaGIC, Chiocci et al., 2009). This dataset is enriched and compared with literature-derived information on uplift rates, instrumental seismicity, bathymetry, coastline distance, and a newly computed GNSS velocity field across the peninsula (DISS Working Group, 2021; Ferranti et al., 2006; Rovida et al., 2021). The expected outcomes of this study will improve our understanding of the connection between the landward migration of canyon heads and active tectonic deformation at different spatial scales. A primary goal is to determine the numerical relationship between the parameters defining these phenomena.

Based on this dataset, we aim to develop the first Italian canyon retreat hazard map for the immediate offshore regions. By elucidating the impact of differential vertical movements on the retrogressive erosion of submarine canyon heads, this study will provide essential information for risk management strategies and action plans, aiding in mitigating potential natural hazards related to tsunamis and rapid coastal subsidence that could affect coastal infrastructures.

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Thermo-rheological modelling of the Yellowstone caldera: insights into volcanic processes

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Keywords: Yellowstone Volcanic Complex (YVC), 3D thermo-rheological model, magnetic Curie depth.

The Yellowstone Volcanic Complex (YVC) in Yellowstone National Park (Wyoming, USA) attracts intense geological interest, as it ranks as one of the largest active continental silicic volcanic fields worldwide. Despite extensive research on the region's high heat flow and abundant geothermal features, a detailed quantitative analysis of the brittle-ductile transition has been lacking. Such analysis is essential for investigating the volcanic plumbing system, advancing geothermal exploration, and improving the assessment of volcanic hazards. This study aims to deepen understanding of the subsurface geological and geophysical properties of the Yellowstone area, with a specific focus on obtaining an optimized lithospheric thermal profile, which is fundamental for reliable rheology and lithospheric strength analysis. Initially, extensive mapping of the Curie isothermal surface depth was performed using high-resolution aeromagnetic data and innovative spectral analysis techniques. This mapping revealed a notably shallow Curie isothermal surface, ranging from 1 km to 5 km deep beneath the YVC. Subsequently, a three-dimensional thermal model of the Yellowstone lithosphere was developed using COMSOL Multiphysics software to simulate heat transfer in a purely conductive regime. A comprehensive rheological model was also conducted to delineate the distribution of the brittle-ductile transition within the analyzed lithospheric volume. The results highlight a brittle region in good agreement with the distribution of earthquake epicenters, and reveal a non-homogeneous structure in ductile zones, supporting the "sandwich hypothesis" for the local lithospheric structure. We conclude that our approach contributes to a better understanding of the YVC subsurface dynamics, providing insights into its complex geodynamic processes and offering methodologies applicable to similar studies in volcanic and geothermally active regions with large calderas.

3D stratigraphic architecture of the late Quaternary Pescara paleovalley and seismic site characterization

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Keywords: late quaternary paleovalley, 3d modelling, site characterization.

Late Quaternary Paleovalley systems have been extensively documented worldwide in the geological record. These shallow subsurface incisions were formed in response to the post MIS 3 sea-level fall and subsequently filled with new sediment during the Last Glacial Maximum and post-glacial sea-level rise. Due to the sharp contrast between the soft valley fill and the over-consolidated substrate, these sediment bodies can amplify earthquake ground motions; however, the influence of buried geometries and stratigraphic architecture on seismic amplifications still needs to be investigated. In this study, we carried out the detail subsurface reconstruction and seismic characterization of the Pescara Paleovalley System, located in a highly urbanized area undergoing rapid infrastructure development. To reconstruct the 3D stratigraphic architecture, we built five cross-sections: four running transversal and one perpendicular to the main paleovalley axis. These cross-sections were built using 60 stratigraphic descriptions and one continuous core. The stratigraphic cross-sections highlight a prominent valley geometry; in the depocentral area, a 52 m-thick succession includes fluvial gravel, overlain by organic-rich clay, 30 m thick, capped by 9 m of fluvial sand. Using 85 microtremor-based horizontal to vertical spectral ratio curves (mHVSR), we produced a resonance frequency map, highlighting low resonance frequencies (0.9 Hz) in the depocentral area and high resonance frequencies (4 Hz) close to the valley margin. Following a calibration of 20 mHVSR curves with the stratigraphy, we built a Frequency-Depth model and obtained a 3D paleovalley map. To perform a reliable 2D ground motion analysis, it is crucial to build an accurate subsurface model, however the complexity of facies architecture poses a challenge. To this purpose, we derived five simplified cross-sections and according to geometric and geophysical criteria we identified six seismic layers. Relying on six Down Hole test we assigned a Vs value to each layer, building a robust subsurface model that reflects the stratigraphic complexity. In addition, highlighting the differences between the high-resolution stratigraphic cross-section and the simplified reconstruction we point out the possible sources of error. In this work, we show that detailed information about facies architecture, sediment body geometries and resonance frequencies can be used for ground motion analysis.

Analysis of possible failure mechanisms of a coastal rocky cliff by means of a three-dimensional discrete element model

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Keywords: discrete element model, failure mechanisms, 3DEC.

The analysis of the possible instability mechanisms of a rock cliff characterized by a large number of discontinuity sets, which assigns a marked anisotropic behavior to the rock mass, turns out to be a fairly complex operation, which can be pursued only through the use of numerical calculation codes. In recent years, the availability of increasingly powerful computational tools has favored the application of such codes to the analysis of complex case studies, which is justified since they allow to define failure mechanisms of the rock mass that are more reliable than the traditional two-dimensional softwares. This is certainly the case of the distinct element method, which has experienced a new acceleration in the application to the study of fractured rock masses after the introduction of the three-dimensional version, which is more accurate and reliable in simulating the real discontinuous rock mass behaviour. This contribution proposes a three-dimensional application of the discrete element method, which has been carried out with 3DEC software (Itasca Consulting Group, 2023), to the study of the failure susceptibility of the fractured limestone coastal cliff located at the rear of the Vignanotica beach, in the territory of Vieste (Southern Italy). The numerical study was aimed at identifying the possible instability mechanisms that can be generated in the cliff as a result of the evolution of the factors controlling the cliff stability. Therefore, the contribution presents the procedure adopted for the construction of the three-dimensional geometric model within the software environment starting from the point cloud obtained from laser scanner survey, the choice of the main computational assumptions adopted and the numerical results that have been obtained. In particular, the contribution discusses the effects of the choice of the value of the joint shear strength angle on the stability conditions and the associated failure mechanisms of the cliff.

Itasca Consulting Group, Inc. (2023) - 3DEC — Three-Dimensional Distinct Element Code, Ver. 7.0. Minneapolis: Itasca.

A new insight into the dynamics of the Pisciarelli hydrothermal system (Campi Flegrei, Southern Italy) based on the integration of geophysical and numerical modelling

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Keywords: thermo-fluid dynamic numerical modelling, Pisciarelli Fumarole Field, Phlegraean volcanism.

The Pisciarelli fumarole field (Campi Flegrei caldera, Italy) has exhibited progressive activation since 2011. This area, located along the eastern outer flank of the Solfatara volcano, has become the main degassing area of the caldera, with a main fumarole currently releasing more than 600 tons/day of CO_2 (Tamburello et al., 2019). Sudden morphological changes, the opening of new fumaroles, variations in the water level of the local spring, and mud emission have also characterized the evolution of Pisciarelli. These phenomena have been accompanied by a significant increase in seismicity, which currently represents a significant fraction of the entire caldera.

Here, we attempt to develop a thermo-fluid dynamic numerical modelling applied to the Pisciarelli fumarole field in order to understand the main processes driving the increasing activity and the role of the main geological features present in the area. Specifically, our work aims to provide a more accurate and comprehensive understanding of the hydrothermal processes occurring in the shallow feeding system of the Pisciarelli area, following an integrated approach based on multi-method geophysical prospecting (i.e., electrical resistivity and time-domain induced polarization tomographies, and self-potential mapping) and numerical modelling to achieve this goal.

Previous 3D resistivity and chargeability models (Isaia et al., 2021; Troiano et al., 2021) identified a highly fractured area that acts as a conduit for shallow hydrothermal fluids to generate a water/gas plume covered by a clay-cap formation. At the same time, a structural survey and a self-potential mapping identified the main fault systems present in the area. Based on these geophysical evidences, a conceptual model of Pisciarelli has been developed and imposed during the numerical simulation of fluid flow dynamics in the fracture system, also integrated with recent and accurate volcanological and geochemical analyses available in the literature.

The results of the numerical modelling, performed using the Tough2 numerical code, have confirmed the role of the main fault system, which acts as a permeability barrier parting the hydrothermal circulation into two separate sectors. A clear characterization of the state of the fluids rising into the permeable conduit was also obtained in terms of water and CO_2 pressures, as well as temperature and saturation of the gaseous fraction. This reconstruction of the present state of Pisciarelli gives an original insight into the main and still unresolved questions about this fumarolic field, in particular concerning the compatibility of its physical conditions with the possibility of sudden explosive events of a hydrothermal nature.

Isaia R. et al. (2021) - Volcano-tectonic setting of the Pisciarelli fumarole field, Campi Flegrei caldera, southern Italy: Insights into fluid circulation patterns and hazard scenarios. Tectonics, 40, https://doi.org/10.1029/2020TC006227.

Tamburello G. et al. (2019) - Escalating CO_2 degassing at the Pisciarelli fumarolic system, and implications for the ongoing Campi Flegrei unrest. J. Volcanol. Geotherm. Res., 384, 151-157, https://doi.org/10.1016/j.jvolgeores.2019.07.005.

Troiano A. et al. (2021) - The Pisciarelli main fumarole mechanisms reconstructed by electrical resistivity and induced polarization imaging. Sci. Rep., 11, 18639, https://doi.org/10.1038/s41598-021-97413-1.

Integrated approach for Arsenic contamination assessment in the entire Padana Plain (Italy)

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Keywords: geostatistics, geochemistry, aquifer.

A comprehensive dataset from over 3600 wells is created by integrating, correcting, and standardizing groundwater data collected across the Padana Plain (Lombardy, Piedmont, Emilia-Romagna, Veneto, and Friuli-Venezia Giulia regions) by various Environmental Protection Agencies in 2018. The dataset is initially used to classify groundwater of unconfined and confined aquifers into hydrochemical facies and assess the main geochemical processes, providing a complete overview of the natural and anthropic processes characterizing the entire Po plain. Then, the database is used to spatially simulate the depth-averaged As concentration of the wide and complex aquifer systems. Utilizing in-depth geostatistical analysis and Monte Carlo simulations, the research aims to elucidate the variability of As concentrations and provide a probabilistic perspective on contamination, quantifying the probability of local concentrations exceeding national regulatory limits. Results highlight the most probable As contaminated zones in confined aquifers in the proximity of the mountainous areas and in the phreatic aquifers of the lowland territories. By integrating hydrogeological, geological, and geochemical information, the study identifies the sources and mechanisms of As release, with reductive dissolution of Fe and Mn oxyhydroxides and organic matter mineralization identified as major drivers. Vulnerable areas, such as the Po, Adige, and Brenta river basins, are identified, along with localized high As values in the Friuli-Venezia-Giulia region. The study underscores the importance of monitoring and management strategies to mitigate contamination in groundwater resources, offering insights to aid local and national authorities in sustainable resource management.

Past and recent evolution of the submerged beach, shoreline, and dune-beach morphology as baseline to monitor a nature-based reef solution for coastal protection and marine biodiversity enhancement

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Keywords: nature-based solutions, coastal dynamics.

In a context of sea level rise and the intensification of extreme wind events and storm surges, low coastal areas and sandy beaches experience intensified damages and erosion processes. Engineered hard solutions are often necessary to protect inhabitants and ports; however, a soft approach is desirable for natural coastal systems and beaches. The LIFE NatuReef project implements a solution based on the exploitation of the work of species that can be considered ecosystem engineers, as they are able to build reefs on sand beds along the coast, thereby protecting the shore and mitigating erosion. The construction of a limestone artificial reef near the Bevano outlet (Ravenna, Italy) will serve as the substrate for the development of populations of oysters (*Ostrea edulis*) and sabellariid worms (*Sabellaria spinulosa*), which are native species capable of building three-dimensional structures atop and around the original artificial reef. These structures retain sediments and dissipate wave energy, thereby counteracting coastal erosion.

In this work, we present the activities and preliminary results of continuous monitoring conducted on the submerged beach and the dune-beach system. The activities aim to establish a baseline that, through a reconstruction of past and recent morphological evolution, defines the current state of the system. This provides qualitative and quantitative elements for assessing fundamental morphological features as well as for describing habitats of key importance as for example embryo-dune, foredune, and back-dune habitats. Integrating Global Navigation Satellite Systems (GNSS) observations and digital photogrammetry obtained from UAVs (Unmanned Aerial Vehicles), we created a detailed model of the dune-beach system. This information was corroborated with the distribution of vegetation species. The morphology of the submerged beach was retrieved using OpenSWAP vehicles equipped with multibeam, sub-bottom profiler, side-scan sonar and single-beam echosounder. The combination of results obtained from different methodologies provided a comprehensive picture of the morphology of the entire submerged-emerged beach and dune system at extremely high spatial resolution.

Continuous monitoring of the system state through periodic surveys will yield quantitative results on the variations caused by the constructed reef in front of the beach, including detailed analyses of shoreline dynamics resulting from the surveys.

Geophysical and geochemical data integration for agricultural soil monitoring and prevention of the effects of salinity, organic matter, and climate change in the Province of Ferrara (Northern Italy)

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Keywords: soil, geophysics and geochemistry, salinity.

Agricultural soil monitoring plays a crucial role in ensuring sustainable agricultural practices and environmental conservation, particularly in areas like the Ferrara plain in the Po Valley, known for its rich agricultural potential. Nowadays, this area is threatened by climate change effects, including frequent and prolonged droughts, which are responsible for the decrease of field yields and the increase of greenhouse emissions from soil. Unfortunately, traditional soil monitoring techniques often fall short in providing comprehensive insights into soil properties and dynamics, hampering farmers to develop more efficient and sustainable agricultural practices to preserve soil from degradation. Therefore, in recent years, there has been a growing interest in integrating geophysical methods with geochemical analyses to enhance soil characterization and monitoring at field-scale (van der Kruk et al., 2018; Ratshiedana et al., 2023). In line with this, we integrated both geophysical and geochemical data to characterize the soil properties in particular agricultural areas of Mezzano Valley (Ferrara province), a recently reclaimed lowland with peaty soils located near the Adriatic Sea coasts and therefore affected by salinity issue. For this study, geoelectrical and electromagnetic methods, such as electrical resistivity tomography (ERT), electromagnetic induction (EMI) and ground-penetrating radar (GPR) offered non-invasive means for in-situ investigation of soil properties, such as moisture content, porosity and soil texture or structure, to delineate soil horizons up to 200 cm in depth. Meanwhile, in laboratory, geochemical analyses of soil collected at different horizons (0-15 cm; 15-30 cm; ...) provided valuable information on variations in salinity, pH, and major, and trace element compositions, including concentration of contaminants, along depth. In addition, for each horizon were measured total (TC) and organic carbon (OC) contents and relative isotopic ratios to reconstruct the soil organic matter dynamics. This synergic approach furnished insights into the extent of organic matter depletion, saline contamination, fertility levels, and the degree of overexploitation resulting from unsustainable agricultural practices in the investigated area. Therefore, the correlation of geophysical 2D and 3D soil mapping and monitoring over time with geochemical signatures represents a valid method to infer spatial variations in soil properties and identify critical areas for targeted interventions, including precision agriculture practices or remediations efforts in contaminated sites. This is useful for better-informed decision-making in agricultural management practices, in areas facing the effects of climate change, such as droughts which leads to salinization issues, soil organic matter degradation and decrease of fertility.

Ratshiedana P. E. et al. (2023) - Determination of Soil Electrical Conductivity and Moisture on Different Soil Layers Using Electromagnetic Techniques in Irrigated Arid Environments in South Africa. Water, 15, 1911, https://doi.org/10.3390/w15101911.

Van der Kruk J. et al. (2018) - Calibration, inversion and applications of multi-configuration EMI for agricultural top- and subsoil characterization. SEG Technical Program Expanded Abstracts 2018, 2546-50, Society of Exploration Geophysicists, https://library.seg.org/doi/10.1190/segam2018-2965257.1.

Fluid migration along fault and fracture systems in the Sicily straits: high-resolution mapping reveals connections

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Keywords: pockmarks, seismic attributes, machine learning.

Pockmark are seafloor depressions which offer valuable insights into subsurface fluid migration and geological processes, representing a significant forcing on the offshore landscape evolution. This study adopt a novel approach based on the integration of 2D seismic reflection profiles and multibeam bathymetric data in order to investigate the pockmark distribution on submerged area (i.e. Adventura Bank), closed to South-Western Sicily.

The primary goal is to discriminate actively degassing pockmarks and to examine their relationship with geological structures favourably oriented with respect to the current crustal stress field.

Secondly, employing attribute assisted machine learning technique to identify subsurface fluid migration pathways from a grid of high-resolution seismic reflection profiles (Singh et al., 2016; Srivastava, 2018; Kumar et al., 2021). Subsequently we implemented a workflow for the extraction of pockmarks from bathymetric datasets using morphometric wavelength analysis.

Finally, we explored the correlation between the extracted datasets, a newly produced structural map, geodetic and seismological datasets. This investigation aims to assess the potential of actively degassing pockmarks as proxies for blind and tectonically active faults.

Kumar P. C. et al. (2021) - Submarine canyon systems focusing sub-surface fluid in the Canterbury Basin, South Island, New Zealand. Sci. Rep., 11(1), 16990, https://doi.org/10.1038/s41598-021-96574-3.

Mandal A. & Srivastava E. (2018) - Enhanced structural interpretation from 3D seismic data using hybrid attributes: New insights into fault visualization and displacement in Cretaceous formations of the Scotian Basin, offshore Nova Scotia. Mar. Petrol. Geol., 89, 464-478, https://doi.org/10.1016/j.marpetgeo.2017.10.013.

Singh D. et al. (2016) - Interpretation of gas chimney from seismic data using artificial neural network: A study from Maari 3D prospect in the Taranaki basin, New Zealand. J. Nat. Gas Sci. Eng., 36, 339–357, https://doi.org/10.1016/j.jngse.2016.10.039.

Modeling the priming mechanism of phreatic and geothermal eruptions: physical model and preliminary integration results

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Keywords: phreatic eruptions, hydrothermal eruptions, numerical modeling.

Phreatic and hydrothermal eruptions are physical processes consisting in an explosive expansion of groundwater, due to the input of hot fluids and heat of magmatic origin for the former, or without the direct input of magmatic origin for the latter (Montanaro et al., 2022). To the present date, the research for precursory signals for these eruptions is still in progress, and no phreatic or hydrothermal eruption has been successfully forecasted. This is in part due to the fact that we lack a clear and accepted quantitative model for these eruptions.

Here we propose a physical model for phreatic and hydrothermal eruptions composed of a set of differential equations for the conservation of the (total and chemical component) mass, momentum and energy based on the multiphase mixture theory. The goal of such a model is to understand what are the conditions that lead the system into building up an overpressure that would eventually prime a phreatic or hydrothermal eruption.

Due to the complexity of the model, numerical integration is a key tool for solving the problem. A numerical model built with the multiphysics engine ALYA, developed in Barcelona Supercomputing Center, is currently under development and we will show some preliminary results.

The development of such a model is a key step in understanding phreatic and hydrothermal eruptions and will eventually help, in future, forecasting these events.

Montanaro C. et al. (2022) - Phreatic and Hydrothermal Eruptions: From Overlooked to Looking Over. B. Volcanol., 84, 64, https://doi.org/10.1007/s00445-022-01571-7.

A multidisciplinary approach used for winemaking process investigation: the Cantina di Solopaca (Benevento, Italy) case study

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Keywords: geochemistry, mineralogy, winemaking.

In recent years, wine has experienced exponential growth, thanks to the increasing interest by consumers, in the world market leading the scientific community to deepen various aspects related to the wine production process. Some specific geological concerns emerged as central topics into this research once the importance of vineyard soils was assessed. Actually, soils, further than influencing the growth of the vine and grapes, can provide completely different organoleptic characteristics to the wine depending on the type of soil on which the vineyards are established. In this regard, a geochemical fingerprint that reflects the geological features of the vineyard soils and their bedrock is the $^{87}Sr/^{86}Sr$ isotope ratio. This operational approach aims at finding a direct link between the final product and the territory, thus including also wine in the concept of food traceability and, at the same time, limit possible fraud and adulteration. In this work, some vineyards of the Cantina di Solopaca winery were investigated by means of a multidisciplinary approach in order to understand the relationships among geology, soil composition and wine quality. A purely geochemical approach, accounting for the determination of the $^{87}Sr/^{86}Sr$ isotope ratio on different matrices (soil, grapes, microvinifications and wine samples), was flanked by a mineralogical characterization of the soils which included thermal analysis, X-ray powder diffraction (XRPD), and Fourier-transform infrared spectroscopy (FT-IR). A joint work between various experts in different fields such as geology, soil science, and winemaking, was crucial in enhancing the results of the present research shedding a new light necessary for a comprehensive understanding of how geology, viticulture, and wine-making techniques all interact. This collaborative method not only provided valuable scientific novelties but also led to the development of creative solutions in the wine industry.

Holocene sedimentary and geomorphological evolution of the Po Plain between Po, Secchia and Panaro rivers, reconstructed through a morpho-stratigraphic approach

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Keywords: fluvial mapping, alluvial plain geomorphology, Po Plain.

The Po Plain is the widest and most populated alluvial plain in Italy. The Po River, flowing from west to east, receives several tributaries from the Southern Alps and from the Apennines. The Po Plain geomorphology reflects the evolution of these rivers, including episodes of flooding, crevasses and avulsions. In this study, part of the Geological Mapping of Italy at the scale of 1:50.000 (CARG sheet 184), we reconstructed the evolution of the fluvial network between Po, Secchia and Panaro rivers in the last 4ka**.** Within a Geographic Information System (GIS) environment, different types of data and methods were integrated to characterize morpho-stratigraphic features associated to fluvial landforms. Ancient paleochannels were mapped using texture and reflectance features in satellite imagery and orthorectified aerial photographs, whereas digital elevation models were used to identify fluvial ridges. Fluvial-channel deposits were mapped in the subsurface using core data and cone penetration tests. Archeological data and radiocarbon dating were used to constrain chronologically the mapped fluvial landforms. The integration of surface and subsurface data led to the identification of a set of morpho-stratigraphic units reflecting the activity of Po, Secchia, Panaro and Reno rivers. Following CARG nomenclature, we mapped two stratigraphic units: AES8, including Roman and pre-Roman Holocene deposits and AES8a, including post-Roman deposits. In AES8, we also identified: (i) two meandering systems of the Po River that were active during the Bronze and Iron ages; (ii) a fan-shaped system which activated during the late Iron Age in the upper Po delta plain, and (iii) a WE-flowing Apennine paleochannel that was active during the Roman age. AES8a includes (i) two inner delta systems developed in the south during the Early Middle Age from the Secchia and Reno rivers, (ii) a Late Middle-Age Secchia river system to the northwest, and (iii) the Panaro riverbed, active since the Renaissance. This study portrayed a highly dynamic fluvial network during the Holocene. The methodology used in this work, based on the integration of various data types, proved to be effective in mapping the evolution of rivers systems and is potentially applicable to other alluvial settings.

S30.

Women in Geosciences: a journey through the social changes from the past to present and future scenarios

CONVENERS & CHAIRPERSONS

Martina Zucchi (Università di Bari "Aldo Moro")

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The challenge to promote equal opportunities in the daily life at university: searching for best practices

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Keywords: equal opportunities.

Article 21 of the EU Charter of Fundamental Rights (https://fra.europa.eu/en/eu-charter) prohibits discrimination for any reason and specifically stresses that equality between women and men is a fundamental value of the European Union. Although the gender issue nowadays is present in the political debate much more than in the past, and this has produced significant progress in favor of women, the inequality in the division of labor between men and women remains evident. Social and organizational psychology research suggests that organizations – like universities – are mainly driven by masculine defaults, that is, "a form of bias in which characteristics and behaviors associated with the male gender role are valued, rewarded, or regarded as standard, normal, neutral, or necessary aspects of a given cultural context" (Cheryan & Markus, 2020). As a consequence, the chances to get a top-managerial position for women are fewer than for men, because organizational values, norms, practices, interaction styles, and beliefs, disadvantage women within organizational contexts.

Among their different responsibilities, the scholars at universities have a pivotal role in the development of the 'cultural elite' of a country, so they must be aware of the stereotypes that form the foundation of this problem and develop good practices to overcome them starting from the daily life in the classrooms as well as outside them .

The University d'Annunzio is increasingly active in this direction and within this framework the Department of Engineering and Geology (InGeo) established a formal working group on equal opportunities with the goals to: 1. picture the present situation of the department and the trend since its foundation in 2012; 2. reveal which gender stereotypes (if any) are present and how they can undermine women full participation to the Department life in its broader meaning and ultimately affect their career perspectives; 3. promote good practices to help everybody to consciously overcome gender-role beliefs, share an inclusive language and finally inclusive behaviors; 4. promote the organization of scientific events (e.g. workshops, special sessions or study days) which focus on the role of the women in the STEM (science, technology, engineering, maths) subjects.

Hence, moments of guided reflection (e.g., on gender belief, inclusive language and behavior, objectification) and social studies under a scientific supervision are going to be performed among the Academic and the Technical staff together with PhD students and fellows which form the Departmental population of STEM-educated people. Such a preliminary research project has the main objective to identify the cultural obstacles to the gender equality that hide behind the awareness of transgender value and respect.

Cheryan S. & Markus H.R. (2020) - Masculine defaults: Identifying and mitigating hidden cultural biases. Psychol. Rev., 127, 1022-1052, https://doi.org/10.1037/rev0000209.

Gender equality plan (GEP) of Earth Science Department in the framework of the Science Faculty and Sapienza University

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Keywords: women, science, future.

The Departmental Gender Equality Plan (GEP) Commission of the Earth Science Dep. of Sapienza was born in February 2024, coordinating with similar commissions established in other departments belonging to the Faculty of Mathematical, Physical, and Natural Sciences. The objective of this commission is to promote actions aimed at balancing the so-called gender gap in the university Community and, in our department. The Gender Equality Plan includes several different aspects that the commission will explore, starting with the culture of respect in the language and behaviour, to the exploration of mechanisms and reason that control the anomalous distribution of women in scientific academic careers.

Several initiatives have been undertaken during 2023 and 2024 years, to support the described actions. Sapienza is the biggest University in Europe and represents a large community where the gender gap is yearly monitored from 2016. The most recent report of 2022 (https://www.uniroma1.it/sites/default/files/field_file_allegati/bilancio_di_genere_2022.pdf) indicates the majority of the female component for students and technical-administrative staff, and a persistence of the majority of the male component in the academic staff. This obviously results in fewer opportunities for women to attain prestigious and responsible positions which consequently limit their economic status.

But gender gap and discrimination include even more personal involvement of girls and women, passing through language, personal behaviour, gender-based violence, and sexual harassment. Even for these aspects, it was important to be aware of the problem and to create a place where welcome the victims. For this reason, the Science Faculty hosts the Safe Zone project to prevent gender-based violence in all faculties of Sapienza. It is based on targeted training directed at personnel and students on topics related to gender, sexual orientations, gender identities, factors that contribute to reducing discrimination and increasing the sense of safety and well-being.

More complex, (and in some way connected with the previous ones?) is the issue of gender balance in the top grades of academic carriers, which still shows big gaps and disparities in most of the faculties and departments. Our commission has wondered if this noticeable gap is perceived as such by the scientific community or if instead even the presence of a small number of women in leadership positions is already considered sufficient (for example, in Italy there are 61 public Universities and only 13 rectors are women, only the 15%).

Fossils, drawings and letters. Women's contribution to the development of early 19th century geosciences

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Keywords: women in geosciences, drawings, letters.

The early 19th century was a decisive moment in the definition and development of earth sciences. Traditionally, the narrative of this period has featured male scientists as protagonists; however, a more composite and varied picture is slowly emerging in which women, who in different ways and as they were able, participated in the development of geology and palaeontology. This was a particularly lively and dynamic period in Britain where, between the cliffs and the hinterland, a large group of women actively collaborated in scientific research and helped unravel the secrets of the Earth's past (Burek & Higgs, 2007). These were scholars who, neglected by scientific institutions and academies, were able to make their own contribution to the development of geosciences. Mary Anning (1799-1847), Charlotte Murchinson (1788-1869), Elizabeth Philpot (1779-1857) and Mary Buckland (1797-1857) were thus great protagonists of the early 19th century and, thanks to their activities, they succeeded in bringing their husbands closer to the nascent disciplines, they enabled the dissemination and genesis of theories that are still crucial today for understanding the evolution of the Earth, they produced illustrations of great scientific and historical value, they curated collections and they continued their husbands' studies even after their deaths (Emling, 2009). Their numerous letters not only reveal the relationships that united their husbands with other scientists, but also show us the relationships and collaborations they had with each other in the process of research. In particular, a female network of researchers and illustrators began to build up around the figure of Mary Anning who, amidst discouragement, fears and apprehensions, created a united and passionate group of scholars who were able to contribute in a relevant and fruitful way to the development of geology and palaeontology. Multifaceted and independent, the protagonists of this historical period made their voices heard. They were able to approach and infiltrate a predominantly male environment, and they were able to influence the evolution of earth sciences by working alongside and on a par with men. (Turner et al., 2010).

Burek C. V. & Higgs B. (2007) - The Role of Women in the History of Geology. Geological Society, 281, 1-8, https://doi.org/10.1144/SP281.1.

Emling S. (2009) - FOSSIL HUNTER: Dinosaurs, Evolution, and the Woman Whose Discoveries Changed the World. Palgrave Macmillan, 258 pp.

Turner S. et al. (2010) - Forgotten women in an extinct Saurian (man's) world. Geological Society, Special Publications, 343, 111-153, https://doi.org/10.1144/SP343.

The frontiers of the space and the sea: the records of Dr. Kathryn Sullivan

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Keywords: exploration, space, records.

Throughout her career, Dr Kathryn Sullivan has been a pathbreaker in both scientific exploration and space endeavours. Indeed, she is the only person to have walked in space and reached the deepest point in the ocean.

Born in 1951, Kathryn Sullivan received a degree in Earth Sciences from the University of California, Santa Cruz, in 1973, followed by a PhD in Geology from Dalhousie University (Halifax, Nova Scotia) in 1978 (https://www.nasa.gov/former-astronaut-kathryn-d-sullivan/). Her path as a pioneering figure began when she was selected by NASA in 1978 as one of the first six female astronauts in its history. In 1984, Sullivan achieved a historic milestone as the first American woman to conduct a spacewalk during the Space Shuttle Challenger mission. With three space shuttle missions accomplished, she has accumulated over 532 hours in space. In addition, Dr Sullivan was the first woman to wear the Shuttle-era spacesuit, a ready-to-wear suit, not custom-made, with interchangeable arms, legs, and torso units in different sizes (225-pound Extravehicular Mobility Unit) (https://airandspace.si.edu/).

Following her tenure at NASA, Sullivan assumed leadership roles, notably serving as the Under Secretary of Commerce for Oceans and Atmosphere and later as the Administrator of the National Oceanic and Atmospheric Administration (NOAA). In 2020, she made history once again by becoming the first woman to visit the Challenger Deep in the Mariana Trench, the deepest spot in the world's oceans (http://kathysullivanastronaut.com/).

Beyond her pioneering achievements in space and ocean exploration, Sullivan's contribution to the STEM fields has been profound, inspiring countless future scientists and astronauts. Her commitment to environmental awareness and conservation has further strengthened her impact, earning her recognitions and awards that go far beyond her achievements in space exploration.

Anna Fiori and the balance between teaching and research in the years between the Second World War

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Keywords: teaching, palaeontology, women.

Anna Fiori was born in Formigine (Modena) in 1902, she studied at the Bologna University and she earned a B.Sc. in Natural Sciences in 1927, with a top racking score, discussing a thesis in Entomology with professor Ghigi. Short after graduation she began to work as curator (formerly daily technician) in the geological and paleontological museum "Regio Museo Giovanni Capellini" under the guide of his director of the time, Professor Michele Gortani.

In 1932, she upgraded to the role of "technician", and from 1930-31 she replaced Gortani in teaching palaeontology. From 1935 she officially held the Palaeontology course at the Bologna University, without ever gaining the title of "Professor". She taught palaeontology, and especially vertebrate palaeontology until 1953, when she was moved to the teaching of physical geography, as the palaeontology course was reformed: vertebrate palaeontology was abandoned, in favour of micropalaeontology, more useful in the emerging oil and gas industry. Fiori was also one of the people responsible of the safeguard of the museum collections during the WW2 bombing, when most of the museum specimens were packed and moved in the cellars, and consequently moved back upstairs at the end of the conflict.

Little is known about this woman, one of the first to teach palaeontology in an Italian university, but of particular interest is the transcript of her "last lesson", a sort of scientific testament that underline the difficulties in following a career in research and conjugate it with the teaching at the university level, a matter that is still faced nowadays, to account her words: "on the teaching point of view I've reached discrete levels, on the scientific point of view, not; I have missed […]. When young I have done better, but gradually I have folded my wings, I have run instead of flying, then walked instead of running."

Here is thus presented a woman, and a scientist, who has devoted her life to the teaching of palaeontology and tried her best to inspire the minds of future scientists.

Engaging Women in Science: harnessing social media for STEM and Geoscience outreach

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Keywords: gender stereotypes, social media channels, gender statystics.

Gender stereotypes still influence women's access to scientific careers and recognition of their merits. These stereotypes are deeply ingrained in Italian society, often manifested through distinctions between culture and science, such geoscience, as difficult or uninteresting subjects for girls. Furthermore, societal expectations, even in a subtle way, perpetuate these stereotypes.

Despite these challenges, gender stereotypes can be overcome. Anyway, while there has been progress in women's participation in science, they remain underrepresented, particularly in leadership roles. Women should take an increasing more active role with an increased investment in research and education.

Geosciences offer opportunities to Increase the involvement of women because such research can bring diverse perspectives and approaches, enriching scientific efforts.

To encourage young women to pursue their passions in science, sharing attractive scientific content via social media can be one tool. To develop a communication plan whose objectives are encouraging young women to follow a scientific career, it is necessary to start from knowledge of what may interest them.

The National Institute of Geophysics and Volcanology manages a large number of social media channels. Among these, particularly those that convey scientific information are the channels managed by the three communication groups related to the three departments: Earthquakes, Volcanoes, and Environment. Thus, we have three Facebook pages, two Instagram pages, three institutional X/Twitter accounts, three YouTube channels, in addition to three blogs.

It is possible to obtain statistics regarding the gender and age of participants only for the Facebook, YouTube and Instagram pages. Therefore, our analysis will focus specifically on these social media platforms.

30 years of Women in Science in Italy through the lens of the Major Risks Commission

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Keywords: major risks commission, gender balance, civil protection.

In Italy, the National Commission for the forecasting and prevention of the Major Risks is a technical-scientific advisory body of the Civil Protection Department (Legislative Decree 1, 2018). Often referred to simply as the Major Risks Commission, it provides technical-scientific opinions on questions and topics posed by the Head of the Civil Protection Department in relation to the various types and potential risk situations, imminent or ongoing, or even proposals to update or improve assessment, forecasting and prevention skills with respect to civil protection risks. Its contributions are fundamental for implementing the strategies for forecasting and preventing civil protection risks and for the management, from a technical-scientific point of view, of emergencies (Dolce et al., 2020).

The long tradition of interaction between the Italian civil protection and the scientific community dates back to the 1976 Friuli earthquake, according to the intuition and vision of Giovanni Zamberletti, the founder of modern civil protection.

Steps to set up a Major Risks Commission were taken during the 1980s, but its formal establishment came with law no. 225, enacted in 1992 (Law 225, 1992). Since then, the Commission has operated until today, albeit with organization and internal composition that have varied over time.

The Commission has always been made up of high-level experts in various scientific disciplines related to the different risks faced by Civil Protection. Therefore, it can be considered a kind of indicator of the gender balance of the represented scientific community for over 30 years.

In this work, we analysed the number, expertise and gender distribution of the Commission's members since its establishment. We retrieved the official Prime Minister's Decrees appointing the members of the Commission, to investigate the absolute number, percentage and role played by women scientists over the considered period. For the last decade, we compared our results with the most recent gender analysis for the Academia and Research Institutes, conducted by the National Agency for the Evaluation of the University and Research System (ANVUR, 2023).

Our results show that the percentage of women in the Major Risk Commission is rather low, but almost in line with the percentages observed at the highest levels of the Academy. A general increase can be observed over time, but the growth is still slight.

Some considerations can be made to understand the reasons for this limited presence of women. For instance, the members of the Commission are generally selected from among Full Professors and Research Managers, or from high hierarchical level of State Technical Agencies. These positions, in turn, are occupied in high percentage by men. Moreover, the technical skills required by the Major Risk Commission over the years are largely represented by STEM disciplines (science, technology, engineering and mathematics), which still have a low percentage of women.

ANVUR (2023) - I Focus del Rapporto ANVUR 2023. Analisi di genere, 58 pp, ISBN 978-88-32041-06-4, https://www.anvur.it/wp-content/uploads/2024/01/Focus-equilibrio-di-genere-2023.pdf.

Dolce M. et al. (2020) - Civil Protection in Italy. Civil Protection Department – Presidency of the Council of Ministers. First edition: September 2022, 229 pp, ISBN:9791281195011, https://www.protezionecivile.gov.it/it/pubblicazione/civil-protection-italy-basic-training-civil-protection.

Law 225 (1992) - Istituzione del Servizio Nazionale della Protezione Civile, https://www.gazzettaufficiale.it/eli/id/1992/03/17/092G0253/sg.

Legislative Decree 1 (2018) - Codice della Protezione Civile, https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2018-01-22&atto.codiceRedazionale=18G00011&elenco30giorni=true.

Promoting the Geosciences among the young women: an example in the framework of the PLS program

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Keywords: gender balance, piano lauree scientifiche.

The underrepresentation of women in the field of Earth Science persists as a significant challenge within the broader context of gender inequality in STEM (Science, Technology, Engineering and Mathematics) disciplines. Additionally, the limited emphasis placed on Earth Sciences within the Italian secondary education system, contributes to the disproportionately low enrollment of girls in Geological Sciences courses. Promising strategies and interventions aimed at promoting the gender balance in these disciplines have been developed within the PLS (Piano Lauree Scientifiche), an institutional program aimed at the diffusion of STEM disciplines among the students of the upper school. With the aim of fostering gender diversity and inclusion in STEM disciplines, the Women's Studies Center "Milly Villa", together with the different scientific courses of the University of Calabria, promoted in 2023/2024 a training focused on "Environmental Sustainability", entirely dedicated to young women from six different high schools. The program featured a preliminary seminar intended for all participants and titled "Science and Gender Issues", which highlighted the barriers faced by women scientists at various stages of their careers (from recruitment to advancement and leadership opportunities), notwithstanding their important role in the scientific development. Subsequently, the young women followed theoretical lectures and practical activities on a specific environmental topic, different for each school. One of the sessions was dedicated to soil protection, with a focus on the key factors influencing the erosion and resulting landforms, as well as techniques for estimating soil loss. By using satellite images and Q-GIS, the young women gained practical skills in assessing annual soil erosion in a study area close their school and residences. Afterwards, the girls independently developed experimental plans to further investigate soil erosion dynamics, followed by delivering a comprehensive presentation. The results gained by each school were presented during an event held at the University of Calabria on 14th February, coinciding with the International Day of Women and Girls in Science. This event, which welcomed students from other upper and intermediate schools, provided a platform for the young women to present their research outcomes and experimental findings, thus becoming "scientists for one day". A survey to assess participants' satisfaction and to monitor the students' opinions was conducted among all the participants.itrevealed that most of girls found the initiative both interesting and stimulating, particularly appreciating the hands-on aspects and collaborative opportunities.

Participation of women in engineering geology and hydrogeology research in Italy

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Keywords: women, engineering geology, hydrogeology.

The aim of this study is to present relevant concepts and open questions stimulating the discussion on women and research in Engineering Geology and Hydrogeology in Italy (GEO05 discipline), starting from historical data and proposing points of reflection for the future. In research, and particularly in the field of geology, women face problems mainly related to: i) discrimination in access to employment; ii) discrimination during their working career. It is believed that women's performance is less relevant than that of men, partly because women are considered less suitable for field work. During their working career, women sometimes receive «attention» at different levels from male colleagues, facilitated by field trips and summer schools, which often include overnight stays.

Moreover, there are prejudices linked to motherhood, linked both to the absence of young women researchers in the workplace and to their lower participation in research. Often the male colleagues, instead of supporting them in this delicate moment of their working life, take the opportunity to get ahead of them in the career. In the GEO05 discipline, all these aspects related to geological careers are exacerbated by the fact that engineering disciplines are considered even more as a male discipline, not suitable for women.

My research between gender and engineering geology and hydrogeology, conducted with the substantial contribution of the female colleagues of the GEO05 disciplinary sector, concerns the representation of gender, barriers, and experiences. Statistics on the trend of the sector show a strong gender inequality: in particular, in 2001 there were 148 GEO05 scientists and only 18 female scientists, among whom no one was a full professor; after 22 years, at the end of 2023: the numbers were 46 women and 118 men, but only 6 female full professors, despite the bibliometric indices being similar (H-index around 20-22 for full professors and around 15-17 for associate professors). The small number of women in top positions is an issue that deserves much attention in the future. The gender gap confirms that women's roles are poorly valued, almost always kept in the shade, marginalized or even unacknowledged. To overcome this gap, it is necessary to highlight the benefits that women have brought and carry in the field of engineering geology and hydrogeology.

Learning from the pioneer women in Geosciences

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Keywords: women geoscientists, dissemination, education.

From the beginning of the 19th century, when geology was firmly established as a modern science, many women geoscientists made significant contributions to the advancement of the geoscience's knowledge, although many universities were still closed to women. A recent review of the existing literature on the role of women in the history of earth sciences (Vincent, 2020) indicate that at least 210 women geoscientists were active before the 1950, a number which undoubtedly exceeds what we would imagine. In fact, they are not sufficiently well known in the scientific community, to the public and accordingly within young students. As part of the group "Women in Geosciences" of the University of Bari, we have started a dissemination activity, mainly involving young students, bringing together the individual histories of female earth scientists from the 17th to the 20th century. They were active in various fields of geoscience such as mineralogy, paleontology, petrography, marine geology, stratigraphy, geological mapping, exploring mines, mountains and oceans, while collecting and studying minerals, fossils and rocks. In many cases, their activity resulted in economic and cultural improvement of which little groups, at first, and entire communities, later, got benefit. The lesson from the past tells us that most of them have faced numerous obstacles and huge prejudices over time due to persevering of unequal gender balance in Earth Sciences. Some of them remained invisible because their scientific goals were mainly attributed to well-known men (the Matilda effect of Rossiter, 1993), and some others only received recognition later. All of them are a great source of inspiration for their perseverance and their contribution to the development of geology as a science. Learning from the pioneering women geologists should encourage more young women into geosciences and help all of us to understand which prejudices we have overcome and what we still have to achieve.

Rossiter M. W. (1993) - The Matthew Matilda Effect in Science. Soc. Stud. Sci., 23(2), 325-341.

Vincent A. (2020) - Reclaiming the memory of pioneer female geologists 1800–1929. ADGEO, 53, 129–154, https://doi.org/10.5194/adgeo-53-129-2020.

Uncovering the glass ceiling mechanisms in the Geosciences: towards equality in Academia and the private sector

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Keywords: gender gap, representation of women, STEM.

Numerous studies across Europe, including Italy, have illuminated the gender disparities prevalent in academic positions across various disciplines. Within STEM fields, notorious for historical gender imbalances, the underrepresentation of women persists, notably within geosciences, which is going to be the focal point of this inquiry. While there has been significant progress, evidenced by near gender parity among doctoral graduates in geosciences by 2018, the journey to higher academic echelons remains fraught with challenges for women.

The phenomenon of the "glass ceiling" is palpable, particularly in leadership roles and decision-making spheres, with ramifications extending beyond individual careers to the quality and diversity of research outcomes. Recent research by Agnini et al. (2020) underscores this complexity, revealing a diverse landscape in the representation of women in Italy across geoscience fields, whereby some areas show low levels of female representation more than others.

The "glass ceiling" phenomenon is particularly evident in leadership and decision-making positions, with implications beyond individual careers for the quality and diversity of research outputs. This disparity indeed exacerbates financial inequalities, reinforcing the gender pay gap, since STEM disciplines are usually the ones that offer the most remunerated career paths with the most stability. Furthermore, Agnini et al. (2020) shed light on the underrepresentation of women in leadership roles within various geoscientific fields in Italy, emphasizing their concentration in specific disciplinary sectors (SSD), thus highlighting a heterogeneous distribution across the spectrum of leadership positions.

In light of these findings and the imperative to gain deeper insights into this phenomenon, we aim to investigate contrasts and parallels of this trend within the private sector of the same domain. Drawing from a feminist framework (Harding, 2004), our research endeavors to critically examine and disrupt the prevailing paradigm that sustains gendered biases and discriminations within the geosciences. By challenging assumptions regarding women in geosciences, our aim is to illuminate collective solutions and develop effective tools for dissemination, education, and design. Ultimately, we aspire to cultivate an environment where the pursuit of a career in geosciences is not exceptional but rather encouraged and accessible to future generations.

Agnini C. et al. (2020) - Women in geosciences within the Italian University system in the last 20 years. Adv. Geosci., 53, 155-167.

Harding S. (2004) - The feminist standpoint theory reader: intellectual and political controversies. Taylor & Francis Ltd (Ed), 394 pp.

Webinars of Ud'A ex-students to valorise the professional careers of women geologist

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Keywords: geoscience careers, women geologist.

To celebrate the 30th years of the Geology degree at Univ. d'Annunzio (Chieti-Pescara) a series of webinars with ex-students (https://udascienza.unich.it/?p=573) have been organized to show the potentiality of a degree in geological sciences as professional career to undergraduate students. All speakers have described their own working experiences after graduation, highlighting failures and successes to inspire students.

The aim of this abstract is to enlighten the professional careers of women geologists as aspirational paths for young women and suggest the various options in the geoscience field.

Adele Garzarella works as biostratigrapher at Geological Survey of Italy, ISPRA, for the CARG Project (Geological Map of Italy). She described with passion and competence the importance of geology for the social and economic development of the territory, resembling the UNESCO guidelines. She was strongly involved in the application process of the Maiella UNESCO Global Geopark and also reported the impact of geology in the II World War strategy in Abruzzo, a strategic point of the Gustav Line for the German Army.

Valeria La Torre, R&D specialist at the Centro Ceramico (Sassuolo), completed her scientific training with a master's degree in Ceramic Business and Technology. Her journey tells the importance of geology in raw materials study for the ceramic tile manufacturing industry, from the productive process up to the technical-performing parameters of the finished product. Her scientific background allowed a transversal application of her skills in the field of ceramic tiles ranging from the execution of laboratory tests, to the coordination of regional/European projects or training of technicians.

Vittoria Morena Salerno, Environmental Compliance Officer aboard Princess Cruise Line ships, told us how she built her expertise on the strong leverages provided by the systemic and holistic approach acquired during her studies in Structural Geology and her PhD in Computational Geodynamics which helped to interpret complex sets of data and information of various kinds. This mindset has been pivotal in quickly mastering environmental compliance and effectively applying it in the maritime sector, to achieve sustainability and circular economy goals.

Edisa Shahini, is part of the Oil Field service and Equipment (OFSE) organization. During her speech, she has passionately summarized her career path in Structural Geology and Geodynamics and her professional career at Baker Hughes. She started as Field Operator in Pescara and moved through different management position in operations and product management in Europe. Exposing herself into different working positions aimed to reduce carbon footprint for more sustainable solutions for human and planet such as the role for Clean Power Solution as Program Manager, and more recently as Remote Operations Manager for all OFSE product lines.

Is there still a price to pay for being a woman geoscientist? Perspectives and lessons learnt

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Keywords: women, gender equality, geoscience.

Women geoscientists in the 21st century challenge the traditional norms and, with their pioneering science, produce remarkable achievements in STEM and pave the way for future generations with dedication and passion. Yet, gender bias, stereotypes, underrepresentation, and discrimination negatively influence their working environments, affect their career choices and hinder their advancement in academic science. Despite some progress made to mitigate gender equality in STEM over the past two decades, recognizing, addressing and taking action to overcome these barriers is crucial for creating a more inclusive and equitable environment where science can thrive. In this contribution, we collectively revisit available data from the literature and compare with recent data and our personal perspectives and lessons learned thus far. We provide preliminary questionnaire results which give valuable insights on how and to what extent women geoscientists face disparity and underrepresentation in academia. We report some of the pivotal challenges that women geoscientists face and highlight the opportunities that arise from those challenges. We propose strategies for reshaping the equality and diversity agenda, promoting women geoscientists to serve as role models for inspiring future generations. To reach this goal, collective actions and commitment from individuals, institutions, and academia should be put into practice. We recommend a working environment where counselling services are available to employees and students in conjunction with effective support strategies at the institutional level. Such actions will allow women geoscientists to access support networks for families, brighten their scientific and professional achievements, and find empowerment in their roles in the academic community.

The Gender Equality Plan @ UniTo

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Keywords: gender gap, motherhood penalty, glass ceiling

Following the European Commission guidelines in the frame of an European Project (MINDtheGEPs: Modifying Institutions by Developing Gender Equality Plan, Horizon 2020, ccordinator Prof. C. Slera and with the contribution of CIRSDe -Centro Interdisciplinare di Ricerche e Studi delle Donne e di Genere and CUG- Centro Unico di Garanzia) the University of Torino approved the new "Gender Equality Plan" (GEP) (https://www.unito.it/sites/default/files/gender_equality_plan_unito_2023.pdf) last July 2023.

The GEP focuses on reducing the gender gap that till now is very wide in the University.

After a carefull revisions of the state of the art in the Departments of the University in terms of gender equality in different academic roles, the GEP takes into account different actions, both cultural and structural (i.e. supported by funds) to reduce this gap.

Even if the number of women is higher during the university studies and most of the PhD students are females in the following academic carrier men override women in the stable positions, starting from the lower level, i. e. researcher. The difference in academic roles grows enourmously in the case of associate and full professors.

The main structural actions approved to try to reach a gender balance are particularly focused on the so call "motherhood penalty" and to break the "door and glass ceiling" to allow women to reach not only apical positions but also a stable position.

In particular to try to reduce the "motherhood penalty" main actions will regard funds dedicated to cover baby-sitters expenses and additional research funds will be dedicated to the new mothers. In addition Departments that enrole women in stable and apical positions will be granted.

In addition cultural action will be active (i.e. short online courses regarding unconscious gender prejudices and transformative mentoring dedicated to young women in academic carrier).

The role of women in the Geosciences: the case of INGV in preparing and managing the emergencies

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Keywords: preparing and managing the emergencies, INGV women.

It is well known that in the geosciences (as in all STEM disciplines), the percentage of women in top positions decreases in favor of men, despite comparable academic careers and, sometimes, even better results for women.

The authors of this contribution hold managerial roles in preparing and managing seismic and tsunami emergencies at INGV (Istituto Nazionale di Geofisica e Vulcanologia). It has been a long journey, but it is now a positive reality. But it has sometimes been different!

Since its establishment in 1999, the INGV has undergone significant growth and transformation. De Lucia et al. in 2021 analyzed gender diversity within the organization, revealing that the workforce comprised 38% female and 62% male. While these proportions have remained relatively stable over subsequent years, nuances emerge when examining gender distribution with higher representation of women in administrative roles and men in technical positions. What is slowly changing in recent years is the presence of women in research and managerial leadership positions.

Notably, between 2016-2020, a woman served as General manager and, since 2017, one of the three Department Directors (Environment, Earthquakes and Volcanoes) is a woman. Currently, 4 out of the 10 Directors of the INGV Offices are women, reflecting a positive trend towards gender parity in leadership roles. Additionally, both the recently elected INGV members of the Scientific Council are women, underscoring the growing influence of female voices in shaping scientific discourse and decision-making. In the present day, an increasing number of women fulfill pivotal roles across research, technical, and administrative realms, actively contributing to coordination and leadership. Notable instances include women actively engaged in the preparation and execution of seismic, volcanic and tsunami emergency protocols. Their responsibilities encompass crucial tasks and providing support services for emergency response teams (including operational rooms for seismic, volcanic, and tsunami surveillance, network monitoring infrastructures, or emergency response teams).

In this contribution, the authors recount their experiences.

De Lucia et al. (2021) - Le persone dell'Istituto Nazionale di Geofisica e Vulcanologia a venti anni dalla sua istituzione. Quad. Geofis., 173, 192, https://doi.org/10.13127/qdg/173.

Women at the Geological Survey of Italy: where we were, where we are, where we are going

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Keywords: gender equality, mentoring, geological field survey.

At the Geological Survey of Italy, women in research or technical roles are 34%, a number confirmed by women geologists applying for new positions: 41% for general geologist positions and 33% for field geologist positions. The percentages: i) reflect the situation of female graduates in earth sciences in Italy (36%, ALMALAUREA 2017-2022, https://www2.almalaurea.it/cgi-asp/classi/Scheda.aspx?codiceAggr=10016&tipoCorso=L&lang=it; https://www2.almalaurea.it/cgi-asp/classi/Scheda.aspx?codiceAggr=11086&tipoCorso=LS&lang=it); ii) are comparable with those of other national "geoscientific" institutes (INGV: 29%, INGV 2021; OGS: 40%, OGS, 2023) and iii) are considerably higher than other working realities (e.g. companies or universities).

The higher number of women geologists present in public institutes may be due to a less biased recruitment system, where competition is also based on tests and less affected by personal career.

The lower number of women applying for field geologist positions compared to those applying for other geologist positions might be instead associated with the perception that being a field-geologist is an demanding job in terms of physical energy or the long time required by fieldwork; women tend to apply for jobs requiring less in-person time to attend the "care-work" at home which are culturally induced to.

Nevertheless, in the last years, at the office responsible for the geological field survey and mapping activities of the Department of the Geological Survey of Italy, many of the roles of responsibility have been covered by women. This peculiar situation, enforced by the hiring of some women at the office, has created the conditions for mentoring the younger employees; moreover, set the basis for a more receptive environment, where emerging upcoming needs have encountered privileged spokeswomen, capable of finding flexible solutions.

In addition to encouraging attendance at training courses organized as part of the Institute's Three-Year Plan of Positive Actions (PTAP), some strategies have been positively adopted.

These include simple actions, like welcoming small children on video calls or at dinner during field campaigns, but also more complex and codified procedures that aim to take family priorities into account. The possibility of smart-working with no-fixed days or hybrid solutions, like the alternation of smart-working and parental leave, are all arrangements helping women (and men) willing to have a job but, in the meantime, busy with care work at home.

When the needs of the employees are met and the organization's performance goals are achieved, it is a win-win situation. This might also induce male colleagues to take their "family time".

We believe that these best practices, implementing the rules and actions defined by ISPRA in the PTAP and in the "Gender Equality Plan" (GEP), are a positive step into the gender-equality direction, and might be a step further. Detection and satisfaction of employees' needs don't deal only with women: it might be a virtuous model aimed at creating a better working environment for everyone.

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ISPRA (2022) - Bilancio di Genere ISPRA 2022.
OGS (2023) - Piano di uguaglianza di genere 2022-2024.

Stubbornly holistic: Zonia Baber and her groundbreaking work in the field of Geosciences education

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Keywords: interdisciplinary education, experiential learning, historical gender bias.

There are many uncredited women in Science's past whose tales may never be uncovered, and even though the chances were stacked against them, they yet made significant contributions that endowed the development of some breakthroughs and discoveries which, apart from anything, have historically been associated with males. To honour one of these trailblazing ladies who enabled the current level of understanding in Earth Science, this paper seeks to shed light on Zonia Baber's life and her pioneering contributions to the Geosciences in terms of communication and education.

The Geosciences continued to serve as preparation for war, conquest, and exploitation of natural resources during the turn of the 19th and 20th centuries, when the United States' mostly informal imperialism sought to merge with Great Britain's global hegemony. Nonetheless, throughout her multifaceted career as a professor of geography and geology, an activist against racism and imperialism, an environmentalist, a pacifist, and a feminist, Zonia Baber (1862-1956) stressed the value of a young-age holistic, interdisciplinary education and emphasised the importance of experimentation and field work as tools of experiential learning, showing how geography and geology should be used to unite rather than divide humanity (Baber, 1904). She put forth a dynamic, flexible, and constantly evolving educational approach (Baber, 1901a; 1901b; 1901c) in which the Earth and environment are explored as keepers of diversity, which ought to be praised as a source of enrichment rather than seen as a cause of conflict.

Zonia Baber had a strong commitment to all of the delicate issues of her era. And she managed to bring them all together in her educational mission: indeed, among the other things, she served as the chair of the Race Relations Committee of the Chicago Women's Club and as a member of the National Association for the Advancement of Coloured People's (NAACP) of Chicago's executive committee; she served as president of the Women's International League for Peace and Freedom (WILPF); in addition, she continues to be greatly valued for her assistance throughout the unforgettable Puerto Rican women's voting rights campaign. All of this occurred while she co-founded the Geographic Society of Chicago in 1898 and was appointed to lead the Geology, Geography, and Palaeontology departments at the University of Chicago from 1901 to 1921 — she was the only female professor there.

In Baber's view, geosciences education was a means to improve the world since all things were interconnected, part of a comprehensive view of the total — a belief that holds true to this day.

Baber Z. (1901a) - Geography. The Course of Study, 1(5), 409-412, http://www.jstor.org/stable/991980.

Baber Z. (1901b) - Geography. The Course of Study, 1(8), 704-706, http://www.jstor.org/stable/992015.

Baber Z. (1901c) - Geography. The Elementary School Teacher and Course of Study, 2(2), 108-110, http://www.jstor.org/stable/992227.

Baber Z. (1904) - The Scope of Geography. The Elementary School Teacher, 4(5), 257-270, http://www.jstor.org/stable/992498.

A contribute to the PLS Project from "Women in Geosciences" of Bari University

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Keywords: women in geosciences, PLS scienze geologiche, Bari university.

The "Women in Geosciences" Group ("Donne nelle Geoscienze", in italian) was born in the "Dipartimento di Scienze della Terra e Geoambientali" of the Aldo Moro Bari University, at the beginning of 2021, as an "appendage" of the "Diversity, Equity, Inclusion – PanGEA" Division of the Italian Geological Society, which includes women geologists from all over Italy. The objective of the "Women in Geosciences" group is to encourage secondary school girls to undertake scientific studies, to break down the prejudice according to which girls are less capable than boys in STEM subjects (Science, Technology, Engineering, Mathematics).

The group formed thanks to the idea of Luisa Sabato (LS) and Martina Zucchi on 11 February 2021, on the occasion of the 7th "International Day of Women and Girls in Science". Currently, the group is made up of around 60 women, including PhD students, postdocs, researchers, and professors. Their activity falls within the themes of the PLS ("Progetto Lauree Scientifiche", i.e., Scientific Degrees Project) aimed at the University orientation of students in the final years of high school, in this case with a particular focus on girls.

The group work consists of creating a series of very short videos, with light tones, to also tell personal experiences in the field of geological sciences, and to demonstrate that girls can also undertake paths that some continue to consider exclusively male. Some videos follow the style of double interviews, others show through comics or stories the various types of activities that a geologist can carry out, still others are dedicated to the pioneers of Geosciences, women who get a notable contribution in the past (even very recent) to the development of the discipline of Geosciences, but remained "invisible", obliterated by the often-cumbersome male-presence.

The group also organized numerous days on February 11, hosting many high school classes, and even during the lockdown due to the COVID pandemic many classes connected for these meetings, even outside the regional perimeter. The group also played an important role in spreading the concept of geodiversity, organizing a series of seminars on October 6th (International Geodiversity Day), also playing on terms geodiversity and geo-diversity, and further highlighting the role of women in the scientific disciplines.

This contribution aims to present an overview of the activities carried out by the group and to share our experience. http://www.scienzegeologiche.uniba.it/2-non-categorizzato/1082-donne-in-geo.html.

S31.

The art of Geosciences communication

CONVENERS & CHAIRPERSONS

Valeria Giampaolo (CNR-IMAA)

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The valorisation of Cultural Heritage and the archaeometric studies as effective tools for disseminating scientific culture: the experience of the ADELE-RS project

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Keywords: valorization, heritage science, innovative museum.

The Adele-RS Project, funded by the Erasmus+ Programme (measure VETKA2020; https://erasmus-plus.ec.europa.eu), started at the begin of 2022, has been promoted by the Association "Arte e Fede" of Gerace (RC) and its general aim is developing an innovative e-Learning and Smart-Working system (D'Angelo, 2007) in the fields of Heritage Science.

The partners involved in European working group are: University of Calabria, Italy; Distretto ad Alta Tecnologia per i Beni Culturali S.C. a R.L., Naples, Italy; University of Malta, Msida; Fondazzjoni Belt Victoria - Heart of Gozo Museum and Cultural Centre, Malta; Universidade de Evora, Portugal; Museu Nacional de Arte Antiga, Lisbon, Portugal; Universitatea Politehnica din Bucuresti, Romania.

The general purpose of the ADELE-RS Project (https://www.adele-rs.org/) includes the design, development and implementation of specialization training courses aimed at graduates in disciplines in the Cultural Heritage field. Among these, in particular, the Partnership, developed a peculiar profile of specialization devoted to the scientific communication for valorisation of Cultural Heritage and dissemination of scientific culture aimed at involving the general public (Ponterio et al.,2019).

The tasks of this profile, named "Expert in Advanced Valorisation of Cultural Heritage", has been individuate in: to accepts the requests for new solutions for CH communication and dissemination, identifies resources and recognizes possible areas of development; to identify the starting technological and economic characteristics; to assess the costs and strategies of the project idea in terms of feasibility and competitiveness; to recognize the requirements for the realization of new valorisation tools, services and strategies and analyses their effects and impact in terms of economic, social and cultural development and sustainability improvement, also through the involvement of the communities of reference.

The Expert develops valorisation solutions for Cultural Heritage in different contexts and for different target groups and knows in depth the complex sector of innovative technologies for communication and information including those on based on the use of innovative Information and Communication Technologies (ICT) and Internet of Things (Casillo et al., 2022). The Expert also knows the use of social media and virtual communities applied to the context of Cultural Heritage communication and he/she is also able to develop technological solutions for the virtual reconstruction of sites, works and finds and to solve problems and themes of the communication for Cultural Heritage in complex and specialized contexts and for different audiences, finding solutions also aimed at dissemination of the Cultural Heritage.

This professional profile finds solutions, in particular, to improve the "traditional" communication, learning methods and in general the fruition of Cultural Heritage, designing innovative strategies for training and educational purposes based on scientific knowledge.

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D'Angelo G. (2007) - Dalla didattica alla e-Didactics - Paradigmi, Modelli e Tecniche per l'e-Learning. Liguori Editore, 416 pp., ISBN 9788820740658.

Ponterio R.C. et al. (2019) - Materials and Methods in Cultural Heritage: The role of Archaeometry in Museums. Herit. (special issue), ISSN 2571-9408.

An educational escape room experience for teaching younger generations about seismic risk

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Keywords: escape room, seismic risk communication.

Effective science communication is crucial for ensuring the societal impact of research. In today's digital age, the abundance of information circulating significantly influences public perceptions of science. However, the effectiveness of risk mitigation relies not only on the scientific community but also on society's readiness and understanding of risks. Educating local populations is essential for enhancing disaster preparedness and societal resilience. Seismic risk communication has evolved from one-sided, top-down approaches to prioritizing individual involvement (Musacchio et al., 2023). Italy, with its history of earthquakes, faces challenges in public perception, particularly among youth (Crescimbene et al., 2018). To address this, interactive experiences like Serious Games can effectively engage youth and convey the importance of seismic risk preparedness (Solarino et al., 2021; Musacchio et al., 2016). Several Serious Games have been utilized in Italy for seismic risk education, typically as part of extensive awareness campaigns and projects.

The didactic experience developed in this work represents a one-time endeavor, making it more accessible for testing and replication. Its primary aim is to stimulate students' interest in the topic rather than establish enduring knowledge. Amid the COVID-19 pandemic during the 2020/21 academic year, there was a need to adapt orientation and engagement activities with schools to virtual platforms approved by the schools. A novel educational approach was employed: an escape room experience designed to educate high school students about seismic risk. The escape room experience begins with a brief frontal lecture to introduce basic concepts. Students are then immersed in an interactive world where they grapple with challenges and decisions related to seismic risk. It offers a compelling narrative, puzzles, and scenarios mimicking real-life situations. Through this experiential learning approach, students are placed at the center of activities, observing how the gained knowledge can be applied in seismic events to estimate earthquake location and magnitude estimation. To personalize the experience a regional case study near the student's residences was chosen.

The impact of the experience was assessed through tests. Results demonstrated an improvement in pupils' interest in the topic. The 'one-time endeavor' protocol in seismic risk communication emphasizes a concentrated educational experience over continuous programs. It aims to stimulate interest and awareness effectively. While ongoing initiatives are common, this approach offers a fresh perspective, suggesting that a singular, intensive experience can be more replicable and impactful. Although international examples are limited, the interactive nature of disaster communication supports the idea that focused experiences can engage individuals and communities in preparing for seismic risks.

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Musacchio G et al. (2023) - A scoping review of seismic risk communication in Europe. Front. Earth Sci., 11, 1155576, https://doi.org/10.3389/feart.2023.1155576.

Solarino S. et al. (2021) - Playing games for risk prevention: design, implementation and testing of serious games in recent European projects UPStrat-MAFA and KnowRISK. Ann. Geophys., 63, 8, https://doi.org/10.4401/ag-8436.

The world in 2D: Alfonso Di Pasquale, between paintings and geological maps

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Keywords: Alfonso Di Pasquale, figurative painting, geological maps.

Geological maps, bidimensional representation of the complexity of structures forming the outer layer of our planet, are definitely art works. From the dawn of their presence on Earth, early humans had the urge to depict with lines, symbols and colors their perception of reality. Basically, history of art follows the path of human ingenuity towards an increasingly refinement of such capacity. Since 19th century, modern geology found a tool for representing, on the two dimensions of a paper sheet, the 4D vision of our dynamic Earth: geological mapping, a "screenshot" of a system continuously changing in space and time.

This contribution focuses on a particular character, worth a mention having been an excellent 'supporting actor' in the history of 20th century Italian geology: Alfonso Di Pasquale (1899-1987), painter and draughtsman from Apulia (Masi, 2013). He served for more than 40 years in the Italian Geological Survey, becoming a real artist of geological mapping (Argentieri, 2021). This notwithstanding, he cultivated concurrently the lifelong passion for realist painting, actually the downside of his ordinary job. After the reconstruction of Di Pasquale's human, professional and pictorial path, our storytelling ends with an unexpected finding. A postcard, drawn by Alfonso in 1917 and suddenly lost, reappeared after a journey across the Alps lasted more than a century, revealing a peculiar and touching story (Tortonesi, 2024): a further evidence of Alfonso's personal contribution to the art of Geosciences communication.

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Masi V. (2013) - Alfonso Di Pasquale pittore, la vita e le opere. Banca di Credito Cooperativo di Lavello, 85 pp.

Tortonesi E. (2024) - Le due storie di una cartolina dipinta dall'artista e cartografo Alfonso Di Pasquale, www.geoitaliani.it.

Science in the Riviera dei Fiori: 'traces elements' of geology in Italo Calvino's literary output

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Keywords: Floriano Calvino, Italo Calvino.

The literary output of Italo Calvino (1923-1985) reveals a solid scientific culture, derived from his family tradition, education and youth reading about astronomy and natural sciences. As known, he grew up in the Flowers Riviera of Liguria, in a family environment strongly permeated of scientific culture (Scarpa, 2013). The father Mario, born in Sanremo, was agronomist, republican and Freemason. The mother Giuliana Eva Mameli, mathematician, botanist and naturalist, was the first Italian woman to hold a chair of botany, at the University of Cagliari in 1926. Moreover, the maternal uncle Efisio Mameli was professor of organic chemistry in Pavia. In 1909, Mario Calvino emigrated to U.SA. and then to Mexico, participating to the revolution of Pancho Villa and becoming afterwards deputy director of the Escuela Nacional de Agricultura. In 1917, he moved to Cuba to head the Experimental Station of Floriculture of Santiago de las Vegas, where Italo was born six years later. In 1925, the family returned to Italy, and Mario became director of the "Orazio Raimondo" Experimental Station of Floriculture in his hometown. Thus, the Calvino- Mameli couple gave impetus to the floricultural activity which has made Sanremo world-famous. In 1936, Mario was appointed as a professor of tropical and sub-tropical agriculture in the Torino University and joined the Fascist Party. The second son of Mario and Eva, Floriano, was born in Sanremo in 1927. The two kids studied at the local Lyceum, entitled to Gian Domenico Cassini, the astronomer born in Perinaldo, on the Ligurian Alps: this is another subtle connection to scientific culture for Italo and Floriano. In autumn 1944 the Calvino brothers, to avoid conscription to the Italian Social Republic army, escaped on the Maritime Alps and joined the Resistance. After the war Italo obtained a degree in literature at the University of Turin (1947), having quitted the initial and unrewarding course of study in agronomy; Floriano, on the other hand, graduated in mining engineering from the Polytechnic University of Turin, and went on to become an appreciated geologist, later professor at the Genoa University. The enchanting scenario of the "Riviera di Ponente" stimulated in the past the interest for natural environment and scientific studies (Barale & Bicknell, 2024). In these terms, Sanremo and the Calvino- Mameli familiar framework represent the breeding ground for the seeds of a hybrid culture, between Humanities and Science. Following recent celebrations of the writer's birth centenary, we thus propose, starting from Floriano's research output, a virtual journey through Italo's literature, seeking for 'traces elements' of geology (Argentieri, 2023).

Argentieri A. (2023) - Un buco nell'acqua - A hole in the water. Acque Sotterranee. Ital. J. Groundw., AS46-714, 97-100, https://doi.org/10.7343/as-2023-714.

Barale L. & Bicknell M. (2024) - Clarence Bicknell (1842-1918): botanist, archaeologist, Esperantist, and... citizen geologist. Rend. Online Soc. Geol.It., 62, 169-190, https://doi.org/10.3301/ROL.2024.19.

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From bones to bulk: a 3D volumetric approach to estimating theropod dinosaur body mass

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Keywords: theropods, body mass, 3D reconstruction.

Body size estimation of theropod dinosaurs remains a challenging yet crucial aspect of paleontological research, offering insights into their ecology, behavior, and evolutionary dynamics (e.g., Campione & Evans, 2012; Brassey, 2016; Romano et al., 2021; 2023). Traditional approaches relying on regression formulas derived from extant taxa often yield wide and potentially misleading ranges of values. In this study, we propose a methodological framework centered on 3D volumetric reconstructions and density analysis as a more precise alternative for estimating body size and mass in theropods dinosaurs. Drawing from recent investigations, we try to demonstrate the efficacy of this approach in generating accurate estimations while overcoming limitations associated with conventional methods. By employing high-resolution digital scans of real specimens and casts, we reconstruct detailed 3D models of dinosaur skeletons, therefore allowing for precise body volumes reconstruction. Through the application of literature-derived tissue density ranges, we refine weight estimates to provide narrower and more reliable ranges of body mass. Our results underscore the importance of methodological rigor, particularly in reconstructing flesh and bones of extinct organisms with unique anatomical features or very large sizes. This approach not only enhances our understanding of dinosaur paleobiology but also serves as a valuable tool for elucidating broader questions regarding the evolutionary dynamics and ecological roles of non-avian theropod dinosaurs. Moreover, a precise in-vivo reconstruction of these extinct animals, that rules out any speculation and instead is based on peer-reviewed published data, would either enhance the quality of the results dissemination and establish a major reference for future works and for the understanding of a wider public.

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Campione N.E. & Evans D.C. (2012) - A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10(1), 60.

Romano M. et al. (2021) - The smallest of the largest: new volumetric body mass estimate and in–vivo restoration of the dwarf elephant *Palaeoloxodon* ex gr. *P. falconeri* from Spinagallo Cave (Sicily). Hist. Biol., 33, 340-353.

Romano M. et al. (2023) - Body mass estimate of *Anancus arvernensis* (Croizet and Jobert 1828): comparison of the regression and volumetric methods. J. Quaternary Sci., 38(8), 1357-1381.

Depicting the unknown

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Keywords: paleoart,dinosaurs, 3Dmodeling.

"Scotland For Ever!". This was the battle cry of the Grey Scots during the cavalry charge at Waterloo in 1815. The picture capturing this moment, perhaps the most famous and evocative image of the event, was painted by Lady Butler (also known as Elisabeth Thompson) in 1881, nearly 70 years later.

As a woman, Lady Butler never participated in any battles. Instead, she immersed herself in the stories of those who had experienced them, observed the uniforms of the time, and meticulously studied the anatomy and behaviour of galloping horses. From this wealth of knowledge, she immortalised an extraordinarily dramatic scene from an unusual perspective, capturing the motion and intensity of the moment.

This captivating painting and the story behind its creation serve as an excellent example of the work involved in reconstructing Deep Time, and thus, of Palaeoart. Palaeoartists follow a similar process, tasked with representing the lost world of prehistory through extensive research and the study of fossils.

But what exactly is Paleoart? It is the branch of art, whether through sculpture or illustration, that focuses on representing and reconstructing prehistoric environments and organisms based on artifacts found in the field. While allowing for some artistic interpretation, palaeoart primarily operates within the confines of scientific evidence and is subject to the meticulous oversight of scientists. Their role is to convey their research and conclusions through the work of the artist.

The reconstruction of prehistoric organisms or environments is a collaborative effort involving various professionals. Geologists and paleontologists excavate and unearth fossils, preparators in museums extract them from their matrix, and together they assemble the skeletons. Illustrators and sculptors then use these skeletons to imagine the appearance of these extinct organisms in life.

It's a lengthy and intricate process, demanding considerable effort and attention to detail, sometimes bordering on obsession. Yet, it's also incredibly rewarding and, undoubtedly, at times, immensely enjoyable.

GeoSciences IR: 'Thematic geological content dissemination' web system to support users

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Keywords: geosciences, dissemination, e-learning.

The project GeoSciences IR aims at creating a new research infrastructure for the Italian Geological Surveys Network (namely "Rete Italiana dei Servizi Geologici" RISG), a coordination network among ISPRA, Geological Survey of Italy and "Regional Geological Surveys" (RGSs), i.e. technical offices within Regions, Autonomous Provinces and Regional Environmental Agencies with a specific mandate in the geological domain at regional level. GeoSciences will provide to ISPRA and RGSs the technical and scientific skills to carry out their duties concerning responsibilities at national (ISPRA) and regional (RGSs) level in specific geological matters themes identified by RGSs as a priority. This target will be achieved through several actions aiming to transfer scientific and technical knowledge implemented by Universities and Research Institutes on priority themes. Through a highly technological cloud infrastructure, GeoSciences will provide access to a huge amount of data, services, tools, specifically implemented by project partners, made available to target users to fulfil with their institutional mandate. Within the new research infrastructure also a web system and e-learning platform will be available in order to make available all data to a wider audience of users, and to disseminate and give greater visibility to the results and deliverables produced by the project activities. For the training phase, e-learning modules will be available for users' technical and scientific updates. These products cover several issues: geological and geothematic mapping and modeling, landslides, sinkholes, hydrogeological risk mitigation, satellite and in-situ monitoring, active and capable faults, sustainable mining, and land use and consumption. E-learning certainly contributes to create shared knowledge about specific topics involving different skills and it is a valuable driver for the achievement of concrete technology-level goals. Technical offices of the Italian Geological Surveys Network (RISG), which are the main target users of the research infrastructure, will thus have the opportunity to learn about the methods, technology trends and innovative solutions produced for GeoSciences IR. Training starts from data visualization to procedures for complex analyses. Training materials will be developed to meet the needs and requirements of technical personnel of different skill levels. Users will benefit from specific softwares, tools for cloud processing and e-learning modules aimed at increasing technical and scientific skills in the geological domain. All materials created for training and made available in the web system and e-learning platform will be maintained and updated for the next 10 years after the end of the GeoSciences IR project.

Challenges and strategies in geothermal communication

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Keywords: geothermal energy, communication, popularization.

Geoscience communication plays a key role in promoting the transition to a more sustainable future for society and the planet. The complex challenge of a sustainable transition is particularly so for geothermal energy, which integrates various technologies into the invisible nature of underground processes. It is, therefore, difficult to envision the energy resource and associate its strengths and weaknesses with the different technologies.

The initial phase of any activity involves identifying the audience and the message to be conveyed: "What do they already know about geothermal energy?" "What is their perception?". Most importantly, "Why should they care about our message: what topics will we use to connect our research to their values and daily life experiences?" (Turnsek & Nibbs, 2023). Here we describe our experience in communication geothermal knowledge, that necessarily entails translating the complexity of research into understandable language and involves choosing the most effective communication modes to reach the recipients of the message. In the frame of a Research Night organised at the CNR Campus of Pisa we created a miniTED (Technology, Entertainment and Design) to raise awareness of geothermal energy in Tuscany: "Do Tuscans know it?". In an ironic and friendly tone, we narrated in just 8 minutes the various geothermal applications and products to be found trivially in a kitchen, completing the picture with a graphical representation of the energy input that Tuscany provides nationally and globally. For the celebration of the Centennial of the CNR, a day was dedicated in Padua to new forms of energy for energy efficiency and sustainability for the future of the planet. It was another opportunity to popularise the diverse geothermal applications, from the best known, such as spas, to the lesser known, e.g., vegetable drying. We created and explained a 2-meter roll-up entitled "Geothermal Energy for Decarbonization", depicting a thermometer embedded in a section of soil to show the increasing temperature with depth and the correspondence of temperature with different applications. We focused on the peculiarities of the Euganean Hills to inform citizens about the geological and geothermal characteristics of the Padua subsoil. In addition to traditional communication channels, websites, social channels, and newsletters, we are implementing a set of graphic drawings to represent geothermal technologies in a simple, understandable, and catchy way for a Horizon Europe project (DeepU, G.A. 101046937) and a European Cost Action, DHC Geothermal.

In conclusion, the variety of approaches and solution tested proved effective in engaging the public and in making complex messages understandable appears effective. We will continue to explore communication activities to promote the dissemination of this important renewable energy source in a strategic and informative way.

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The National Antarctic Museum-Section of Trieste: integrated educational approaches for understanding environmental and climate changes

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Keywords: scientific museum, geosciences communication, climate change education.

The experience of the National Antarctic Museum – Section of Trieste highlights the crucial role of scientific museums as places of informal learning.

The National Antarctic Museum has adopted various participatory pedagogical methods to actively engage students in learning. The Socratic method, based on questioning and dialogue, stimulates critical thinking and creative problem-solving. Peer education promotes knowledge sharing among students, creating a collaborative and inclusive learning environment. Collaborative learning, through group projects and practical activities, encourages the development of problem-solving skills and interdisciplinary collaboration.

The integration of these pedagogical methodologies in a museum context offers a unique opportunity to engage students in authentic and meaningful learning. Scientific museums provide a space where students can interactively explore complex concepts and connect acquired knowledge with real-life experiences. Interactive exhibits, simulations, and practical laboratories allow students to experience scientific concepts firsthand and develop a deeper understanding of environmental and climatic issues.

In conclusion, the National Antarctic Museum – Trieste Section offers an example of how collaboration between educational institutions and other actors can enrich students' learning experience and promote an interdisciplinary and participatory approach to scientific knowledge. The integration of innovative pedagogical methodologies in a museum context offers a unique opportunity to engage students in authentic and meaningful learning, preparing them to become informed and active citizens in the future society.

Satellites, or the Big Eye at the time of the Anthropocene: remote sensing for capturing landscape changes

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Keywords: Earth observation, Copernicus data, land change.

For some time now, remote sensing, i.e., the technique of observing and analyzing objects from a distance without being in direct contact with them, has captured both media attention and practical applications, revealing its enormous potential in various disciplinary contexts (meteorology, engineering, agronomy, archaeology, etc.). The synoptic view of large areas (using various platforms: satellites, aircraft, helicopters, drones) and the privilege of being able to go back in time make remote sensing unique in estimating the human footprint on landscapes, which are to be intended as the dynamic and complex expression of natural and human factors and also as an economic asset. Human development needs have led to a deep transformation of natural ecosystems, with agriculture and urban areas significantly increasing their ecological footprint in the last century, resulting in a reduction/degradation of ecosystems' ability to provide goods and services. Considering the extensive nature of the subject, an educational initiative was developed specifically for high-school students. It aims to enhance their capacity to interpret dynamic landscapes using remote sensing tools and techniques. The goal is to grasp the scale, duration, and extent of human impact on Earth.

The proposed activity consists of three distinct phases. The first phase has been theoretical, focusing on the scientific introduction to remote sensing and its potential applications across various disciplines (ecology, zoology, forestry, climatology, urban planning, etc.), demonstrating how human influence has deeply affected landscapes configuration and health. The second phase has been predominantly a training activity: through the Copernicus Data Space Ecosystem platform (https://dataspace.copernicus.eu/) that provides a large amounts of open and free Earth observation data mainly included those derived by the Copernicus Sentinels Missions, students have been guided to explore and engage with satellite imagery, using the user-friendly and intuitive browser. The main purpose has been to recognize the impact of human actions and natural events on land surface. The third step has been focused on an independent student work carrying out analyses on selected pilot areas concerning adverse phenomena affecting the Italian peninsula (fires, floods, etc.). Finally, students have showcased their conclusive findings through presentations showing excellent ability in engaging with a new tool, expressing a keen interest in further exploring the platform independently with the aim of becoming sustainability practitioners in a rapidly changing world.

"The Fountain of the Four Rivers" (Rome, Piazza Navona) as a representation of the sense of wonder in Baroque art and science

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Keywords: baroque art, complexity, horror vacui.

The Europe of the 16th and 17th centuries underwent a series of profound transformations, characterized by both tumultuous upheavals and moments of jubilation. The contrast between the Protestant Reformation and the Counter-Reformation ignited violent religious conflicts, coinciding with famines, plagues, and pandemics exacerbated by the Little Ice Age. Simultaneously, the discovery of new continents revealed a vastly diverse, exotic, and enigmatic world, catalyzing a shift in scientific and artistic discourse from the structured medieval worldview to the chaotic natural world dominated by tumult. In the Baroque era, nature was perceived as both awe-inspiring and terrifying, prompting humanity to seek harmony through theatrical, emphatic, and emotionally charged yet scientifically rigorous representations. God was viewed as the necessary and perfect origin and cause of the universe.

Exploring this worldview through the lens of art, science, and mathematics, we turn to one of the Roman Baroque's most iconic symbols: Bernini's "Fountain of the Four Rivers" in Piazza Navona. This masterpiece is interpreted through the scientific thought of two exceptional polymaths of the period: Athanasius Kircher (1602-1680) and Gottfried Wilhelm Leibniz (1646-1716). Kircher, a central figure in the intellectual culture of his time, inspired the allegory of the fountain.

The lower portion of the fountain features the four rivers—the Nile, Danube, Ganges, and Rio de la Plata—symbolizing the intricate nature of the known continents. This diversity evokes both awe and terror in humans, confronting the metaphysical void, indeterminacy, and complexity.

In stark contrast, the upper portion of the monument exhibits straight lines and ascends towards the sky with an Egyptian obelisk, embodying the ordered linear structure ordained by the Catholic Church. A top this structure transcends a bronze dove, symbolizing spirituality and the divine will. During Leibniz's stay in Rome from 1675 to 1676, it is intriguing to ponder his reaction to the grandeur of Roman palaces and Bernini's work. For the German philosopher, the fountain's plasticity, dominated by its folds, constituted a compelling manifestation of the will of God. Leibniz conceptualized reality as an infinite series of spiritual entities known as monads, each encapsulating the entire universe within itself. In his quest to understand and interpret nature, Leibniz developed infinitesimal calculus. The mathematical derivative, in its essence, signifies the interconnectedness and interdependence of variables. Thus, the derivative of one of the folds of the Fountain of the Four Rivers metaphorically represents the interconnectedness between different facets of the universe or folds of human experience.

Science and Art in the dissemination of volcanic risk

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Keywords: Mt. Vesuvius, phlegraean fields, theater.

In scientific research, art plays a crucial role in making complex natural phenomena understandable and accessible. This role is especially significant when an artist, with a musical background, approaches scientific research with a unique perspective. Similarly, researchers may use artistic expression, such as musical performances, to disseminate scientific knowledge about impactful events like volcanic eruptions and earthquakes. Through a combination of musical, visual, and narrative elements, we aim to convey scientific knowledge in an engaging way, encouraging greater awareness and understanding of natural risks. This work explores the role of art in facilitating scientific dissemination and promoting broader dialogue on safety and preparedness in the face of catastrophic events. We create two theatrical representations focused on the famous volcanic areas of Phlegraean Fields and Mt. Vesuvius.

The first show, titled "Dottò, ma quando scoppia il Vesuvio – il Nuovo Grand Tour" is a journey through time, blending images, videos, and music to immerse the audience in Vesuvius's eruptive history (De Novellis & Somma, 2024). The narrative, animated by tailored video and live musical performances, goes beyond describing eruptions, revisiting the cultural growth in the vesuvian area from the Grand Tour era to modern technological discoveries. An innovative vision is proposed for addressing volcanic risk, highlighting how Vesuvius can drive economic growth and development, promoting a "new" Grand Tour that balances ancient and modern elements.

The second show, titled "Phlegraean Fields: Mankind, Fear, and New Sibyl - The Challenge of New AI" is a multimedia work blending the expertise of a volcanologist, a musician, and a VJ creating AI-generated visual content (Zoccola et al., 2024). The project represents human fear of bradyseism in the Phlegraean Fields, where the myth of the Cumaean Sibyl once provided oracular insights. Today, humanity seeks answers from AI, the "New Sibyl" while confronting fears about AI itself. This interdisciplinary approach creatively harnesses technology, generating scores, sounds, and images through traditional and innovative processes, promising a memorable experience.

These shows offer a unique platform to explore the intersection of art and science, combining musical, visual, and narrative elements to convey scientific knowledge in an engaging way. They aim to educate the public about volcanic dangers, promote awareness of natural risks, and encourage critical reflection on our relationship with the natural world. These theatrical representations provide an overview of the history of volcanology, highlighting pioneers, key discoveries, and the discipline's evolution. They illustrate geological processes, emphasize preserving historical volcanic sites, introduce modern volcanic monitoring tools, and stimulate curiosity and interest, fostering a deeper connection with our planet.

De Novellis V. & Somma R. (2024) - Vesuvius, from risk to resource? A theatrical representation for the old and new Grand Tour. EGU General Assembly 2024, EGU24-2541, https://doi.org/10.5194/egusphere-egu24-2541.

Zoccola M. et al. (2024) - Phlegraean Fields: Mankind, Fear and New Sibyl. EGU General Assembly 2024, EGU24-6531, https://doi.org/10.5194/egusphere-egu24-6531.

Ever played a phase diagram? Thermodynamic graphs as musical scores for educational live performance

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Keywords: sonification, state transition, thermodynamics.

In the last two years, an interdisciplinary research project (sosteam.org) has been carried out in the University of Bari Aldo Moro, aimed at bridging scientific knowledge with musical language (and viceversa) by emphasizing the shared principles of symmetries and proportions.

Educational research is trying to gain knowledge on what actually works in the classroom. The fast spread of evidence-based education relates to the need of providing functional data that can be used for taking informed decisions. Such approach leads to introducing novel teaching strategies supported by scientifically based research and connecting different disciplines within a unifying framework.

Our project introduces an innovative educational strategy utilizing interactive sonification, transforming phase diagrams into graphic scores to be played by students under the guidance of a conductor (teacher).

Although graphic scores are attested as early as in the Renaissance, starting from the 1950s several composers (e.g. Cage, Brown, Ligeti, Wolf, Feldman, Stockhausen, Bussotti, Braxton) adopted this form of representation of music with visual symbols sometimes combined with traditional musical notation. The visual language adopted to convey musical information is sometimes extremely precise, sometimes deliberately aleatory to involve the performers in the creation of the music.

Phase diagrams, depicting thermodynamic phases in equilibrium systems as a function of pressure and temperature, offer a parallel visual language which can transmit compositional intentions as well as phase stabilities based on empirical data.

The pedagogical reason for employing musical interpretation of phase diagrams derives from the analogy between musicians interpreting scores and students decoding chemical and physical properties of the materials: musicians need to know the score and the poetics of the composer in order to interpret it properly; students interpreting musically a phase diagram have to learn its chemical and physical aspects in order to decode it. By means of sonification, phase diagrams of substances such as H_2O, $CaCO_3$ and SiO_2 become musical exercises, where the conductor guides the performers through different states of matter using vocal motifs and body percussion for a dynamic and engaging representation of molecules, phases, temperature, and pressure. Each performer plays as a single molecule in a given phase, and concurs in determining the state of the system. Mastery of thermodynamic principles is essential for accurate musical interpretation, promoting the understanding of scientific concepts and social inclusion through unconventional musical stimuli.

This innovative approach not only enriches STEAM (Science, Technology, Engineering, Arts, Mathematics) education but also underscores the potential of interdisciplinary collaboration in fostering creative learning environments.

Gem Session: aural logos of gemstones by sonification

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Keywords: music, gemstones, sonification.

Gemstones can vary widely in terms of their characteristics, but there are several key attributes that are commonly used to describe them, such as color, clarity, carat weight, luster, hardness and cut. These characteristics, among others, contribute to the beauty, value, and uniqueness of gemstones, and are recorded on the grading card associated with each gem.

This contribution proposes an acoustic representation of the mineralogical data and the gemological features which define a cut gemstone by means of a specific sonification algorithm. The result is a musical logo unique for each gem, which makes the object even more fascinating and evocative.

The musical texture of the sonification is homophonic, with the melody based on the sonification algorithm to sonify the mineral species adopted in the project "Aural Structures". The algorithm encodes the stoichiometry and the group symmetry which characterize any mineral into an aural model where rhythm, pitch, dynamics and timbre are organized accordingly. The accompaniment of the melody is obtained by sonification of the clarity, carat weight, color and cut, associated to instrument family, dynamics and attack, type of trichords, number of trichords and bass tones, respectively.

A selection of simulations made starting from gems of different nature (diamond, emerald and quartz) and quality aimed at showing sound differences related to different gemological characteristics. The result constitutes an additional sonification-based fingerprint for each specific gemstone and a new perceptual modality, which could open new perspectives in the field of gemology.

Geoscience communication through videos

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Keywords: engagement, video, outreach.

Effectively communicating geoscience concepts to non-expert audiences and inspiring students to pursue graduate programs in the field demand a unique set of skills that researchers may not naturally possess or know how to develop. This necessitates collaboration between geoscientists and communication professionals to strike the delicate balance between scientific rigor and engaging communication methods.

The successful partnership between geoscientists and communication experts has proven pivotal in bridging this gap. By leveraging their respective expertise, they can craft compelling narratives and interactive experiences that make complex geological concepts accessible and captivating to broader audiences.

Drawing from our collective experience, we have collaborated within the Italian Geological Society in conjunction with SIMP (Società Italiana di Mineralogia e Petrologia) and SPI (Società Paleontologica Italiana) to create the initiative “ON THE ROCKS.” This innovative project utilizes multimedia platforms, including videos, to creatively depict the intricate processes preserved within rocks. Through the art of storytelling and fiction, these videos illuminate some of the geological wonders of our world, making them not only educational but also entertaining.

By harnessing the power of storytelling and visual media, we can effectively convey the beauty and significance of geoscience to diverse audiences, inspiring curiosity and fostering a deeper appreciation for our planet’s rich geological history. Through continued collaboration and innovation in science communication, we aim at cultivating a new generation of geoscientists and empower them to communicate their research effectively to the wider world.

The Italian Paleoart Award

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Keywords: paleoart, communication, outreach.

The Italian Award for Paleoart is an annual international artistic competition, organised and promoted by the Accademia Valdarnese del Poggio and the Paleontological Museum of Montevarchi since 2021.

Among the objectives pursued by the organisers is the desire to spread knowledge of Paleoart (understood as the representation of prehistoric life through various artistic techniques) and consequently to offer a showcase to professional and aspiring paleoartists who wish to promote their creations, as well as to create works that have a great impact in the field of communication of geo-paleontological themes.

The First Edition of the Italian Award for Paleoart already collected more than 120 works by 75 artists from all over the world, as it did in the following years.

The Italian Award for Paleoart, conceived by Sante Mazzei, has been supported since its first edition by the Italian Paleontological and Paleoartistic Association APPI, the Italian Geological Society and the Italian Association of Scientific Museums.

Over the years, the organisation has become more structured and since 2024 the Award has been divided into two categories: illustrations and projects.

Illustrations may depict, either in graphic or sculptural form, any kind of prehistoric animal and plant life form, a particular environment, biotic community and prehistoric ecosystem; works must be original and unpublished, not published in any other context.

Projects may include original proposals dedicated to paleoart and more generally to communication in the field of geo-palaeontology through images such as books, comics, articles, short films, animated shorts, collections of original sculptures, augmented reality experiences, applications for mobile devices, etc., and which must be narrated through the creation of a poster.

Every year, great attention is paid to the selection of the jury, composed of influential figures from the Italian and international geological, palaeontological and artistic scene. Each edition features a different jury, so that the works are judged as objectively as possible and to allow each aspect of the reconstructions to be highlighted by experts from various fields.

Originality, complexity, scientific rigour and technical ability are the aspects that the Italian Award for Paleoart intends to valorise; in fact, all the works are equally evaluated both for their scientific component and from the point of view of artistic technique.

Finally, we would like to point out the enhancement of the authors included in the "budding artists" category (under 18), for the illustrations section.

In order to further emphasise the contribution of all those who participate in the Italian Award for Paleoart each year, the Palaeontological Museum of Montevarchi organises an exhibition of all the entries submitted during the current year's event in its spaces. Every year, the exhibition attracts many visitors and schools and remains open to the public for about a month.

The Time Machine Project - A travel into Deep Time

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Keywords: deeptime, comunicazione, sensibilizzazione.

The concept of Time is very complex and not innate in man. We have always attempted to define and quantify it, but only relatively recently have we managed to determine it absolutely thanks to Patterson's isotopic studies.

The difficulties that man has always had in defining the concept of Time are linked to its nature, to the way in which it is perceived and above all to the discipline with or for which it is attempted to be defined. Not least the difficulty of having a very limited point of view, especially if we relate it to our daily life and our empirical experience. As we commonly understand it, Time is relative, therefore determined by the simple succession of events: by the life of a single man, by a certain historical period, by the development of a civilization.

In geology, it is defined according to a fundamental event: the formation of planet Earth.

One of the main purposes of Earth Sciences is to reconstruct the chronological succession of the biological and geological events that have characterized the history of our planet and to help us measure the immensity of the Deep Time that has passed through it.

But if the age of our Planet, over 4.5 billion years, is a value that researchers and those involved in Earth Sciences are now accustomed to managing, the same cannot be said for all those who are approaching these disciplines for the first time or have a different educational background.

Thinking in terms of billions, millions or sometimes even just thousands of years means having to process too large values that often cannot be fully understood. For this reason, especially if you are dealing with children, students in their first years of schooling or with a general public, it is necessary to adopt, in communication and dissemination activities concerning Earth Sciences issues, a language that is understandable to everyone and try to use tools that allow us to communicate clearly and effectively. First of all, the use of simple but at the same time immediately communicative images, such as paleoartistic reconstructions. For this reason, "The Time Machine Project - a travel into Deep Time" aims to be a useful and effective means in addressing issues concerning time and the geological history of our Planet, offering a relative reading of time, therefore presented as a succession of events, but in the same way try to give value to the dimensions of the various periods and above all highlight their differences.

A complete way to present the dynamics and impact of events that have shaped the Earth, the catastrophes, appearances and extinctions of life forms that have determined the geological past of our planet, to better understand diversity and the environments that still characterize it today. A fundamental knowledge to better understand the world we live in, our role as living beings and useful to us in our relationship with the environment around us.

Land degradation: an unconventional tale

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Keywords: geoscience communication, narrative formats, engagement.

Land degradation is a complex issue that involves the degradation of natural resources across various dimensions, including soil, vegetation, water, and biodiversity. Its profound impact extends to billions of people worldwide resulting in significant socio-economic and ecological consequences. Furthermore, it is recognized that the depletion and degradation of these assets often exceed the capacity for recovery within a single human lifespan.

Given the broad scope of the topic, an educational activity was conceived for high-school students, focusing on the narrative dissemination of land degradation in one of its many facets. Science, like other aspects of human experience, benefits from storytelling - a fundamental aspect of human communication, serving both our innate curiosity about the world and our need to share experiences. Communication of science encompasses two of humanity's fundamental needs: to know and understand one's surroundings and to tell stories.

The workshop unfolded in three phases: an introduction to the theme, independent group work, and presentation of the work. Initially, participants were introduced to the topic through visually rich slides, eschewing excessive text in favor of evocative imagery. The discussion emphasized the interdisciplinary nature of the issue, touching upon its intersections with fields such as humanities, global economics, and social sciences. Using an interactive approach based on debate and involvement, students were encouraged to explore the local ramifications of land degradation, making the topic more relatable to their everyday experiences.

Following, students were instructed to form groups (of about 10 people each) and guided in the construction of their narratives. They were prompted to consider various elements, such as the choice of communication medium, target audience, stylistic approach, thematic focus, and narrative structure. This exercise aimed to foster creativity and critical thinking while encouraging students to engage with the topic on a personal level. After an hour of collaborative work, each group presented their narratives, while their peers evaluated them based on creativity, clarity of content, and engagement. Evaluation was facilitated through software, allowing students to provide feedback directly from their smartphones.

The students' response to this approach was enthusiastic. From their efficient self-organization into groups to their creative choices of communication tools, the students readily embraced their role as science communicators for one day. The resulting works showcased a diverse array of communication methods, ranging from contemporary podcasts to traditional artistic mediums, as well as innovative approaches facilitated by artificial intelligence. Some narratives even drew inspiration from literary figures such as Giacomo Leopardi, T.S. Eliot, Giuseppe Parini, and Primo Levi, demonstrating the students' depth of engagement with both the scientific and cultural dimensions of the topic.

"Can You Sea?": an aerial and acrobatic performance to involve people in marine bio-geoscience researches

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Keywords: performing art, bio-geosciences, climate change.

The ocean is a key element of the Earth system and is an archive and source of information and resources for humanity. Today, this precious piece of the planet's well-being is increasingly threatened by climate change and anthropic activity with tangible losses and degradation of habitat and biodiversity. Unfortunately, the social perception of this situation is disproportionately low, because the affected systems are hidden and not adequately presented by media. To ensure the effective implementation of science-based solutions to restore marine ecosystems and safeguard this critical resource in global policies, society's relationship with the ocean must change, and this requires the adoption of new educational tools and communication processes.

Here, we present the impact of a physical/acrobatic theater performance aimed at raising awareness of the main threats to the ocean. A performance titled "Can You Sea?" was co-created by choreographers, researchers in marine ecology, biology and geology around the themes: marine pollution (including nutrients, plastic, noise), overfishing, bioinvasions and climate change. The physical performances are accompanied by audio recordings, video scenography and short readings, written and performed by scientists, with the supervision of a community theater researcher. Scientists are on stage with thirteen teenage athletes.

The show benefited from three performances in very different cultural contexts: the WeWorld Festival of Milan in May 2023, the Blue Festival of La Spezia in July 2023 and the European Researchers' Night 2023 in Pavia in September 2023.

During the second and third reruns, before/after performance surveys were submitted to the public, in order to measure the performance impact and the level of audience engagement. The surveys were completed by approximately one hundred and thirty spectators. Participants stated that they learned new topics and that what they already knew was presented in an original and particularly clear way. In the free comments collected through the post- performance survey, the spectators proved to be enthusiastic about the approach and particularly emotionally involved. These findings document how the performing arts can represent innovative approaches to communicating complex issues and achieving social change, creating an emotional connection that conveys new values and insights.

Echoes of extinction: how an exhibition can unveil the lost world of dinosaurs through science and art

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Keywords: outreach, palaeontology, Gubbio.

"Dinosaurs in the Flesh: Science and Art bring the Rulers of a Lost World Back to Life" is an educational project made in Italy, managed by Geomodel. Since 2011, it has aimed to create a stable and lasting bridge between the academic community and the general audience. Being initially conceived as a travelling exhibition, each new instalment is designed to fully enhance the host venue and the geopalaeontological heritage of the region, allowing the public to learn about natural treasures previously largely unknown to laypersons (Romano et al., 2016).

In this regard, in 2017, "Dinosaurs in the Flesh*"* journeyed to Gubbio (Umbria, Italy) to bring to life the exhibition "Extinction. Before and after the disappearance of dinosaurs", in collaboration with the Municipality and the Department of Physics and Geology of the University of Perugia. Here, the rock strata of the Gola del Bottaccione are highly significant from a geological, biostratigraphic, and palaeomagnetic perspective, but have become famous primarily as the first evidence of the events underlying the fifth mass extinction, the most famous among those that have marked geological time: 66.0 million years ago, an asteroid the size of a mountain struck the Earth, triggering a series of catastrophic events that annihilated 75% of life forms, including the gigantic non-avian dinosaurs that had dominated the Mesozoic era (Alvarez et al., 1980).

The "Extinction" exhibition tells the story of life on Earth through the traumatic events that have marked it, the major mass extinctions, offering the opportunity to delve into a topic of burning relevance in scientific debate. Spectacular life-size sculptures, fossils, and casts are displayed in the evocative "Ex Monastero di San Benedetto", the ideal setting for a unique exhibition. Panels and multimedia content - such as Paco Lanciano's Quadrisphere - guide visitors through a fascinating journey. Ample space is dedicated to research conducted in Italy and behind the scenes: the work of the palaeontologist and palaeoartist to bring back to life the rulers of a Lost World, amidst old bones and new technologies. At the end of the journey, there is a section on the timeless allure of dinosaurs and Ice Age mammals, icons of the collective imagination and absolute protagonists of Pop Culture.

The exhibition offers a rich educational project aimed at schools of all levels: guided tours, excursions in the area, and workshops tailored to various age/schooling groups. Every weekend, there are events, activities, and workshops for the public.

The primary objectives for the coming years include: 1) the complete redevelopment of the adjacent public park (Orto San Benedetto), 2) the integration of multimedia content accessible via smartphones, 3) improving accessibility with a path for visually impaired visitors, 4) the creation of a diorama representing the last day of the Mesozoic Era, and 5) the complete transformation of the exhibition into a fully-fledged permanent museum.

Alvarez L. W. et al. (1980) - Extraterrestrial Cause for the Cretaceous-Tertiary Extinction. Science, 208(4448), 1095-1108, https://www.science.org/doi/10.1126/science.208.4448.1095.

Romano M. et al. (2016) - Taking up the legacy of Waterhouse Hawkins and Owen. Art and science for a new Italian project to bring back dinosaurs to life. Hist. Biol., 28(8), 1014-1025, https://doi.org/10.1080/08912963.2015.1089436.

How do comics help to learn about Marine Geology?

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Keywords: science communication, comics, research dissemination.

Illustrations are a good way to visualize what is not readily seen and to express ideas and concepts with images. Telling stories in pictures, comics have been proven particularly effective in science communication. Comics can serve as a valuable tool for understanding the geological exploration of oceans by providing a visual medium to depict what may not be easily observable (Farinella, 2018). Through vivid illustrations and storytelling, comics can bring to life the intricate processes and discoveries involved in exploring the depths of the ocean. They enable readers not only to visualize the geology of the ocean and scientific instruments used in exploration efforts, but also to better understand the life of scientists on board. By presenting complex concepts in a visually engaging format (Lin et al., 2015), comics make it easier to grasp the challenges and advancements in marine geology, fostering a deeper understanding of this fascinating field. Due to their sequential nature, comics strips make it easy for readers to follow a story and comprehend the concepts that are covered (Robin et al., 2021). The limited text in each panel can also help those where reading is a challenge or for those who become nervous and/or discouraged with long text passages. The illustrations also add visual clues that can aid in understanding the concepts being laid out.

Drawing inspiration from the IODP "EXP 402: Tyrrhenian Continent-Ocean transition" that took place from 09 February 2024 to 08 April 2024, the CNR ECORD-IODP and ICDP Commission has decided to use comics to engage reading for young and old alike. The "Ocean exploration issue" is aimed at primary and middle school students to spark their interest in Earth Sciences. The issue has been created by Comics&Science, a series by CNR Edizioni, as a special edition ("off-series"). The interaction with the comic book artist Alessio Spataro has helped to develop a contemporary pedagogical approach, rending science concepts such as deep-sea drilling engaging and accessible to students. The issue also includes brief texts about the history and the future of IODP, the ICDP project and the IODP-ICDP land-to-sea proposals. The issue's goal is to create a bridge between science and entertainment, both of which are relevant for individual and societal growth.

Farinella M. (2018) - The potential of comics in science communication. J. Sci. Commun., 17(1), p.Y01, https://doi.org/10.22323/2.17010401.

Lin S.F. et al. (2015) - Are science comics a good medium for science communication? The case for public learning of nanotechnology. Int. J. Sci. Educ., Part B, 5(3), 276-294, https://doi.org/10.1080/21548455.2014.941040.

Robin O. et al. (2021) - Teaching science communication with comics for postgraduate students. Front. Commun., 6, 758198, https://doi.org/10.3389/fcomm.2021.758198.

Earth Sciences in the Divine Comedy: a hidden story

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Keywords: Divine Comedy, geology, mineralogy.

Since Antiquity, Literature has numerous examples of writings that show the close and inseparable relation with Natural Sciences. Both classical authors and modern ones, have produced scientifically important works in the field of Natural Sciences, about plants, rocks, fossils, metals, minerals, etc. Goethe, for example, wrote the Theory of Colors in 1810, which demonstrates how a man of letters can be re-membered as a scientist at the same time. On this theme, the Museum of Earth Sciences of the University of Bari set up a temporary exhibition in 2015 showing fascinating and imaginative connections between the two aspects of knowledge. Although science and poetry may be considered two distinct domains in common opinion, a thin thread connects them. The examples proposed in this note start from Dante Alighieri, the famous author and man of letters endowed with great curiosity and widest knowledge, who lived in an era in which there was no clear division within knowledge. To emphasize the fascinating narratives of his great poem, the Divine Comedy (14th century), he inserted quotations of minerals inspired by Albertus Magnus' treatise De Mineralibus (13th century). Paradise and Purgatory, mention above all gemstones, including diamond, topaz, emerald and sapphire, while in Hell, in addition to helitrope (a form of chalcedony), we find precious minerals such as gold and common ones as ice, which is the glassy-looking component of the infernal lake Cocytus. In this regard, we also propose a video, which combines the sequence of the silent movie L'Inferno (Milano Films, 1911) related to the 9th circle (Hell, Canto XXXII), with the melodies obtained from the sonification of the crystalline structure of ice (I_h) according to the methodology of the project Aural Structures (Eramo et al., 2018; Candela et al., 2023). It represents an effective combination between the vintage images of the movie and the tense mood expressed by the symmetry of ice (I_h) transformed into music. Furthermore, this contribution highlights the morphological analogies between the artistic and imaginative representations of Dorè (1861), Zuccari (1586-88) and Britto (1544), and real karst environments culturally connected to Dante's travels during his exile, such as the Covolo of Camposilvano (Velo Veronese), the Tolmin Cave (Zadlaška Jama) and the Veja Bridge (Lessinia Regional Nature Park). It is said that Dante Alighieri was so fascinated by the latter that he was inspired by the description of the Malebolge, i.e. the 8th circle of Hell in which fraudsters are punished.

Furthermore, current photographic-geographical research makes it possible to draw parallels between the karst environments and the artistic representation of the artists already mentioned. This contribution also includes storytelling that blends some verses of the Poem with real images and eloquent drawings by the greatest illustrator artists of the Divine Comedy.

Candela A.M. et al. (2023) - La simmetria nel Canto XXXII dell'Inferno: versi e sonorità. In: Dante e le Scienze 1321 - 2021 Volume dell'Accademia Pugliese delle Scienze- Atti e Relazioni LVIII- pagg.89-102, ISBN 978-88-94959-03-1.

Eramo G. et al. (2018) - Aural Structures: music as a tool to describe crystals and their origin. In: Gómez Chova L., López Martínez A., Candel Torres I. (eds.), EDULEARN18 Conference Proceedings, 10th International Conference on Education and New Learning Technologies, Palma (Spain), 2-4 July 2018. IATED Academy, pp. 4098-4105, ISBN: 978-84-09-02709-5.

SIGN ME IN - accessibility and usability of MUST (University Museum of Earth Sciences) explanatory panels for deaf visitors: an analysis

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Keywords: MUST, accessibility, cultural democracy.

The art of Geoscience communication is also the art of choosing the right words for the public you want to engage. This is particularly true when considering publics with special needs. In order to promote in everyone the basic knowledge and understanding of the principles of Earth Sciences crucial to make conscious choices about environmental sustainability, climate change and the exploitation of energy resources, any obstacle preventing the widest participation in science education, especially in non-formal and informal settings, must be removed. To foster public engagement, active citizenship and cultural democracy, and in compliance with objectives 4, 10 and 11 of the Agenda 2030, any action towards accessibility of scientific contents must be taken with the involvement of the interested parties.

SIGN ME IN is a Sapienza Earth Science PhD project in Environment and cultural Heritage that aims to:

improve deaf people visiting experience of the MUST (Museo Universitario di scienze della Terra) by adapting and translating into LIS (Lingua dei Segni Italiana - Italian Sign Language) the texts of some of the explanatory panels;

make the museum's cultural offering more available also to people with low education levels and/or a low literacy in the italian language, according to the principles of UDL (Universal Design for Learning).

This project investigates the challenges deaf people may face in understanding scientific communication inside the MUST and tries multiple strategies to adapt the existing texts to suit the needs of different audiences with the involvement of a group of deaf (and hearing) students from ISISS Magarotto in Rome and a group of deaf adults. A two-year PCTO (Path for transversal skills and career counseling) involving 3 classes of senior students was carried out to work on the adaptation of 7 of the panels' texts and a LIS translation of a panel chosen by the students. This project will act as a guideline for the design and implementation of the MUST, that's currently under renovation, and for the activities that the museum will promote in its spaces.

Through the pages of the ages: conveying the unfathomable depth of time in an illustrated book

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Keywords: deep time, palaeoart, books.

*"*Tempo Profondo. La storia della vita sulla Terra*"* ("Deep Times: The History of Life on Earth"; Troco et al., 2024) is an innovative, multidisciplinary attempt at tracing the evolution of nature in all its forms, from the origin of the cosmos to the history of humanity. One of the goals of the volume is to communicate the richness of modern scientific discoveries to as wide an audience as possible, through engaging and immersing artistic and storytelling techniques. The use of oil paintings featuring novel and unexpected compositions, combined with a lively yet authoritative popularizing approach, allows readers to transport themselves into the most evocative, and almost alien, scenes of the deep past. The presence of easy-to-follow brief text sections, carefully designed as expanded captions to accompany each painting, allows for a piecemeal understanding of the multidisciplinary contents and improves the consolidation of memory retention. The book also offers an enticing large-scale perspective approach rarely before seen in similar publications, in which the entire range of historical and natural sciences is included to supply a most comprehensive history of life, i.e., cosmology, the geological and palaeogeographical history of planet Earth, the interactions between organisms and their environment, palaeoanthropology, and human history. Furthermore, this sweeping narrative extends to the development of scientific thought and addresses the challenges of modern society, from pressing ecological problems to the currently undermined legitimacy of scientific research, reconnecting the topics previously addressed in the book with modernity and the state of our planet. The readers, upon reaching the end of this expansive narrative, will perceive the events featured in the early pages as unfathomably distant, but will also acquire a strong sense of historical continuity between the deep past and the present day, and will understand the strong links that tie together all earthly ecosystems past and present. This universal worldview allows readers to embark on a journey through the ages and make sense of the vastness of the Deep Time.

Troco E. et al. (2024) - Tempo Profondo. La storia della vita sulla Terra. Piacenza: TIP.LE.CO, 464 pp.

From 'Gerusalemme Liberata' to Dante's Divina Commedia: the seismogenic hypothesis of earthquakes linked to underground winds

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Keywords: history of geology, Dante Alighieri, seismogenic theories.

Earthquakes and seismic phenomena in general have always attracted the interest and awe of human civilizations, especially in connection with the emotional impact that such energetic events could evoke following great destruction and loss of human lives. In this contribution, we analyze the earliest seismogenic theories dating back to the Middle Ages, essentially inherited from the new translations available at the time of fundamental texts including Aristotle's "Meteorologica". According to the knowledge of the time, earthquakes were connected and believed to be caused by the thrust of underground vapors and winds, with varying intensity based on the ease or difficulty these air masses encountered in traversing the "veins" of the Earth. After Aristotle, the theory that saw underground winds and vapors as the cause of earthquakes and the birth of mountain ranges is extensively found in the work of the Arab physician Avicenna Ibn Sina (980-1037), who essentially reworked the theories presented in the "Meteorologica" with his vision. Furthermore, echoes of this theory, or system of theories, can also be traced in Albertus Magnus and Ovid. In the work of Ristoro d'Arezzo published in the 1200s, the Italian cosmographer curiously compares earthquakes caused by the movement of underground vapors to gases produced and expelled from the bodies of animals (Romano, 2023). Similarly, the same comparison is found in the Commentary on Aristotle's "Meteorology" by Nicolò Vito di Gozze, this time using flatulence in the human body as an analogous phenomenon. In addition to treatises, including those of Brunetto Latini (Romano, 2020), in this contribution we show how this theory also found space in the verses of various poetic works, starting from Dante's immortal work in the Divine Comedy (Romano, 2016), but also in later works such as Cecco D'Ascoli's "L'Acerba" and Torquato Tasso's "Gerusalemme Liberata". The theory was initially embraced by the genius of Leonardo da Vinci and shortly thereafter by Bernardino Telesio (1509-1588), an Italian philosopher and naturalist who can be considered the true initiator of the new Renaissance philosophy of nature and from whom thinkers such as Descartes, Giordano Bruno, Tommaso Campanella, and Francis Bacon drew inspiration.

Romano M. (2016) - "Per tremoto o per sostegno manco": The Geology of Dante Alighieri's Inferno. Ital. J. Geosci., 135(1), 95-108.

Romano M. (2020) - La Geologia nel Il Tesoro di Brunetto Latini. Rend. Online Soc. Geol. It., 50, 39-55.

Romano M. (2023) - Geological elements in the in thirteenth-century treatise "La Composizione del Mondo" (The composition of the World) by Ristoro d'Arezzo. Ital. J. Geosci., 142(2), 217-243.

S32.

Geosciences at school 2024

CONVENERS & CHAIRPERSONS

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The dissemination of Marine Geosciences in schools as a contribution to the Ocean Literacy process: from teachers' training to hands-on activities

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Keywords: ocean literacy, marine geosciences, scientific approach.

Widespread environmental education is essential to meet the challenges of an increasingly interconnected planet whose future is at stake. Since we have just entered the UNESCO Decade dedicated to Ocean Sciences for Sustainable Development, Ocean Literacy (OL) is a way to link marine science with education for sustainability through the promotion of behavioural change and the adoption of a systems approach to marine environmental issues. The role of schools is therefore crucial in acquiring and strengthening environmental knowledge, skills, and competences, educating the citizens of the present (teachers) and those of the future (pupils). However, teachers' involvement is necessary to achieve the goal of bringing OL into the European school system in the short and long run. Therefore, to engage teachers and keep them engaged on this topic in the coming years, there is a need to combine traditional and innovative teaching methods and educational tools in integrating the content knowledge (CK) on ocean science issues, mainly lacking in the primary school, with the pedagogical one (PCK), often not considered in the secondary school. During the last 4 years, several EU projects and initiatives were dedicated to bringing OL to school (e.g., BlueS_MED, BlueNIGHTs, BlueMinds4Teachers, EMSEA, EU Blue School Network). Thanks to this, a permanent multidisciplinary working group where scientists, teachers, and young ocean ambassadors can fruitfully and continuously interact was formed. Long-lasting educational communities (Mokos et al., 2022), as well as quality, modern, and innovative educational materials and tools (Alvisi et al., 2022; Cheimonopoulou et al., 2022; Koulouri et al., 2022), were built and consolidated, giving birth to innovative teachers' training and school activities. Some of the best practices developed will be presented and discussed, including:

1. the open-access online course and digital toolkit developed as part of the BlueMinds4Teachers project () that provide teachers and educators with materials and tools, relevant references, resources, and links;
2. the practical seascape activity entitled "How deep is the sea? Discovering the underwater territory". The aim is to familiarise oneself with the 'land beneath the water' by building 3D models of sea and ocean basins using simple techniques and low-cost materials;
3. the hands-on activity on the water cycle "Water Pathways". Its aim is to: a) discover the link between water and climate and the elements needed to build the water cycle in different climatic contexts, b) explore the physical processes that transport water across continents to the sea and c) find the "water numbers" through the dedicated "Water Quiz";
4. the hands-on activity + guided tour "There's wall and wall! " to discover the link between the building materials of our historical centres, often of marine origin, and the geology of the surrounding areas.

Alvisi F. et al. (2022) - The Blue Challenge Framework: A guide for the development and implementation of Blue Challenges at schools. Proceedings of the Marine and Inland Waters Research Symposium 2022, 16-19 September 2022, Porto Heli, Greece. ISBN: 978-960-9798-31-0; ISSN: 2944-9723.

Cheimonopoulou M. et al. (2022) - Implementation of a new research tool for evaluating Mediterranean Sea Literacy (MSL) of high school students: A pilot study. Mediterr. Mar. Sci., 23(2), 302-309, https://doi.org/10.12681/mms.29712.

Koulouri P. et al. (2022) - Ocean Literacy across the Mediterranean Sea basin: Evaluating Middle School Students' Knowledge, Attitudes, and Behaviour towards Ocean Sciences Issues. Mediterr. Mar. Sci., *23*(2), 289-301, https://doi.org/10.12681/mms.26797.

Mokos M. et al. (2022) - Navigating Ocean Literacy in Europe: 10 years of history and future perspectives. Mediterr. Mar. Sci., 23(2), 277-288, https://doi.org/10.12681/mms.26989.

The sea: life's source

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Keywords: sea, pollution, protection of ecosystem.

This work comes from a Social Studies Project developed during 2023-2024 school year including the disciplines of Natural Sciences, Mathematics and Physics with the support of the teachers of the Polo Liceale in Monopoli, Lillo Arianna and Lucia Barbarito.

The III B of the Liceo Scientifico, composed of 22 students, has been subdivided into 7 groups who faced making original works on the theme of the sea, scientifically suitable (poems, podcasts, newspaper articles, stories, posters, photos). At the end of the creation of the various works, the most appreciated one that obtained the highest consensus and approval, has been chosen by the students themselves, through a process of self-evaluation, with the teachers' support.

The group who made the selected work, is composed of the students Heden Menga, Matteo Marzolla and Giacomo Ricco. Initially, they consulted a series of bibliographical scientific sources with the aim of studying the sea in its various aspects (resources, legality, ecosystems protection, sustainable transport via the sea and the life in the coastal community). Later, the group translated the acquired knowledge and its relationships in a PP presentation and in a drawing made by the technique of pastel colours (a synthesis of the content of the PP slides). Moreover, the drawing has been commented by a description - shown below- that explains in a poetical form the profound sense of the problems connected with the sea, according to the students of the group.

'Under a veiled sky, grey of smoke, the sea cries tears of oil. In the obscure abysses, the silence is interrupted by the noise of ships that discharge venoms and the corals, once shining, suffer their obscure destiny in a gloomy procession. Man, with his carelessness, has dishonoured the sea, maternal lap and cradle of life. Hope is renewed in the wave crashing against the cliffs of human indifference and in the hands of those who tear the sorrowful painting to colour a new source of life'.

The work made by Heden Menga has received the first prize at the National Competition "The citizenship of the Sea", announced by the Department of Education and the Department of Transport and Infrastructures. Giuseppe Valditara, Minister of Education and the Deputy Commander General Admiral Inspector Sergio Liardo awarded the student during a ceremony held in Reggio Calabria on 11th April 2024, during "The Sea Day and the maritime heritage".

Science Nights at the High School Complex in Monopoli (BA)

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Keywords: celebration of scientific culture, dissemination activities, workshop activities.

During the 2023/2024 school year the "G. Galilei - M. Curie" High School in Monopoli (BA) hosted the sixth edition of "La Notte delle Scienze" (The Night of Sciences), an event aimed at promoting scientific culture. The event stems from the teamwork of teachers from the Departments of Natural Sciences, Mathematics and Physics, Sports Sciences, with the collaboration of Art History and Philosophy teachers, and students from all high school addresses, with the aim of opening the doors of the Institute to the community through scientific dissemination activities (conferences with nationally and internationally renowned speakers) and workshop activities (carried out in various Biology, Chemistry, Earth Sciences, Physics, and Computer Science laboratories). The students were the undisputed protagonists, lively and brilliant, and they were able to positively infect guests and all attendees with their enthusiasm.

Throughout this year, experts, researchers engaged in internationally resonant projects, such as Dr. Massimiliano Morelli, Prof. Domenico Mavilio, and Prof. Francesco Colucci, presented on topics related to the fascinating field of Biotechnology, accompanied by students who acted as moderators, presenters, and animators.

In all editions, we aimed to draw the attention of young people, and beyond, to the importance of scientific culture in our society to better understand the world we live in. Scientifically relevant topics were addressed in various sectors such as moon landing, complexity of biological systems, fake news in the scientific field, and climate change. Among the laboratory activities, there were in-depth studies on rocks, karst phenomena, and numerous experiments conducted by students. Seminars by qualified experts were particularly stimulating, such as Telmo Pievani's "The virus of fake news: what vaccine," Piergiorgio Odifreddi's "The two cultures: humanism against Science," Donato Boscia's "Xylella in Puglia: an annoying truth," and Mario Tozzi's "Science, misinformation, and fact checking." In the first edition, guests included Colonel Vitantonio Laricchia, who spoke about "Climate change," the IPSP-CNR Research Group and DiSSPA University of Bari, with "The case of annoying Xylella," Prof. Domenico Di Bari with a seminar titled "How is the Universe made? The physicist's story," Dr. Ciola Gianfranco, with the seminar "Coastal environments between nature and tourism," and Dr. Alessio Perniola, with the theatrical workshop "Magical Science: theater, magic, and science." These are just a few of the speakers and disseminators who participated in various editions. Over the years, this event continues to represent for the entire school community and the citizens of Monopoli and neighbouring towns, an opportunity for growth, discussion, and celebration of scientific culture.

An experimental approach to improving the teaching-learning process in the geosciences

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Keywords: geosciences literacy, inquiry-based learning, instructional model.

How can the teaching-learning process in the field of Geosciences be made more effective? Geosciences are difficult disciplines, because of their complexity and articulation, and this makes the teaching – learning process challenging. In order to implement an effective didactic approach teachers should have a solid geological background that allows them to structure effective activities characterised by inductive approach, innovation and engagement. Furthemore, most teachers don't dedicate the right amount of time to the Geosciences, and the deductive approach to teaching scientific disciplines is widely used. In order to overcome these difficulties we have designed an instructional model based on the literature data (Hoffman & Ritchie, 1998; Bybee, 2014; Ambrose et al., 2017) on how we learn, that can be used with different inductive methodologies and for all type of topics. The model has been applied in the framework of the PLS/PNRR project in two different high schools in Sicily and has been proposed to the Lyceum students from the third to the fifth year. In this context the pathway aims to guide students towards discovery by investigating the causes, evidences and effects of Climate Change. As detectives, the students collect "clues" through real data, observations, tools and use investigative techniques that allow them to piece together the current complex climatic process in its general aspects. The objectives are to develop knowledge, skills and competences in the Geosciences and the way Geoscientists study the Earth. This is important to acquire Geosciences Literacy and to educate citizens who make conscientious and sustainable decisions for our planet. The path consists of four activities building on inquiry-based learning, each addressing an aspect of the Global Climate Change. For each activity a different methodology which place the student at the centre of the didactic action in order to promote the construction of learning has been used. Each activity is included in the instructional model that is developed in 3 phases: preparation, construction and evaluation. In order to explain this framework, we will present one of the four activities, according to the DGBL methodology, regarding the main cause of Global Climate Change. The students are guided step by step in the learning process, and they are given a "Pre-Test", a "Post-Test" and a metacognition survey. The Pre-Post Tests are designed to evaluated the success of the activity and its effectiveness in developing the Geosciences Literacy, while the metacognition questionnaire is structured to assess the students' satisfaction with the activity and to make them aware of their cognitive path, and preconceptions and misconceptions. The data obtained shows that there has been an improvement in skills and knowledge acquisition. Furthemore, an improvement of competences development in Geosciences Literacy and consciousness of what it means to be a Geoscientist has been recorded.

Ambrose S. A. et al. (2017) - Come impariamo. Sette principi per un insegnamento efficace. Edizione Italiana a cura di Dany Maknouz. Zanichelli, 239 pp., ISBN 9788808520708.

Bybee R. W. (2014) - The BSCS 5E instructional model: Personal reflections and contemporary implications. Science and Children, 51(8), 10-13.

Hoffman B. & Ritchie D. (1998) - Teaching and learning online: tools, templates, and training. In Society for Information Technology & Teacher Education International Conference. Association for the Advancement of Computing in Education (AACE), 119-123.

Caving and hiking activities for promoting knowledge and landscape preservation

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Keywords: geodiversity, environmental conservation, speleology and hiking.

The "G. Galilei - M. Curie" High School in Monopoli (BA) has implemented over the past four school years the "Speleo-Trekking Course" Project, aimed at promoting the knowledge and protection of the local territory, starting from the identification and documentation of geological, geomorphological, karstic, and vegetational aspects. One of its objectives is to provide basic knowledge in order to introduce students from different educational paths to spelunking and trekking in a totally safe way.

The activities were developed with the involvement of Natural Sciences teachers and the support of experts from the tourist promotion agency Puglia Escursioni and the Italian Society of Environmental Geology SIGEA-APS (an environmental protection association recognized by the Ministry of the Environment).

The educational program, which includes approximately 25 students at the Institute, was carried out through the attendance of:

4 two-hour laboratory meetings, during which basic concepts of geology, spelunking, and natural elements of the local landscape were introduced;

4 field trips, during which students had the opportunity to visit several locations near Monopoli, some nearby caves, and practice trekking on tested routes in the municipal territory and surroundings.

Participants in the Project were able to enrich their knowledge of local territory and to acquire skills related to the curricular activities of Earth Sciences (types of rocks and their properties, karst processes and phenomenology) and Biology (types of local vegetation and ecological balances).

Students from all classes of the High School Complex had the possibility to visit some sites of naturalistic, geological, speleological, and vegetational interest in their vicinity. The specialized guides of Puglia Escursioni and SIGEA-APS (geologists, spelunkers, foresters) were able to convey precise information, raising awareness about safeguarding the local territory.

Participation in the Courses allowed students to realize the importance of safety in hiking, to practice caving and hiking movement techniques, to understand the main aspects of the local landscape. The students involved appreciated the project activities, and some of them expressed their interest in continuing this experience, by participating in future courses and/or enrolling in proper spelunking courses. Over the years, the Project, included in the Institute's Educational Offer Plan and evaluated as a relevant "experience" for the PCTO (Paths for Transversal Competences and Orientation), continues to represent an important opportunity for an in-depth study of topics related to Earth Sciences.

Outdoor science experiments, hands-on learning in nature: the Nirano Mud Volcano (NMV, Fiorano Modenese, Italy) open-field laboratory

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Keywords: environmental geology, mud volcanoes, open-field laboratory.

Mud volcanoes (MVs) are part of the "sedimentary volcanism" due to their morphological resemblance to igneous volcanoes and are characterized by the uplift of sediments and fluids (Martinelli & Judd, 2004; Mazzini & Etiope, 2017). They are widely diffused and, although not always as fascinating as "ordinary" volcanoes, no less investigated by various disciplines, e.g. botanics, microbiology, geophysics, geomorphology, geochemistry and structural geology. In particular, they are taken into account for hydrocarbon prospection, mainly gas, since they are mostly located in petroliferous basins and constitute the second natural source of CH4 (Sciarra et al., 2019) and as earthquake precursors (Martinelli & Judd, 2004).

In Italy, MVs occur in both Northern and Central Apennine and in Sicily (Martinelli & Judd, 2004; Sciarra et al., 2019). Nirano mud volcano (NMV) of the Emilia Romagna region is one of the biggest in Italy, situated close to a small anticline in the outcrop of the Plio-Pleistocene "Argille Azzurre" clays (Martinelli & Judd, 2004), and is widely investigated for the gas composition (Mazzini & Etiope, 2017). Thousands of people of all ages and levels of education visit this magnificent area every year. Master geology students from the University of Ferrara, the course "geochemical prospecting", have been putting into practice the theoretical geochemical skills of measuring in-situ temperature, pH, and electrical conductivity, as well as collecting water and mud samples for analyses (X-Ray Fluorescence, XRF; Inductively Coupled Plasma Mass Spectrometry, ICP-MS; Ion Chromatography, IC; Elemental Analyzer for coupling to Isotope Ratio Mass Spectrometers, EA-IRMS) in the laboratory.

The results of their curiosity and abilities focused on the geochemical composition of NMV mud and water, as shown during the second Italian Geochemistry Society congress. The aim of this work is also to raise and increase awareness of peculiar geochemical threats in the national territory at many levels using the NMV area as an open-field laboratory, which is suitable for everyone interested in improving their geological knowledge and understanding and the processes occurring in the Earth crust (fault formation, fluid circulation, and earthquake indicators). In particular, this outdoor experience fits very well with exploring teens, who can make first-hand observations, mud, water and gas sampling (be prepared to get hands dirty!) and experience simple analyses on the field, such as pH, EC, and water salinity measurement throughout specific probes.

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Mazzini A. & Etiope G. (2017) - Mud volcanism: An updated review. Earth-Sci. Rev., 168, 81-112, https://doi.org/10.1016/j.earscirev.2017.03.001.

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The didactical experience of the "Laboratory of climatology and environment" of the Master Course in Environmental Science of the University of Pisa

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Keywords: geoscience comunication, high school, Massaciuccoli Lake.

In the 2020 the master course in Environmental Science of the University of Pisa promoted a convention with the Viareggio Municipality, thanks to a financial support of the "Fondazione Cassa di Risparmio di Lucca" to develop a laboratory on the shore of Massaciuccoli Lake, for monitoring climate and environmental conditions as part of wider project of environmental protection. The selected area has a great environmental value, and it belongs to the Migliarino San Rossore Massaciuccoli Natural Park, and it is a protected area by RASMAR convention, it is an archive to study past climate condition, but it also has several environmental issues (e.g. eutrophication, salinization). Although motivated by scientific interest, the main aim of the initiative was to create a scientific structure on the territory able to involve local administration, school and local community to disseminate geo and environmental science knowledge. Specifically, the Laboratory wanted to promote active interaction of local school to disclose scientific methods applied on the environment and the climatic system, as a part on long term continuous support of the geo and environmental sciences. In the last three years the laboratory promoted important initiatives with primary and secondary school and was recognized as an important centre for innovation in the didactical methods (https://labclimambiente.dst.unipi.it/). Among the others (e.g. #io_sono_ambiente project; Adotta_una_duna Project) the lab hosted the project LAGOrà promoted by High School G. Galilei Viareggio that passed the national competition Science on stage and will be presented this year at Science on stage Europe. The project and the lab would like to transform the Massaciuccoli Lake in an open lab for monitoring and analyses of environmental data. High school students had the opportunity to work tougher with Phd Students, University students. Students of Industrial Technical Institute and Scientific High School of Applied Sciences realized low cost monitoring instruments used in didactic and in research activities. Thanks to the lab activities, Administrative Entities acquired new data improving the territory knowledge and its management. The scientific activity promoted by the laboratory and supported by local institutions also produced important scientific achievements (Bini et al., 2020; Luppichini et al., 2021; Luppichini et al., 2022; Luppichini et al., 2024).

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A nationwide effort to engage secondary school students in geology - The new Progetto Nazionale Geologia of the Piano Lauree Scientifiche

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Keywords: piano lauree scientifiche, geology, secondary school.

The Piano Lauree Scientifiche, known simply as PLS, was born twenty years ago as a joint initiative of the Italian Ministry of University and Research, the Confindustria association and con.Scienze, the national conference of directors of structures and articulations of science and technology of universities. Its initial mission was to strengthen the recruitment of students in Chemistry, Math and Physics. After then, the PLS expanded to include all scientific disciplines, including geology. Today the whole PLS comprises 9 scientific disciplines that involves more than 260 operative units throughout the Italian university system. The new 2023 call of the PLS has three main aims: to increase student recruitment and reduce the student dropout, to close the gender gap in STEM (Science, Technology, Engineering and Math) enrollment and to reduce social and economic barriers to access the university education system. The duration of this new PLS call is nominally 4 academic years, from 2022/23 to 2025/26.

The Progetto Nazionale Geologia features all the 28 public universities that offer the 1st cycle degree in Geological Sciences and its main activities are: 1) active orientation for enrollment in the Geological Sciences degree, 2) training of tutors to contrast the dropout rate within the first year of enrolment, 3) design and implementation of indoor and outdoor laboratory activities for the secondary school students and teachers, 4) design of self-assessment and knowledge recovery pathways for university entrance, and 5) professional development of secondary school science teachers.

To date, most of the initiatives of the Progetto Nazionale Geologia are aimed at the active orientation of prospective students (44% of all initiatives, n = 239) and the laboratory activities (40%), the latter often involving experiences outside the classroom. This reflects (a) the urgent need to increase the number of students enrolled in a Geological Science degree, given the nearly 20% loss of enrolled students in 2022 compared to 2018 and (b) the firm belief that field experiences are those that add value to a Geological Science degree. Almost 10% of the initiatives of the Progetto Nazionale Geologia is aimed at the professional development of the secondary school science teachers, who generally have a background in biology and related disciplines and are keen to improve the quality of their teaching of geology.

Our contribution will outline the essentials of the new Progetto Nazionale Geologia of the PLS and will showcase a few examples on how we reach the secondary students to make them discovery geology and its societal impacts.

A journey in the Caput Mundi geodiversity

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Keywords: geoheritaghe, urban geology, education.

Within the framework of the initiatives for the dissemination of Earth Sciences knowledge promoted by the Geological Survey of ISPRA, a project called "Conoscere la Geodiversità" was proposed to secondary school students. In particular, the project was carried out with four fourth-year classes of a scientific high school in Cisterna di Latina.

The project was articulated in three different moments.

A workshop dedicated to the recognition and classification of rocks was held at first. The workshop consisted in an initial theoretical part where the basic concepts of minerals and rocks, the rock cycle and their classification into igneous, sedimentary and metamorphic rocks were explained. The second part of the workshop was practical and was dedicated to the identification and classification of rocks by the students. A "dichotomous key" approach was chosen, in which choosing the correct definition among those proposed in the recognition path allowed the students to arrive at the definition of the chosen rock (Schirolli, 2012). Some of the stages of the recognition path, in addition to the simple observation of the samples with the help of magnifying glasses, included physical (hardness, determination of the specific weight of the rock) and chemical (reactivity of the rock with acid) tests.

The second meeting of the project was dedicated to a theoretical lesson on the concepts of geodiversity, geological heritage and geosites. On this occasion, ISPRA's inventory of Italian geosites was presented and illustrated to the students, and a search was made for the geosites listed in the inventory closest to the school, with a brief description of their characteristics. The meeting ended with an excursion on the geological history and geodiversity of the Roman territory, a preparatory moment for the third meeting. The third day of the project was dedicated to an urban excursion in the centre of Rome to discover the geodiversity of the city and the relationship between geology and urban development (Pantaloni et al., 2023). The itinerary started at the Basilica of San Clemente, followed the Via dei Fori Imperiali from the Colosseum to Campidoglio, and ended at the churches of Baroque Rome (Santa Maria sopra Minerva and Sant'Ignazio di Loyola), where it is possible to admire the decorative stones from the different areas of the Mediterranean basin that belonged to the ancient Roman Empire. This excursion was previously proposed to other high school students on the occasion of the second World Geodiversity Day, 6 October 2023. In this case, which only included a visit to the city, a lecture (after the excursion) proved necessary to clarify many issues that could not be dealt with on the day. From this test came the idea of holding the workshop on rock identification and the lecture on the geology of Rome before the field day. Questionnaires were given to the students to assess their involvement and interest after the three project days.

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Pantaloni M. et al. (2023) - Rome before Rome: a river among two volcanoes. Discovering the relationship between the history of the city and the territory. Geol. Field Trips Map., 15(1.5), https://doi.org/10.3301/GFT.2023.05.

Georesources: finding the perfect mixture between science and dissemination in PCTO activities

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Keywords: georesources, dissemination, PCTO.

The critical role of georesources and the environmental footprint of human activities in shaping the current and future societies are sometimes overlooked by the public, especially by the youngest generations. Mining is often associated with environmental threats and dangers while the importance of georesources is greatly underestimated or, worse, neglected. This could be a major issue as social acceptance will be pivotal in the implementation of mining in EU countries as required by the 2023 Critical Raw Material Act. The responsible exploitation of georesources is a key requirement to reshape the current economic model into a more environmentally friendly one while still maintaining a sustainable economic growth. In the framework of PTCO (Paths for Transversal Skills and Orientation) activities we have organized a 15-hours project aimed to sensibilize students to the needs and risks of mining activities. Laboratories, movies, frontal lectures, thought experiments and interactive visits to the Earth Sciences facilities at University laboratories have been organized paying attention to keep high levels of engagement and participation through the involvement of the students in the activities and an informal context. The project has so far been presented to 19 high school classes and over 360 students. Following each cycle, students were invited to fill a three-minute anonymous questionnaire to evaluate the project offering valuable insights for further improvement and development of the activities. The general evaluation was positive to highly positive for all the activities. Not surprisingly, the most appreciated one was that at the University lab facilities, which was deemed by the majority "too short", highlighting the need to produce more active-oriented environments to engage the students.

Teaching geosciences with ChatGPT during the first year of an upper secondary school

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Keywords: ChatGPT, teaching, learning.

Chatbots are computer programs based on artificial intelligence (AI) that can answer human questions in a chat-like manner. They are now publicly available and can generate a wide range of features including text, images, videos, software code and so on. One of the most famous chatbots is ChatGPT. Since its launch in late 2022, it has generated an exponential growth of excitement and concern among science teachers and educators, who are discussing risks and opportunities of chatbots in the learning and evaluation processes (Cooper, 2023).

In this contribution we explore (1) the attitudes of science teachers and students of a Istituto di Istruzione Superiore towards generative AI tools and (2) the use of ChatGPT as a collaboration coach, i.e., students enter prompt into Chat GPT to complete learning tasks during a part of the geoscience curriculum. We considered two first-year classes attending the Earth in the Solar System topic: one class used ChatGPT to assist their learning activity while another class used more conventional learning activities without the assistance of AI-based chatbots. We will discuss the results of our experiment, our decisions about the content, structure and timing of the learning activities, and the challenges we faced in terms of the accuracy of the information retrieved by the students.

Cooper G. (2023) - Examining Science Education in ChatGPT: An Exploratory Study of Generative Artificial Intelligence. J. Sci. Educ. Technol., 32, 444-452, https://doi.org/10.1007/s10956-023-10039-y.

Building bridges between academia and high school: the experience of "Open river Laboratory" project (in the framework of Percorsi per le Competenze Trasversali e l'Orientamento)

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Keywords: environmental school education, urban river ecosystem, citizen awareness.

The study and monitoring of water resources are increasingly important, not only for better understanding natural processes but also for evaluating the human impact on ecosystems. The winning key for the study of environmental ecosystems is therefore a transversal and multidisciplinary approach, which requires technical-scientific skills but above all a strong propensity towards the surrounding environment. Added to this is the need for training aimed at all levels. Based on these considerations the research group coordinated by prof. Elena Comino, with the support of the AKANoah student team of the Department of Environmental, Land and Infrastructure Engineering (DIATI), proposed the "Open River Laboratory" training project for high school students. The project has two objectives: the first offer to the students an opportunity to better understand the value of water resources and environmental monitoring, with particular reference to the topic of micro and macroplastics, the second give to high school students a first opportunity to begin themself towards a university future.

In the framework of the whole school approach, the integration of university research with basic level education activities takes on a leading role in the process of greening the school and makes environmental education a central component of schools curricula. The value of academic research for the development of environmental education high school is often overlooked. However, what better utility could academic research have other than promoting awareness and spreading knowledge to the younger generations? There is a lack of research in the role of academia, in terms of its utility as a tool for social improvement through environmental education. Specifically, the creation of environmental and sustainable education programs will form the citizens for tomorrow world.

In the poster we will start by describing the project idea and the implemented methodology, which is not only for this specific project, but more generally the importance of creating a connection between Academia and High School will be underlined. The results achieved, both by the students and by the teachers involved in the "Open River Laboratory" project, will be referred, as a case study. The strengths of the project itself will be underlined by suggesting approaches to the integration of academic research in institutions of high school in the form of best practices

Findings show the benefits that can be obtained from the involvement of the academy in the creation of environmental and sustainable education programs. First, the academic involvement bridges the gap between high school and research world by providing continuity to the very role of teachers and educators alike. Second, the dissemination of results of pedagogy and sustainability research to a larger public and staff involved in the development of educational programs and their implementation, it would promote awareness and dissemination of knowledge on multiple levels, vertically and horizontally. Finally, the analysis of different experiences underlines the advantageous role of academia in facilitating the development of educational experiences which create critical reflective thinking.

Geosciences through the eyes of primary school students: a visual journey

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Keywords: children drawings, perception of science, statistical analysis.

Starting in 2005, the Istituto Nazionale di Geofisica e Vulcanologia (INGV), initiated a project involving the creation of calendars designed for schools, featuring drawings from a contest for primary school children. Each year, schools eagerly participate by submitting pupils' drawings on specific themes, which vary annually and align with Earth science subjects. Engaging primary school children in this project serves a dual purpose: it brings them closer to science and provides an opportunity to explore their perspectives on the Earth, science, the environment, and sustainable behavior. In fact, children's artwork can offer valuable insights into their feelings and thoughts about the world and its workings. Drawing plays a crucial role in children's development, as it fosters imagination and serves as an effective means of expressing emotions.

Over the years, we have collected more than 35,000 drawings. We have decided to analyze this extensive and unique dataset by comparing drawings related to competitions with similar and comparable main topics, such as children's perceptions of science, scientists, and their views on the Planet Earth, its sustainability, and its future. The methodology involves a qualitative and statistical analysis of the drawings, representing the first comprehensive comparison of drawings created by primary school children across the entire Italian territory. This spans a decade or more, providing insights into how children's visions of Earth science subjects have evolved over time.

Furthermore, the results contribute to evaluating how science is portrayed, assessing whether it has fostered a shared understanding and a less stereotyped image. Additionally, we aim to examine how environmental science and sustainable behavior are conveyed to the future leaders of the world.

STEAM project to raise young people's awareness of land protection

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Keywords: STEAM, Matilda effect.

The aim of this work is to describe the activities of the inter-school project, financed by the Puglia Region (Schools in STE@M). Matilda effect: a stereotype to overcome is the name of the project.

Secondary school students involved in the plan of activity, worked in an inclusive climate between three different schools in the Bari area.

The first step was to visit the Lama Picone. The blades, which starting from the highest points of the Murgia and following the inclination of the land, head towards the sea, were formed over time by the dissolution of limestone rocks, constituting natural channels.

The involved students photographed and recognized the plant species of the area, learning to appreciate their characteristics: from colors to scents, to finally recognize some properties in the geometry of nature, such as symmetries and self-similarity (fractals).

From the knowledge of the rich native botanical heritage we moved on to the creation of a prototype, through the art of images (photography) and 3D modeling (autocad) up to the creation with a 3D printer.

REKHOVER-Science: REalizing Kits for HOspitals to Visualize EaRth Sciences

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Keywords: inclusion, education, hospital school.

One of the primary goals of institutions is to promote activities with an inclusive approach, to cancel physical and social barriers that prevent the individual fulfillment.

The REKHOVER-Science project, led by the Department of Earth Sciences at Sapienza University of Rome, aims at developing hands-on kits to support Earth Science education in Hospital Schools.

Hands-on experiential activities have been demonstrated to be highly effective as learning tools, enabling users to visualize concepts and enhancing learning by involving all senses. This is particularly significant for Earth Sciences, which are often overlooked in school curricula, despite their relevance to pressing environmental issues.

The general project objective is to provide hospitalized or homebound students with access to laboratory experiences to augment their learning. These kits will be co-designed with teachers from Hospital Schools or involved in home education services from the Hospital School at the “Bambino Gesù” Pediatric Hospital, the “Policlinico Umberto I” University Hospital, and the “Agostino Gemelli” University Polyclinic in Rome, covering primary, secondary and high-level education. Working groups are being formed with teachers from various institutions to identify concepts and topics in the field of Earth Sciences that require laboratory kits for hands-on activities, aiming at enhancing understanding through practical engagement. Co-designing is crucial because it enables the creation of kits tailored to specific needs and personalized training plans, ensuring maximum functionality.

The kits will be practically developed by children and young adults from Roma Capitale within workshops held at the Technotown creative science hub at Villa Torlonia, which will provide both space and expertise for designing and practically implementing the laboratory kits during the second phase.

Interdisciplinary approaches in geoscience education: exploring the application of entomology in ichnoentomology

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Keywords: ichnoentomology, geosciences, interdisciplinary-education.

This study presents an innovative approach in the field of ichnoentomology, a discipline focusing on the analysis of insect fossil traces, situated within the geological context of ichnology. This expanding research area unveils new horizons in paleoclimatology by leveraging the observation of insect fossil traces to identify humid and arid periods associated with Dansgard-Oeschegert (DO) (high frequency climate changes) events, providing insights into paleoenvironmental conditions from late Pleistocene related to insect activity.

One limitation of this discipline is that, from various perspectives (sampling, statistical analysis, morphological studies), ichnoentomology is still predominantly regarded as a branch of geology, and thus studied solely from a geological standpoint. The work elucidates an intriguing biological perspective grounded in entomology. Through a mentoring project within the doctoral school of the University of Sassari, students from the Faculty of Agriculture explored the challenges of scientific research in an attempt to integrate two seemingly distant disciplines: geology and biology.

The educational approach centered around problem-solving methodologies, fostering an interactive exchange of knowledge across diverse domains: on one hand, the dissemination of geological research to an audience with a biological background, and on the other hand, the welcoming and assimilation of new perspectives from students and the professors in the entomology course. In fact, during frontal lectures, research challenges were presented, followed by engaging discussions and Q&A sessions with students.

The mentoring program was structured over a total duration of 30 hours, divided into laboratory activities (25 hours) and instructional sessions (5 hours). Concurrently, the entomology course, valued at 3 CFU, aimed to provide students with a comprehensive understanding of insect morphology, anatomy, and physiology, as well as biological cycles and population dynamics, with a focus on recognizing major groups and species harmful to agricultural crops.

The findings underscore the importance of interdisciplinary education in geosciences, promoting inclusivity and diverse teaching approaches. Collaborative learning enriches students' educational experiences and prepares them for multidisciplinary challenges in academic and professional contexts. Emphasizing geosciences education for students from diverse backgrounds highlights its multidimensional nature, enhancing their problem-solving abilities from various perspectives.

Geoscientific school heritage: from the past to the future

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Keywords: geoscientific school heritage, Collegio Nazareno, Joseph II.

A considerable amount of literature has been published on school-museum partnerships. However, relatively few studies investigate school museums, particularly natural history school collections. This work presents the recovery, study, cataloging, and valorization of the 18th-century geo-mineralogical collections belonging to the Mineralogical Cabinet of the Collegio Nazareno (Crocetti et al., 1997), one of the most important Roman institutions for the study and learning of physical and natural sciences in the modern era. The collection is now housed at the Istituto San Giuseppe Calasanzio (Roma).

The project, which was participated in by science and history teachers along with the students enrolled in the fourth- and fifth-grade high school classes, retrieved 1724 geo-mineralogical samples. All the recovered specimens and their accessory parts (i.e., original display containers and labels) were photographed and inventoried in an online database to be used to program cross-curricular learning activities. Two hundred samples were cataloged using the national standard for the cataloging of mineralogical and petrographic heritage (BNM and BNPE catalographic standards) issued by the Istituto Centrale per il Catalogo e la Documentazione (ICCD), part of the Ministry of Culture, and published in open access on the Catalogo Generale dei Beni Culturali database. The results of this study found that most samples were collected by renewed naturalists such as Scipione Breislak and Giuseppe Gismondi or donated to Collegio Nazareno's Mineralogical Cabinet by popes and prelates (e.g., Pio VI and the Cardinal Stefano Borgia) together with members of the Italian and foreign nobility (e.g., Francesco Maria Ruspoli, Prince of Cerveteri and Karl Theodor, Elector of the Palatinate). The most striking finding was the recovery of the geo-mineralogical collection donated by the Holy Roman Emperor Joseph II of Habsburg-Lorraine in 1785 (Mottana et al., 2012). This collection is the only one that can be attributed with certainty to Joseph II since no other samples, kept in natural history museums preserving 18th-century Habsburg geo-mineralogical collections, show proper labeling (Franza & Pratesi, 2023). Joseph's II collection and 250 specimens from the general collections were displayed in the new permanent exhibition area.

In conclusion, this work proved that geo-mineralogical school museum collections can be positively used as scientific-educational tools in object-based learning experiences to promote science literacy (Franza & Pratesi, 2024). For instance, the cataloging activities, included in PCTO plans, represent valuable tools for developing interdisciplinary proposals even in traditional classroom lessons. The case study illustrated in this work showed that geo-mineralogical school museum collections are a unique heritage deserving to be rediscovered and made accessible to anyone interested in learning more about the history of geoscientific education.

Crocetti G. et al. (1997) - Il Museo Naturalistico Mineralogico del Collegio Nazareno. Il Cercapietre, 7-24.

Franza A. & Pratesi G. (2023) - Dono Imperiale. La collezione mineralogica dell'Imperatore Giuseppe II al Collegio Nazareno di Roma. Firenze University Press, Firenze, 102 pp., https://doi.org/10.36253/979-12-215-0235-0.

Franza A. & Pratesi G. (2024) - Learning Sciences from the Past: Recovery, Study, and Cataloging of a Historical Natural History School Museum. Educ. Sci., 14(1), 80, https://doi.org/10.3390/educsci14010080.

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Can the interdisciplinary approach be an asset for teaching Geosciences in Natural Sciences?

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Keywords: Geosciences, natural sciences, interdisciplinarity.

The need to consolidate and facilitate the teaching of Geosciences in Italian upper secondary schools has been evidenced by several studies (Greco & Gualtieri, 2010; Realdon et al., 2016; Furfori I. et al., 2023; Gravina T. et al., 2023). To investigate the possible effectiveness of interdisciplinary pathways in the Natural Sciences, with a focus on the Geosciences, in upper secondary school, some teaching programs were designed and realized with an interdisciplinary approach linking geosciences, biology and chemistry. The objectives of these teaching paths were: (i) to assess the feasibility and effectiveness in introducing or consolidating the teaching of Geosciences; (ii) to examine whether such paths can facilitate the teaching of Geosciences to Natural Science teachers who do not have specific training in geology. Three schools were involved in the study: ITIS, Liceo Classico and Liceo Scientifico. The classes involved were first through fourth year, with the ITIS offering a course in environmental biotechnology. The schools were contacted by e-mail, sent to school principals, explaining the purpose of the project and asking for contacting and starting a cooperation with the Natural Sciences teachers themselves. After contacting interested teachers, in several meetings, both in person and online, the teaching materials to be used were presented and discussed/adapted and the time frame was agreed upon. Seven pathways were proposed, from which three were chosen:

1. A survey of geodiversity and biodiversity for the Agenda 2030 Goal 15 - Life on Earth. Aim: understanding the relationship between biodiversity and geodiversity and the importance of preventing environmental depletion.
2. Oceans: hydrosphere and biosphere for the 2030 Agenda Goal 14 - Life Under Water. Aim: investigating the relationships between the Earth's different spheres.
3. The carbon cycle: Where does a tree's carbon come from? Aim: understanding how the inorganic and organic worlds are connected in this biogeochemical cycle.

To investigate the previous students' knowledge (including informal and nonformal one) of the chemistry, biology and geosciences topics that would be covered, a pre-test, consisting of 10 multiple-choice questions, was provided in each pathway. These questions were the starting point for examining the topics together. The teachers involved were asked to fill out a questionnaire in order to verify how effective this type of approach really was in improving the teaching of Geosciences in the upper secondary school.

Furfori I. et al. (2023) - Geosciences in Natural Science and Civic Education in Italian upper secondary school: is interdisciplinarity a resource?. In: The Geoscience paradigm: resources, risk and future perspectives. Abstract Volume, National Congress SIMP, SGI, SOGEI, AIV, Potenza (Italy), 19-21 settembre 2023.

Gravina T. et al. (2023) - Earth science teaching in Italian Upper secondary school: the floor to Natural Science teachers. In: The Geoscience paradigm: resources, risk and future perspectives. Abstract Volume, National Congress SIMP, SGI, SOGEI, AIV, Potenza (Italy), 19-21 settembre 2023.

Greco R. & Gualtieri A. (2010) - Studio geologia perché... Risultati preliminari sull'indagine quali-quantitativa relativa alla scelta del corso di laurea in Scienze Geologiche. Geoitalia, 30, 38-41, doi:10.1474/Geoitalia-30-19.

Realdon G. et al. (2016) - Teaching Earth Sciences in Italian Liceo High School following the 2010 reform: a survey. Rend. Online Soc. Geol. It., Vol. 40, 71-79, https://doi.org/10.3301/ROL.2016.74.

Didactics and dissemination in the field of georesources: the experience of the GeothermiX 2023 conference

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Keywords: geosciences, georesources, natural sciences.

Between November and December 2023, the "Geothermix" (http://geothermix2023.dst.unipi.it/index.php/en/) conference took place in Pisa. It was organized by PhD students of the Department of Earth Science of Pisa and addressed various aspects of geothermal energy, from specific studies on geothermal areas and technologies used to obtain the energy resource, to the didactic activity needful to correctly disseminate the geothermal energy concept. With a dedicated session, one of the main objectives was also to share innovative teaching methods and detailed information to provide teachers with the necessary tools to develop such topics effectively.

The main goal of the session concerned teaching and dissemination in the georesources sector and in particular for geothermal energy, sharing different teaching methodologies and insights to provide tools for teachers in developing these issues (Invernizzi et al., 2011). Several aspects have been considered in the different presentations. Among these: the potentialities of introducing an ecocentric perspective in geoscience teaching, founded on the relationships between humans and Earth, and how this can affect the discussion on geothermal energy; the geothermal energy for thermal energy production and storage and its integration in multivalent district heating and cooling grids; examples of innovative Geosciences Education through Episodes of Situated Learning, ESL (Piangiamore & Maramai, 2024), as interactive teaching tools for geothermal resources; didactic approaches for geothermal energy and sustainability; a laboratory approach on geo-resources; a survey on the presence of geothermal energy in the curriculum (topics dealt with at school) in Tuscany upper secondary schools (Indicazioni nazionali per i licei, 2010).

Indicazioni nazionali per i licei (2010) - Indicazioni nazionali riguardanti gli obiettivi specifici di apprendimento concernenti le attività e gli insegnamenti compresi nei piani degli studi previsti per i percorsi liceali, DPR 15 marzo 2010, n. 89.

Invernizzi C. et al. (2011) - Realizzare una comunicazione biunivoca: i linguaggi del progetto "energie". Museologia scientifica, 8(1), 98-103.

Piangiamore G.L. & Maramai A. (2024) - When the past teaches the future: earthquake and tsunami risk reduction through episodes of situated learning (ESL), Geosci., 14(3), 65, https://doi.org/10.3390/geosciences14030065.

Geological narratives, a new approach to assensing skills

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Keywords: IBSE, elaborate phase.

IBSE, Inquiry-Based Science Education, offers the possibility of developing consolidated skills not only in knowing how to do but above all in knowing how to think, argue and transfer what has been learned into new contexts. The IBSE teaching action is based on the 5E cycle, the 5 phases: Engage, Explore, Explain, Elaborate and Evaluate. Creating didactic learning units with this approach is not easy and there is a risk of achieving it only partially by having to resort to missed lessons, the "program" to be finished, grades, etc. This work presents a learning unit on "minerals and rocks" created in a third class after understanding chemical bonds.

The Engage phase consisted of reading two newspaper articles on the "Fibronit" case in Bari and the damage caused by asbestos. Some stimulus questions were thus asked through brainstorming, "what is asbestos?", "what are minerals?", "which minerals do you know?", "are all minerals dangerous?" to bring out prior knowledge on the topic. A double Explore phase followed, a first phase of searching for information on minerals and their characteristics followed by a laboratory phase in which the students found themselves having to try to classify unlabelled minerals on the basis of their characteristics and properties such as the crystalline appearance, the scratching, the reaction with dilute solutions of hydrochloric acid and the colour.

The Explain phase consisted of arguing and explaining their classifications. At this stage they were also asked to explain the danger of asbestos minerals.

From minerals to rocks it was a short step. The term "rock" had already appeared in the initial brainstorming and now, looking at a granite, the students are able to say that it is an aggregate of minerals but recognize minerals in other types of rocks is not easy. Engage's trigger question becomes "why don't we see minerals in all rocks?".

The following Explore and Explain phases follow the same approach as that of minerals with study of the different characteristics of the rocks and subsequent recognition and classification phase. For the Elaborate phase it was the most surprising one. The students were asked to write a story "Imagine you are a rock or a mineral and talk about your life, your expectations, your fears....". The students, after choosing the mineral or rock to give life to, further researched themselves by inserting references into the text on the use of different materials today as in the past, thus creating imaginative stories but with solid scientific bases, some were able to insert interdisciplinary ideas with the use of materials in the history of art, exceeding the teacher's wildest expectations.

For the Evaluate phase, all student feedback, participation, laboratory activities, multiple choice questionnaires and the final paper were used.

Fostering inquiry and engagement in Earth Science: designing and testing a specialized curriculum for Italian liceo students

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Keywords: upper secondary school, Earth science teaching.

In the Italian upper secondary school system, Earth science is included in the Natural Science curriculum, mandatory for a specific 4-year period. However, Italian natural science teachers often overlook Earth Science in favour of Chemistry and Biology (Greco & Gualtieri, 2010). Gravina & Iannace (2023) investigated the challenges of teaching Earth science in Italian upper secondary schools through a survey and explored the type of support needed for Earth science education. The findings underscored the necessity for new teaching materials in Earth Science that align with National Guidelines, particularly regarding the allocation of hours dedicated to Earth Science lessons.

Therefore, we have embarked on developing a specialized 5-year Earth science curriculum tailored specifically for Liceo students (Classico, Linguistico, Scientifico, Scienze Umane) that fully aligns with Italian national guidelines. The curriculum focuses on the following key points:

- Adherence to national guidelines concerning knowledge, methodologies, and skills;
- Integration of inquiry-based learning and historical approaches;
- Utilization of authentic Earth Science data and reliable sources;
- Adoption of a STEM approach.

This curriculum is designed to provide engaging and hands-on Earth science lessons, specifically addressing the challenges faced by teachers who may not have a background in geology. Additionally, comprehensive lesson plans have been developed for each activity within the curriculum. These plans encompass references to national guidelines, digital resources for hands-on activities, civic education components, and assessment rubrics. The curriculum underwent review by a group of Italian upper secondary school teachers during a focus group aimed at gathering feedback and finalizing it before implementation in schools. The participants of the focus group were selected from a pool of teachers who responded to a call shared within the online teacher community. The selection process aimed to form a group that could adequately represent the Italian teacher community in terms of geographical diversity, years of teaching experience, and educational background. Additionally, we decided to invite two expert teachers with extensive experience in teaching earth science. Participants analyzed the proposed Earth science curriculum, identifying strengths and weaknesses in its conceptual design and organization of materials. In this contribution, we present the results of the focus group and how we utilized them to finalize the curriculum. Furthermore, we discuss teachers' remarks regarding Earth Science education in Italian upper secondary schools.

Gravina T. & Iannace A. (2023) - Earth science teaching in Italian Upper secondary school: the floor to Natural Science teachers. In: The Geoscience paradigm: resources, risk and future perspectives. Congresso congiunto SIMP, SGI, SOGEI, AIV, Potenza (Italy), 19-21 Settembre 2023.

Greco R. & Gualtieri A. F. (2010) - Studio geologia perché... Risultati preliminari sull'indagine quali-quantitativa relativa alla scelta del corso di laurea in Scienze Geologiche. Geoitalia, 30, 38-41.

Advancing geoscience education in Italy through teacher professional development: insights from the EGU-GEFO field officer initiative

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Keywords: geoscience education, earthlearningidea, european geosciences union.

Although Earth Sciences are part of both primary and secondary school curricula in Italy, they are not given enough attention in Natural Science education. Moreover, these subjects are often taught by teachers who do not have the necessary academic qualifications (e.g., Realdon et al., 2016; Bonaccorsi et al., 2020). This issue, which is prevalent in several European and non-European countries (King et al., 2021), has been worsened in Italy due to the limited availability of professional development opportunities for educators in the field of geosciences.

In 2018, the Committee on Education (CoE) of the European Geosciences Union (EGU) suggested improving the professional development of teachers through a pilot initiative, which involved the appointment of Geoscience Education Fieldwork Officers (GEFOs). Four school and university teachers from EU countries (France, Italy, Portugal, and Spain, funded by EGU) and two from India and Morocco (funded by International Union of Geological Sciences-IUGS and the International Geoscience Education Organisation-IGEO) were trained to run interactive hands-on workshops tailored for "teachers of science or geography who incorporate some geoscience into their teaching but have limited expertise in this area." The workshops utilized teaching resources from Keele University' Earth Sciences Education Unit, which were developed by the late professor Chris King and have been available in the Earthlearningidea open access repository since 2008 (https://www.earthlearningidea.com).

In 2022, after the period of forced interruption due to the COVID-19 pandemic, the GEFO project was extended to include the training of additional fourteen GEFOs from various countries, such as Albania, Burkina Faso, Chile, Colombia, Estonia, Germany, Greece, India, Malaysia, Romania, Togo, Turkey, and the United Kingdom. Since 2019, GEFOs have organized 156 in-person workshops, with approximately 3000 participants, 23 conferences and webinars, published research papers and teaching articles, fostering the diffusion of geoscience teaching among a growing global education community.

The purpose of this presentation is to showcase on the outcomes of the Italian GEFO program and highlight the relevance of conferences in promoting workshops as an opportunity for teacher professional development and sharing of best practices.

Bonaccorsi E. et al. (2020) - Student enrolment in geology from a systemic earth science education perspective: An Italian case study. Eur. Geol., 50, 34-38.

King C. et al. (2021) - International comparisons of school-level geoscience education–the UNESCO/IGEO expert opinion survey. Int. J. Sci. Educ., 43(1), 56-78.

Realdon G. et al. (2016) - Teaching Earth Sciences in Italian liceo high schools following the 2010 reform: a survey. Rend. Online Soc. Geol. It., 40, 71-79.

MACMAP: a student-designed game to simulate multidisciplinary climate change progect

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Keywords: climate change, educational game, MACMAP project.

MACMAP is a project funded by INGV and devoted to study climate evolution in the Mediterranean and polar regions. The period of interest covers the recent past to the near future.

Important components of the project are the interdisciplinary approach to study climate, the data sharing and management of data following international standards and best practices, the support of observing systems and the integration between measurements and models, with the aim to provide more accurate indicators of the ongoing climate change. The topics covered span from atmospheric sciences to oceanography, from space to sea level studies, from seismological to geochemical and glacial sciences. A peculiarity of the project is also the historical approach to climate change in the past. An attempt has been made to extrapolate historical oceanographic data by ancient volumes, in detail by the book considered one of the first treatise about oceanography: Histoire physique de la mer of L.F. Marsili (1725). This activity was possible, amongst the others, through the study of the volumes of the collection preserved at INGV's historical oceanography library. In addition, MACMAP puts a particular emphasis on outreach activities, to bring to the public's attention both the issues being addressed, the research process being used to study this topic. For this purpose the design of an "educational-scientific game" was planned, covering the topics involved in the project and drawing the attention to the importance of the multidisciplinary approach, both addressing specific project activities and more broadly scientific research in general. INGV has long experience in creating this type of games (Garvani et al., 2017; Locritani et al., 2020), but in this case the novelty lies in the involvement of high school students who designed the game directly, through a School & Work Project (PCTO - Percorsi per le Competenze Trasversali e l'Orientamento) supervised by their Science, Physics, Art and Foreign Language teachers, and in collaboration with the research centers (INGV and CNR's Institute of Marine Science (Merlino et al., 2019). The rules, the game strategies and the drawings are completely prepared by the students during the school time in 2022/2023 and 2023/2024. Before releasing the final version, a tryout will be organized to identify and correct potential errors. Then the resulting final version will be made available (downloadable online and printable at home on paper or cardboard) and printed in larger size for use during temporary exhibitions, educational workshops, schools' open days, science festivals, etc.

Garvani S. et al. (2017) - Games As Educational Tools in eARTh Science: MAREOPOLI and THE ENERGY CHALLENGE. In: EGU General Assembly Book of Abstracts 2017, European Geophysical Union (EGU), 6760 pp.

Locritani M. et al. (2020) - Fun educational and artistic teaching tools for science outreach. Geosci. Commun., https://doi.org/10.5194/gc-3-179-2020.

Marsili L. F. (1725) - Histoire physique de la mer, Amsterdam.

Merlino S. et al. (2019) - Shortening the Distance between Students and Ocean Challenges Towards Greater Integration of Marine Science into School Curricula. J. Ocean Technol., 14(2), 43, https://doi.org/10.19080/OFOAJ.2019.10.555783.

Geology in down town: easy fieldtrips for learning Earth sciences out of school

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Keywords: out-of school learning, urban geomorphology, effectiveness of teaching activity.

The historical centers of cities offer many opportunities to talk about Geosciences. Ancient buildings are often made from local stones which can tell the geological, economical and cultural history of the area. Very often the first settlements from which our cities originated were built in places with natural defenses, such as next to river or close to natural reliefs, and the history of their evolution goes hand in hand with the geomorphological changes of the area.

Here, we offer a short guide consisting of three activities to carry out in cities crossed by rivers. The case study is the town of Pavia and the starting point was the urban geomorphology and geocultural heritage work published by Pelfini et al. in 2020.

The guide presents three distinct activities:

– a geomorphological fieldtrip to discover the landforms of the river landscape and their integration with the urbanization of the city;
– a geological - lithological fieldtrip with the recognition of the different lithotypes present in the buildings of the city centre;
– a practical activity directly on the river bed with observation of the modern depositional and erosional features, the anthropic defense systems and the river sediments.

The guide is designed to be used by teachers not only in Pavia schools since the practical activities are easily extendable to other similar contexts. For each activity, the guide reports educational goals, class targets, keywords, additional materials to view before going out into the field and a trace of the observations that can be made during the activity with images or simple portable experiments. The activities also include the collection of photos and short videos that can be used by students create short documentaries or presentations useful both for the acquisition of transversal skills and for the evaluation process. The three fieldtrips include increasing levels of difficulty and student participation and are easily adaptable to the age of the participants. The activities are connected to each other but can be carried out at different times and even in different school years.

The effectiveness of the geomorphological fieldtrip was verified in 3 high school classes (Liceo Scientifico Copernico di Pavia): a first-year class with few rudiments relating to fluvial geomorphology, 2 fifth-year classes with greater preparation.

The students participated in pre- and post-activity surveys and a good level of learning and correction of misconceptions emerged. The activity was appreciated by the students who actively participated, demonstrating the educational effectiveness of out-of-school activities.

Pelfini M. et al. (2020) - Papai civitas gloriosa: urban morphology for a thematic itinerary on geocultural heritage in Pavia (Central Po Plain, Italy). J. Maps, 17(4), 42-50, https://doi.org/10.1080/17445647.2020.1736198.

Two virtual reality tools to enhance earthquake and tsunami awarness

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Keywords: virtual reality, earthquake, tsunami.

Knowledge is the basis for risk reduction and the dissemination of knowledge of Geosciences to the widest possible audience it's an essential goal to increase awareness towards natural events.

Making people aware of the correct behaviour to adopt in case of an earthquake and/or a tsunami is one of the skill of science communicators. Therefore, researchers are constantly searching for new appealing methodologies to communicate science arousing public interest.

The BET-VR (Big Data Earthquake and Tsunami-Virtual Reality) project of INGV uses Virtual Reality for visualization of earthquake and tsunami. Virtual technology has interesting educational potential, allowing an immediate approach that carries the users into a reality where they can learn in a direct way. Considering children's high comfort level with smart devices and gaming, portable devices for education could have a positive impact on children's interest and engagement. Therefore, the virtual reality represents an innovative and unconventional forms of knowledge transfer. Exploring geophysical phenomena, such as earthquakes and tsunamis, through digital tools like virtual reality, can certainly facilitate the understanding of these processes and, consequently, enhance the natural risk perception.

The BET-VR is mainly addressed to children of Primary School but it can be also performed for the dissemination to general public. The general purpose is to increase awareness of the risks related to earthquakes and tsunamis through the knowledge of the main characteristics of these natural events. To this end, dedicated 3D environments have been designed, aimed to achieve a most effective embodiment edutainment.

Concerning earthquakes, the "3D Earthquake journey" virtually lead the children inside the seismogenic structure originating the 2016/2017 seismic sequence in Central Italy. Simulating a person's physical presence in that specific environment, the users stand in a privileged observation point, acquiring relevant geological and seismological information during the journey.

The "3D Tsunami journey*"* is focussed on the tsunami topic: through two virtual characters facing a tsunami, the user virtually experiences this event, learning the main concepts and acquiring the correct behaviour to adopt in case of a tsunami.

Virtual reality is entirely digital and immersive, isolating the user from the external environment. By wearing a specific helmet visor, he is transported into a completely absorbing parallel reality and through the controllers he can interact or move within the digital world.

Thanks to the very realistic immersive scenarios, this didactic software is a very useful tool for scientific dissemination, engaging children with geophysical topics as earthquakes and tsunamis.

It also allows to explore the potentials of entertainment technologies in educational processes and it contribute to innovative Technological Enhanced Learning (TEL) pedagogies for scientific learning.

A web virtual world activity on critical minerals in smartphones for 14-years old students

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Keywords: critical mineral, web virtual worlds, education.

Critical minerals are essential components in the manufacturing of smartphones, playing a crucial role in their functionality. These include indium for touch screens, lanthanum and europium for displays, lithium and cobalt for batteries. These minerals enable the high-tech capabilities of modern smartphones (Bookhagen et al., 2020). The extraction and processing of these minerals have significant industrial and environmental impacts and social issues (Berthet et al., 2024). Understanding the importance of critical minerals is crucial for fostering awareness among students about sustainable consumption, the environmental implications of technology, and the geopolitical complexities of mineral supply chains. Education can empower individuals to make informed decisions regarding the use and disposal of technology, and it can inspire innovation in recycling and alternative materials. (Helmi & Zwolinski, 2020). Web virtual worlds, such as Framevr, are suitable platforms for collaborative projects (Jeong, J. et al., 2022) acting as online repositories and exhibits in schools. They are engaging educational scenarios for students, which can share ideas and divide jobs according to the project-based learning approach.

The activity described here, targeted to K8 students (14-year-old) aims to improve the knowledge of the properties and uses of critical minerals, especially those used for smartphone components. The experimentation (total time 1 month) was divided into four steps:

1. a lecture held by a researcher of the National Research Council (CNR) to introduce the concept of critical elements and their importance
2. students' semi-guided web research to get information about critical minerals
3. organization of the retrieved contents in a virtual exhibition using multimedia presentation, images, online games and 3D models.
4. definition of a phase of assessment to evaluate the students' work on the platform and the acquired knowledge, using multiple choice and true/ false questions (online test).
5. a survey to determine the students' opinion about the activity

Based on observations of students' behavior, test, survey and the virtual exhibition, the results are highly satisfying . Students got good mean test score on knowledge acquisition, cooperated during the team works and were highly involved in the activities. They appreciated the possibility to carry out the project in autonomy and judged positively the experience.

Berthet E. et al. (2024) - Assessing the social and environmental impacts of critical mineral supply chains for the energy transition in Europe. Global Environ. Chang., 86, 102841, https://doi.org/10.1016/j.gloenvcha.2024.102841.

Bookhagen B. et al. (2020) - Metallic resources in smartphones. Resour. Policy, 68, https://doi.org/10.1016/j.resourpol.2020.101750.

Helmi B.R. & Zwolinski P. (2020) - Development of educational contents on circular economy and critical raw materials challenges. Procedia CIRP, 90, 759-765, https://doi.org/10.1016/j.procir.2020.01.132.

Jeong J. et al. (2022) - Virtual Reality Collaborative Platform for E-learning: Analysis of Student Engagement and Perceptions. Proceedings of the 27th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), 202210.52842/conf.caadria.2022.1.019.

The learning process in Geosciences: analysis, evaluations, and proposals

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Keywords: curricola, education approaches, unexpected connections.

The fragility characterizing the teaching and learning process of Geosciences throughout the educational cycle in Italy, as well as in many other countries, is unfortunately well known, despite data clearly showing how environmental and geological issues are universally prevalent in all these countries. This situation persists even though Geosciences represent the discipline most implicated in the Sustainable Development Goals of the UN's 2030 Agenda. Geosciences are indeed directly relevant and serve as repositories of content related to environmental issues, including risk factors such as global warming or extreme weather events, as well as economic aspects such as georesources for energy transition or the search for critical raw materials.

The study presents the results of research conducted through a long process of experiences, workshops, and projects aimed at schools of different levels, but particularly focusing on final classes, which are particularly interesting for university and professional orientation choices. The main objective is to understand the reasons for this lack of attention to this discipline and to try to find some ideas and solutions to make it more attractive, particularly by analysing the teaching and learning process.

Several factors contributing to the construction of the teaching and learning process of Earth Sciences have been analysed. Some historical and intrinsic peculiarities make this process particularly problematic: the lack of unity and disciplinary cohesion that makes it difficult to build an epistemological identity, the difficulty of constructing meaningful experimental approaches, the progressive structure of ministerial curricula, often limited to lists of information distributed with little coherence in the school path, not integrated into other disciplines, in a metacognitive process based on assumptions and a sequence of events and information that does not favour the construction of reasoned knowledge.

A substantial modification of methodological approaches that avoid frontal communication valorising effective communication styles, the use of experimental practices that, even through the use of new technologies, promote investigative activities even in virtual environments, a radical revision of the curriculum and learning path that promotes the understanding of processes, and cycles, the complexity of phenomena of global dynamics, to replace the current fragmentation of notions, often reduced to a checklist of names, devoid of prerequisite and above all connections with the geographical, geological, and historical context, effective collaboration between the school system and academia, which, each for its competencies and experiences, builds collaborations and bridges aimed at producing a different vision of a Science for the Earth.

Soil ecosystem: STEM approach for developing scientific thinking

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Keywords: soil, exploration, science education.

In order for education to produce meaningful and lasting learning, it is necessary to implement skills-based teaching at school (GUUE, 2006). Earth Sciences are naturally multidisciplinary and allow for a strong connection between theory and practice starting from real and complex situations, as suggested by STEM guidelines promoted by the Italian Ministry of Education since 2023 in all school levels. With this contribution, we aim to provide an example of a possible active didactic approach aimed at building scientific thinking from early childhood (Onida, 2021), with increasing levels of formalization throughout the entire educational path. A fragment of soil is a small, complete and precious ecosystem, whose care and conservation is very important for global climate change. Its observation allows us to put into practice a methodology based on learning by doing and Inquiry science education. The research process is at the heart of the proposal and generates curiosity, questions and discovery possibilities. It starts with a systemic approach, at the core of ecological thinking that encourages the search for interconnections between parts. Then, the different components (organic and inorganic) of the soil sample are separated based on their physical variables by implementing classification and seriation procedures (Arcà & Guidoni, 2008). Observing living beings, both plants and animals, allows for understanding the relationship between structures (how they are made) and functions (nutrition, support, movement, vision, etc.). Observing how animals move and what they eat also confronts us with the key ideas of life sciences related to the growth and development of living organisms in relation to the flows of matter and energy (NRC, 2012). Exploring the inorganic parts of the soil allow us to investigate the relationship between the structures and properties of matter, discretizing an apparently continuous material like soil: from stones to sands to clays, separable through the use of sieves or water decantation. Thus, it is discovered that the soil is made up of particles of different sizes, each of with different absorption, filtration and retention properties. From here, different paths can be taken depending on the school level, from sensory manipulations to consistency transformations with the younger ones, to the exploration of non-visible components (microorganisms collected with the Berlese funnel, presence of air, water retention, pH) or to the study of original rocks and minerals, in progressively higher grades. The important thing is to maintain the focus on working methodologies, implementing real research paths to promote the development of STEM skills. These methodologies are inherently inclusive and allow the involvement of everyone at any age, contributing to strengthening motivation to learn and fighting the gender gap.

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#Io sono ambiente, a laboratory path on education for sustainable development in the "I.I.S. Duni-Levi", a secondary school at Matera (Southern Italy)

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Keywords: environment, education, sustainable development.

The October 2023 saw at the start of the "# Io sono ambiente" (I am the environment) project, a secondary school project devoted to the education for sustainable development. The "I.I.S. Duni-Levi" Secondary School of Matera (southern Italy) was part of the network of schools that have joined the "#Io sono ambiente " project, aimed at the diffusion of the values of environmental protection and sustainable development, and whose school leader was the Liceo Ginnasio Statale "M. Cutello and C. Salnitro" of Catania (Italy).

The school classes 3^B of the "Liceo Classico E. Duni" and 3^D of the "Liceo Artistico C. Levi" were involved in the project, based on an agreement between the "I.I.S. Duni-Levi" of Matera and the "Dipartimento di Scienze della Terra e Geoambientali" of the Bari University (Italy).

The activities were performed at school and in the field with the aim to study natural events that during the geological eras moved plates and led to relative variations of the sea-level, inducing deep changes in the observed/analyzed region. Students were encouraged to understand how, through a careful reading of the territory and the analysis of marine fossils found in present-day exposed areas, it is possible to trace the presence of the Mediterranean Sea in past geologic history of the region and to reconstruct the climatic variations that have affected the same region over time.

Adopt-a-Dune project: use of 'virtual adoption' and citizen science approach to increase knowledge and raise student awareness on coastal systems management

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Keywords: coastal environment, citizen science, geoscience at school.

Sand dunes are typical component of lowland coastal landscape. Fascinating formations, they are also fragile habitats that suffer from human impact and natural hazards. They have an important function in coastal dynamics by counteracting beach erosion and saline waters ingression. Many countries have designated dune and sandy areas as protected sites to preserve their unique ecosystems and prevent further damage due to human intervention.

The aim of this project was to bring the pupils closer to the coastal zone with a special focus on dune formations and evolution. They used different types of investigation tools and technologies to carry out multi-perspective research activities, supported by their teachers and mentored by a team of experts in different disciplines. The activities took place during the school year 2023-2024 with a citizen science approach. This made it possible not only to understand with direct experience the peculiarities of the studied fragile system, but also to collect data useful for scientific research purposes.

The project used the "virtual adoption" of the stretch of coastline located in the locality of Marinella di Sarzana, near La Spezia. Here, a previous LIFE project took a stretch of beach away from seaside use to make it an SCI area within the Montemarcello Magra Park. Thanks to this action, the dunes that were once typical of this stretch of coastline are being reformed in this area.

The pupils then began to learn about the Site of Community Interest through introductory classroom lessons and then monitored it in the field, between November 2023 and May 2014, through its sedimentological, geomorphological, and ecosystem components, also assessing any human impact on it. As part of the activities, the students had access to the dune to carry out sampling and measurements based on the knowledge acquired in the classroom training. The sampling activities were supplemented with an aerial survey carried out with a drone. All the data collected were analyzed and integrated in order to draw up a final report of the activities. They will also produce audiovisual and multimedia material dedicated to dissemination and awareness-raising activities on the importance of dune systems. The pupils acquired theoretical and practical knowledge and skills in scientific tools and methods that may be useful to them in their further studies and possible future work. The activities can be continued by their peers of future classes with the intention of maintaining the adopted site in good health.

Acknowledgements: This project received financial support thanks to the #iosonoAmbiente Call for Proposals of Ministry of the Environment and Energy Security. Participation in the Call for Projects includes the establishment of a network of schools: IIS Capellini-Sauro (lead partner), ITCT Fossati-Da Passano, ISA13 and ISA8, all in La Spezia province. The project was accredited by the EUBLUESCHOOL network, present on the European ATLAS of the SEAS.

IN-MUST: for an inclusive Earth Sciences museum

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Keywords: inclusivity, sustainability, PCTO.

In the last decades inclusiveness has become an integral concept in the valorization of museum exhibitions for informative and educational purposes. Indeed, the aim of cultural institutions has shifted from simply increasing the numbers of visitors to adopting valorization strategies to make exhibition venues more receptive to social changes and universally accessible.

The IN-MUST project (funded by Sapienza Third Mission Grant) aims at creating an open culture hub model, where the exhibits are co-designed through the synergy and cooperation of different social actors.

The project is focused on the University Museum of Earth Sciences (MUST) at Sapienza University of Rome and is aimed at finding inclusive strategies for the dissemination of issues related to the objectives of the 2030 Agenda in a dedicated space inside the museum.

A dedicated Path for transversal skills and career counseling (PCTO) IN-MUST was organized to involve schools and teachers in the project with the aim of highlighting both the importance of a sustainable global development of planet Earth and the need to create an inclusive society open to all.

The PCTO started in January 2024, and involved, for the first year, 8 high schools in Rome and districts (169 students), whose students were challenged to design and develop exhibits for visitors with special needs. The activities included an initial training to provide tools on sustainability, the 2030 Agenda and the Museum as well as an introductory meeting with associations or bodies that support the activities of people with different disabilities.

The exchange and discussion with those associations resulted in 15 different projects on the themes of risk and resources that the students presented in Sapienza at the end of March 2024 and that will be included in the executive project for the MUST renovation.

European Museums' Night 2024: understanding radiometric dating through a scavenger hunt inside the MUST (Museo Universitario di Scienze della Terra, Sapienza)

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Keywords: hands-on activities, radioactive decay, MUST.

Hands-on activities are experiential learning opportunities that allow students to engage with a topic through direct interaction. These "learning by doing" activities achieve, through the active involvement of the participants, an improved understanding and a long term retention of the studied topics. Hands-on activities allow to see, touch, manipulate, hear and even smell or taste aspects of the learning material, in a process that caters to the needs of students with different learning styles. When involving collaboration and teamwork, hands-on activities are also powerful tools to improve students' soft skills. Such tools, if introduced in dissemination and outreach activities, can have an effective impact in enhancing the understanding of difficult topics (e.g. the concept of deep time) by the general public. For this reason, during the European night of Museums 2024, at the Sapienza University Museum of Earth Sciences in Rome (MUST), children and young adults were offered the opportunity to join a scavenger hunt and to date their geological find. This activity used recycled materials such as bottle caps and paper clips to build specimens that explain the basic concepts of radioactive decay and half-life. The participants witnessed radioactive decay "in real time" by manipulating the specimens and watching the caps "decaying" into paperclips and then proceeded to the radiometric dating of their own sample based on its caps to paper clips ratio.

Raising environmental awareness in the students through geosciences: the educational importance of geotrails

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Keywords: geotrails, education, nature paths.

In a student's educational path, adopting an experimental scientific approach holds the utmost significance. Within this framework, the laboratory serves as a pivotal educational setting, offering valuable learning opportunities both in the classroom and the field. Geosciences are particularly indicated for field-based laboratory activities, thus serving as a useful tool for facilitating the learning process. Indeed, through these activities, educators can effectively provide students with essential skills, such as the ability to draw logical connections, discern and establish correlations, generate hypotheses based on available data, and critically and consciously engage with scientific and technological subjects, by the journey's end. In this scenario, nature trails constitute the best educational laboratories to implement a tailored teaching approach across various student classes (Huguet et al., 2019; Palacio Prieto et al., 2019), as these trails serve as ideal learning spaces, catering to both elementary school students engaged in nature exploration and description, and high school one approaching into deeper interpretations from initial observations.

The aim of this contribution is to highlight the importance of two educational geotrails selected on the base of their geological aspects to underline their effectiveness for teaching geosciences. One of these trails is located on the southern flank of Mount Etna, where distinctive features of the volcano have been pointed out and chosen for educational activities conducted directly in the field (Punturo et al., 2019). For each of these features, a corresponding informative panel has been created and installed along the pathway. The second one, is located on the left bank of Loddiero river Valley, (Scordia, Italy) where the stratigraphic relationships between Plio-Pleistocene tholeiitic and alkalic lavas as well as the morphology of an ancient lava delta can be observed. Furthermore, along the pathway it is visible the complex interplay of subaerial and submarine volcanism, eustatic sea level variations, and shallow water carbonate sedimentation (Sturiale et al., 2016).

This nature trails showcases various distinctive volcanic and sedimentation features ideal for on-site educational activities. These educational approaches are crucial to promote people engagement with geosciences, encourage student enrollment in geology courses, and increase broader environmental awareness and appreciation.

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Ocean Literacy beyond knowledge: investigating ocean connections among a sample of children in Friuli Venezia Giulia (N-E Italy)

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Keywords: ocean literacy, ocean connection, content analysis.

The Ocean Literacy movement, born twenty years ago in the US, initially focused on the dimension of knowledge by issuing the Ocean Literacy Principles that every adult should know, also highlighting communication and responsible decision-making as skills needed to be an ocean literate citizen (NOAA, 2021). In recent decades, though, Ocean Literacy has been evolving and including multiple dimensions, with the final goal of achieving a desired pro-environmental behaviour change.

According to social psychology research, behaviour change is a complex issue, affected by different internal and external factors, which can foster of hinder the achievement of this goal. Among the internal factors, emotional connections seem to have an important role in affecting human behaviour (Kollmuss & Agyeman, 2002). Starting from these elements, we undertook a survey among 146 children (age 8-14) attending workshops on Ocean Literacy run in 2023 in different settings: a sailing school, a summer camp in a Marine Protected Area and a school located about 30 km from the coast. The used tool was an was an anonymous post-it note written by the children in response to the question "what is the sea to you?" and collected before running the workshops. This procedure was authorized by the adults in charge of the children's groups and in accordance with EU GDPR. The answers were processed by means of inductive content analysis (Bengtsson, 2016) performed by three independent coders (science teachers), who first developed a list of categories, then agreed on a consensus list and used it for an independent analysis of the children's texts. The categories identified in the students' answers largely fall within the dimensions of Ocean Literacy recognised by McKinley and colleagues: knowledge (descriptive remarks on biological and physical aspects of the sea), emotional connections (e.g., joy, peace, freedom), access and experience (leisure, memories), awareness (ocean as source of life, anthropogenic impacts) and attitudes (need for sea protection) (McKinley et al., 2023). Despite the use of a very basic tool, children's answers expressed an interesting range of concepts, with a significant share of answers related to knowledge and emotions about marine environment. Also, the awareness of the importance of the sea for life evidenced an unexpected connection, given respondents' young age; on the other side, the many comments on leisure at sea were obvious for children. Finally, we can infer that the proximity and experiences of coastal environment gave our sample an advantage in developing multiple connections with the sea that could lead to pro-environmental behaviour over time.

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Education and training activities in the frame of the ecological transition: insights from the Earth and Geoenvironmental Sciences context

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Keywords: teaching, inquiry, geoscience.

In the context of teaching tasks related to the "Earth and Geoenvironmental Sciences", it is essential to preserve the value of "situated" scientific knowledge, in which theorization is strictly connected to direct experience, and to promote methodological approaches capable of generating applications in daily teaching activities. To these aims, in situ field surveys, together with laboratories and the use of suitable software that allows for numerous preparatory and in-depth individual activities, appear indispensable.

In this work, we present the activities and outcomes concerning the educational course "Geological risk and ongoing climate change: environments and laboratories for education and training in the frame of the ecological transition". It was organized by the Polo Pugliese of the "I Lincei per la Scuola" Foundation in the year 2023/24, and it has been carried out at the Department of Earth and GeoEnvironmental Sciences of the University of Bari Aldo Moro (Bari, Italy), as part of the educational project "Lincei for a new didactic in the school: a national network."

The training course was attended by teachers who, through laboratory activities, the use of freely accessible web platforms and software (e.g., Google Earth, QGIS), and field trips, were able to experience a methodological approach based on research (inquiry), fruitful of applications within their classrooms.

The results achieved in terms of participation and educational spin-offs are encouraging: teachers identified different disciplinary areas in which to place the scientific-based information and developments learnt during the attended course, proving capable of comprehending the necessary multidisciplinary vision for the analysis of current and expected environmental issues.

Disaggregation of geological dissemination activities in focused initiatives: "hands-on" approach for stimulating geological curiosity and knowledge

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Keywords: geology, dissemination, citizen science.

Geology covers a social role that is not perceived by people not familiar with Earth Sciences, especially in countries, such as Italy, where the awareness of the role of geology in everyday life (both in terms of scientific knowledge, risks, and resources) is limited. When considering the different aspects of geology, it becomes evident that dissemination of this science requires to split the geological knowledge in a set of themes that, despite their common Earth Science background, need to be faced separately.

The experience of hands-on activities in different contexts (such as schools, associations, exhibitions) of a working group from the universities of Rome La Sapienza and Milano Statale led to the identification of geological "targets" distinguished for age (from primary school students to retired persons), scholarity level (from basic schools to college and PhD) and society roles (schools, hospital, third sector institutions or general public).

Activities were grouped in a few main themes according to their appeal to the public: 1) origin and evolution of life and its adaptation to natural conditions, studying real fossils; 2) condition of formation and possible modification of minerals and their synthetic equivalents; 3) development of natural systems by the study of rocks; 4) origin of raw materials, their occurrence and the possibility to partially re-use them; 5) drawing of geological maps and transfer of geological concepts and models into paper sheets or digital support; 6) definition, evaluation and mitigation of natural risks.

Each of these themes has been illustrated with one or more activities: a) associating fossils to reconstruction of organisms (vertebrate and invertebrate, with real fossils and resin models); b) observing microfossils with a stereoscopic microscope; c) observing physical (such as hardness and cleavage) and optical properties of minerals (including fluorescence); d) observing rocks and minerals with polarizing microscope; e) raw materials in rocks and their use for everyday life (applications to everyday objects and to electronic devices); f) "true or false" game, to understand the difference between natural fossils/minerals and artificial ones; g) geological maps as tools to describe the 3D geology of Earth (including digital representations of geological maps in Google Earth); h) simple simulation of liquefaction processes in earthquakes. Furthermore, specific activities have been realized for visually impaired people (but also to explain this situation to people with regular visual).

The planning of these activities highlights that the exposition on a desk of specific objects and instruments triggers curiosity in the public, that was easily involved, frequently asking also for specific topics related to the exposed objects. The possibility to touch real objects (minerals, fossils, rocks, meteorites) is a greatly appreciated experience, and is a great opportunity in introducing geological reasoning.

"Nella fucina di Efesto": a new teaching project to promote meaningful geological learning. Peer tutoring from high school to primary school

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Keywords: vulcanology, education, peer tutoring.

Geology addresses some of the most important issues our society has to tackle nowadays. This includes issues like green energy and sustainability, climate change, the impact of industrial development on the environment, water management, mineral resources and natural hazards. Actually there is no significant geological learning issue in the curriculum of the Italian "Liceo Sc. ordinamentale", as it mainly focuses on biology and chemistry (Roca & Garcia-Valles, 2020). The focus of this project is therefore on Italian volcanoes, in particular in the Eolie Islands. Educators seek research-based learning practices that can facilitate students' access to contents like "Volcanoes" by means of inclusive learning activities, in particular for special-needs students. The project purpose is twofold: firstly, to train older students about causes, composition and structure of Italian volcanoes, secondly how to pass it to Primary School (PS) children. It is a peer tutoring approach that brings together students of different ages: Highschool Students (HS) as tutors and PS stud. as tutees (Topping et al., 2004; Xu et al., 2008). First of all HS stud. learned about the causes, composition, types and history of Italian volcanoes with a geologist. The project work/learning activities started with an overview of the Earth's inner structure, the formation of volcanoes and their shapes. HS were taught about the different types of (volcanic) eruptions, how to identify igneous rocks and how scientists may predict eruptions and volcanic hazards. After indoor activities, students experienced some outdoor sessions in Eolie Islands.The practical experience, supervised by two experienced volcanologists, included: volcanic gas sampling system with sodium hydroxide ampoules, thermocouple for high temperature measurements of fumaroles, thermal imaging camera and multi-gas component analyser, pH meter and conductivity meter for measurement of pH and conductivity in water, environmental water analysis kit and petrographic microscope to observe rocks sections. In a second time, HS students were paired with PS ones to pass volcanological content suitable for the children's level. HS students prepared creative activities to engage the children in hands-on games about plate tectonics, the formation of a volcano, lava density and the formation of Italian volcanic eruptions. HS stud. were engaged in active learning and kept updated about their progress. The "Nella fucina di Efesto" project not only taught HS stud. about the huge variety of volcanoes and their main characteristics, i.e. different types of eruptions, but it also provided them hands-on learning experiences that required teamwork in order to successfully complete the assignments. The mix of traditional teaching methods, outdoor experiences and peer tutoring, gave teachers the opportunity to take advantage of the different skills in an inclusive way, thus making earth science learning accessible and fruitful for everyone.

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The GEOLAB experience at the DiSTAR (University of Naples Federico II, Italy)

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Keywords: outreach, geoscience, dissemination.

GEOLAB is an interactive geosciences laboratory located at the Department of Earth Science, Environment and Resources (DiSTAR) of the University of Naples Federico II (Italy). It is aimed at high school students as part of the PLS (Piano Lauree Scientifiche) and PCTO (Percorsi per le Competenze Trasversali e l'Orientamento) projects. The GEOLAB experience starts with the exhibition of macroscopic fossils and rock mineral samples to be described and classified by students and then observed in thin sections under the polarized microscope. Another educational activity consists of the use of an analogical model made of colored sand layers replicating a stratigraphic succession deformed by a mechanical press to model the orogenic accretionary wedge. In this way the students could appreciate the tectonic processes that act during the formation of mountains (orogeny), such as the Apennines and the Alps. A second Augmented Reality Sandbox allows the active participation of students in the hands-on modelling of kinetic sand aimed to reproduce different topographic landscapes and some natural phenomena such as rainfalls, volcanic eruptions and peculiar climate conditions. GEOLAB module ends with a visit to the DiSTAR laboratories, where researchers and technicians show scientific instrumentation and the way to use it. The PLS activity also includes two seminars and a visit to GEOLAB. This experience represents a valid approach to actively involve high school students in the fascinating field of Geosciences, providing simple educational experiences that could be effectively driven by the entire DiSTAR teaching staff, no matter their scientific specialization.

S33.

Fossil record, paleoenvironment and climate change throughout the Neogene and Quaternary Earth history

CONVENERS & CHAIRPERSONS

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Calcareous plankton and bio-geochemical climate signals during the Pliocene-Pleistocene transition in the Mediterranean area

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Keywords: Plio-Pleistocene transition, paleoclimate reconstruction, Mediterranean area.

We present a high-resolution multiproxy study to unravel climate changes during the Plio-Pleistocene transition (PPt) in the Mediterranean Sea. Our proxies relies on micropaleontological (calcareous plankton), organic geochemical (alkenones), and oxygen isotope data.

The PPt, situated between the Mid-Piacenzian Warm Period (~3 Ma) and further intensification of the North Hemisphere Glaciation (iNHG) at ~ 2.7 Ma, is a crucial climate transition in the Earth's history, during which the scenario progressively changed, recording a long-term cooling (Mudelsee & Raymo, 2005; Ruggieri et al., 2009). In this scenario, we analyzed the Monte San Nicola Gelasian type-section, located in the central Mediterranean area. In this study, we updated the recent climate investigation performed in the Monte San Nicola type-section (Addante et al., 2024), reconstructing new proxy data and extending the record from Marine Isotope Stage (MIS) G4 up to MIS 100, the latter considered the first pronounced glacial stage at the iNHG. A complete paleotemperature and paleproductivity reconstruction was obtained.

The biotic and abiotic proxies indicate relatively weak variability in surface waters during the glacial-interglacial MIS G4 to G1, followed by a pronounced amplitude increase in obliquity cycles, starting from MIS 104, indicative of intensifying glacial conditions. Interference between obliquity and insolation resulted in weak glacial conditions during MIS 102. Surface waters conditions strongly varied on a precessional scale: increase in the abundance of specific calcareous plankton taxa and alkenone (C37) concentration, highlight nutricline depth variation, enhance productivity in surface waters and/or organic matter preservation at the seafloor during the deposition of the precession-related sapropel layers. In addition, superimposed to orbital cyclicity, a millennial-scale variability is identified as a distinct feature of the glacial cycles in the investigated time interval, before MIS 100. The short-term events in the Mediterranean Sea seem related to the deposition of Ice Rafted Debris in North Atlantic (Hayashi et al., 2020). Our high-resolution multi-proxy record highlight both low and high-latitude climate forcing in the Mediterranean at the PPt and succeed in reconstructing previously undetected variability.

Addante M. et al. (2024) - Climate-induced surface water variability at Monte San Nicola type-section (Sicily, southern Italy): New data across the Gelasian GSSP. Palaeogeography, Palaeoclimatology, Palaeoecology, 634, 111907, https://doi.org/10.1016/j.palaeo.2023.111907.

Hayashi T. et al. (2020) - Latest Pliocene Northern Hemisphere glaciation amplified by intensified Atlantic meridional overturning circulation. Commun. Earth Environ., 1, 25, https://doi.org/10.1038/s43247-020-00023-4.

Mudelsee & Raymo (2005) - Slow dynamics of the Northern Hemisphere glaciation. Paleoceanography, 20, https://doi.org/10.1029/2005PA001153.

Ruggieri E. et al. (2009) - Change point method for detecting regime shifts in paleoclimatic time series: application to δ18O time series of the Plio-Pleistocene. Paleoceanography, 24, https://doi.org/10.1029/2007PA001568.

Palaeoceanographic and paleoclimatic changes during the Marine Isotope Stage 5 at IODP Site 1385

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Keywords: Iberian Margin, Marine Isotope Stage 5, Coccolithophores.

The results concerning palaeoceanographic and paleoclimatic changes, occurred during the Marine Isotope Stage (MIS) 5, at the Integrated Ocean Drilling Program (IODP) Site U1385 and inferred through coccolithophores analyses are shown. The site was drilled on the Promontorio dos Principes de Avis, SW Iberian Margin (37°34.285'N; 10°7.562'W – 2585 meters below sea level), during the IODP Expedition 339. The investigated timeframe spans from ~130 ka to 70 ka and it has been the last major interglacial interval occurred on Earth. This interval, particularly the MIS 5e sub-interval, was characterized by global temperatures warmer than the pre-anthropogenic ones (e.g., Kopp et al., 2009) and it is useful to interpret the natural climate evolution beyond the anthropic impact being interested. The North Atlantic and the Iberian Margin are pivotal areas to reconstruct global climate evolution being characterized by high sediment accumulation rate, providing an excellent millennial-scale record of climate variability (e.g., Hodell et al., 2015).

The coccolith assemblages is characterized by good preservation within the sections analyzed with an averaged time resolution of ~700 years. The total nannofossil accumulation rate (NAR; nannofossils * cm-2 * kyr-1) is calculated according to Flores & Sierro (1997) and it is used as a coccolithophores paleoproductivity proxy. Total NAR values range between 6x109 and 9x1010 nannofossils * cm-2 * kyr-1. Reconstructions of water mass variability and paleoecology patterns are detected and associated to Greenland and Heinrich stadials.

Flores J.A. & Sierro F.J. (1997) - Revised technique for calculation of calcareous nannofossil accumulation rates. Micropaleontology, 43, 321-324, https://doi.org/10.2307/1485832.

Hodell D. et al. (2015) - A reference time scale for Site U1385 (Shackleton Site) on the SW Iberian Margin. Global and Planetary Change, 133, 49-64, https://doi.org/10.1016/j.gloplacha.2015.07.002.

Kopp R.E. et al. (2009) - Probabilistic assessment of sea level during the last interglacial stage. Nature, 462, 863-867, https://doi.org/10.1038/nature08686.

Trace organic compounds in speleothems as a pioneering approach to high-resolution paleofire reconstructrion

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Keywords: Speleothems, PAHs, paleofire.

Speleothems are widely used paleoclimate archives given that calcite is often pristine, they can grow continuously for thousands of years, be precisely dated, and provide high resolution paleoenvironmental information (Fairchild & Baker, 2012). Stable isotopes of oxygen and carbon, along with select trace elements, are the primary chemical markers used in speleothems for paleoclimate reconstruction. U-Th dating method allows the construction of high resolution age-depth models, at times with propagated 2 uncertainties lower than 1%, thus obtaining accurate climate-environmental proxy time series. The study of organic compounds in speleothems remains less well developed, despite the fact that they hold the potential to preserve paleoenvironmental signals unattainable by inorganic compounds. Recent applications in speleothem paleoscience used innovative analytical approaches to highlight the huge potential of cave deposits for fire reconstruction. Previous research by Argiriadis et al. (2019; 2024) focused on the use of organic molecules, namely polycyclic aromatic hydrocarbons (PAHs) and *n*-alkanes, for the high-resolution reconstruction of paleofire from speleothems from cave KNI-51, in tropical northwestern Australia, where the absence of permanent water bodies excludes the use of lake sediments for this purpose. A field experiment involving the determination of target organic proxies in soil, vegetation, and cave dripwater prior and following a prescribed fire over the cave is planned for June 2024. Data will be compared with the paleorecord obtained from cave KNI-51, remote sensing data and records from the 20th century.

In addition, the pioneering stalagmite biomarker approach will be tested by the PRIN-PNRR project "PROMETHEUS" on Mediterranean caves. PROMETHEUS will contribute to enhancing the knowledge about paleofires and the role of climate and environmental conditions on the occurrence of fires in the Mediterranean area by producing unprecedented high resolution records. Despite being one of the major contributors to the atmospheric carbon budget, the level of uncertainty related to fire occurrence, frequency, and intensity remains elevated. Understanding past dynamics and building robust databases is vital and complementary to model climate change related future shifts in fire regimes, that will increase risks deriving from fire occurrence in populated areas and the irrecoverable loss of ecosystem services, as observed in the recent past and deemed increasingly likely in the near future.

Argiriadis E. et al. (2019) - Improved polycyclic aromatic hydrocarbons and n-alkanes determination in speleothems through cleanroom sample processing. Anal. Chem., 91, 7007-7011, https://doi.org/10.1021/acs.analchem.9b00767.

Argiriadis E. et al. (2024) - Polycyclic aromatic hydrocarbons in tropical Australian stalagmites: a framework for reconstructing paleofire activity. Geochim. Cosmochim. Acta, 366, 250-266, https://doi.org/10.1016/j.gca.2023.11.033.

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Pliocene-Pleistocene evolution of the upper central Po Plain (Northern Italy)

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Keywords: Po Plain, paleoenvironmental reconstruction, biostratigraphy.

The Po Plain (Northern Italy) subsurface preserves the almost continuous Quaternary and Pliocene sedimentary succession, but outcrops are sparse and difficult to correlate among them. For this reason, data from the few deep boreholes, scanty for the upper portion, are the main indicators to reconstruct the Pliocene-Quaternary stratigraphy of the basin. The upper central Po Plain with its high density of water wells, provides a suitable location for studying the Lower Pleistocene and Pliocene marine sediments and their paleoenvironmental evolution.

We present data from two transects north of Milan comprising 18 wells, 8 of them sampled for sedimentological, petrographic and biostratigraphic analyses on perforation cuttings. From top to bottom, the eastern transect in the Adda-Molgora Valley and the western one in the Seveso-Lambro Valley include a continental succession documenting the transition from gravel-dominated fluvioglacial deposits to braidplain conglomerates and sandy gravels. Both sequences include coarse clasts of alpine and local origin. Below, fine sediments with continental gastropods and wood fragments are reported; they indicate deposition in a meandering alluvial plain. The thickness of the continental deposits increases from east (ca. 40 m) to west, where it reaches ca. 150 m. These deposits have been attributed to the end of Calabrian to Late Pleistocene (Baio & Violanti, 2021). Continental sediments lie on the top of a regional unconformity, which is related to several and diachronous erosional events, and separates the upper continental deposits from the marine/transitional-marine succession. The latter were correlated through micropaleontological data to the neritic domains of the Pliocene-Pleistocene regressive sequence of Northern Adriatic Sea and Po Plain. The marine sequence presents different setting in the two transects. The western transect reports sediments with foraminiferal assemblages typical of delta, beach, and infra-circalittoral environments, dated to the Gelasian and Calabrian stages. Petrographic analysis on interspersed gravel layers indicates sources from alpine and local drainage basins. The eastern transect shows the presence of Calabrian and Piacenzian sediments at similar depth in adjacent wells. The Piacenzian succession includes infra-circalittoral and beach environments with the occurrence of lithodome bores on gravel clasts, derived from local drainage basins. Foraminiferal assemblages in the Calabrian sequence resembles those from the western transect.

The investigations in the two transects show diachronous Piacenzian-Calabrian marine deposits and indicate that from the Piacenzian to the Late Pleistocene the area was characterized by different paleoenvironments, evolving from marine domains to outwash systems. Additionally, the occurrence of Piacenzian and Calabrian sediments at the same depth may suggest local tectonic deformation during the Early-Middle Pleistocene.

Baio M. & Violanti D. (2021) - Litostratigrafia e micropaleontologia del sottosuolo nell'area a est di Milano: studio integrato di cuttings di perforazione di pozzi per la ricerca idrica. Geologia Insubrica, 15(1), 1-43.

The last 2000 years of floods from Arno and Serchio rivers (Tuscany) from historical, geoarchaeological and stratigraphic data

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Keywords: floods, Arno, Serchio.

There are concerns that current climate change is altering the frequency and magnitude of river floods in an unprecedented way (Blöschl et al., 2020). However, the lack of long-term observational time series of flood events makes the verification challenging. Especially in Southern Europe and in the Mediterranean region where the effect of human agency on the landscape has been more profound, flood frequency and magnitude can have been controlled by climatic and non-climatic-human induced factors like catchment deforestation. Historical studies have identified flood-rich periods in the past millennia in various regions of Europe and the Mediterranean using different approaches, notably analyses of historical sources, archaeological and geological data (e.g., Blöschl et al., 2019; Bini et al., 2020). For the most recent period, direct measurement and historical documentary evidence are the most important sources of data, but their availability decreases exponentially as well as their reliability far in time. One way of overcoming this issue is to extend flood series beyond observational and historical data using sedimentary archives or archaeological excavations. We present a reconstruction of flood frequency from the Arno and Serchio rivers in Tuscany from: 1) accurate revision of historical documents; 2) collection of archaeological data, and 3) from flood layers deposited in a swamp area, which collected overbanks and crevasse splay events of the Arno river. This allowed us to reconstruct a flood record since the Roman Period, and to overlap the historical data at ca. 1100 CE, yielding an unprecedented long flood record for these two rivers.

Bini M. et al. (2020) - Hydrological changesduring the Roman Climatic Optimum in Northern Tuscany (CentralItaly) as evidenced by speleothem records and archeological data. Journal Quaternary Science, 35, 791-802, https://doi.org/10.1002/jqs.3224

Blöschl G. et al. (2019) - Changing climate both increases and decreases European river floods. Nature, 573, 108-111. https://doi.org/10.1038/s41586-019-1495-6.

Blöschl G. et al. (2020) - Current European flood-rich period exceptional compared with past 500 years. Nature, 583, 560-566, https://doi.org/10.1038/s41586-020-2478-3.

Calcareous nannofossil response to Holocene climatic events in the North Ionian Sea

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Keywords: Calcareous nannofossils, Bond events, North Atlantic Oscillation (NAO).

The ND14Mbis marine sediment core was analysed to investigate the climate variability over the Holocene in the North Ionian Sea. The core was collected at a water depth of 665 m below sea level during the Next-Data cruise in 2014, aboard the R/V Urania (CNR). In this work, we focused on the study of the calcareous nannofossil assemblages coupled with the analysis of carbon stable isotopes from *Globigerinoides ruber* white, X-Ray Fluorescence data (Ca/Ti, K/Al). The lower portion of the investigated succession records the Sapropel 1 interval, between 10 and 7.7 ky BP (Checa et al., 2020), which onset is marked by the increase of *Florisphaera profunda* pointing out the formation of stable stratified waters and Deep Chlorophyll Maximum (Cascella et al., 2021). Afterwards, increases in the Warm Water Group (WWG) abundance pointed to warmer periods chronologically correlated with the major archaeological subdivisions such as the Copper Age, Early and Late Bronze Ages, and the Roman Period. Conversely, declines in the WWG and rises in the Cold Water Group (CWG) marked cooler short events at 7.4 ky BP and 4.2 ky BP, and cool intervals like the Middle Bronze Age, Iron Age, Dark Age and Little Ice Age. Calcareous nannofossils also indicated mixed and cooler surface waters during the Medieval Climate Anomaly. Particularly, the spectral analysis of the CWG signal revealed a 1.6 ky periodicity, which resulted correlatable with the onset of some Bond events (Bond et al., 2001). Throughout the record, we noted a positive correlation between *Syracosphaera pulchra* and δ13C values and variations in XRF trends, which indicate riverine runoff, confirming the affinity of this taxon with freshwater inputs. The North Atlantic Oscillation (NAO) atmospheric mode impact on Central Mediterranean continental runoff was investigated over the last 7.5 ky BP, using the NAO index by Smith et al. (2016). Negative NAO phases, which characterize the development of wetter winters at site latitude, coincided with episodes of higher riverine discharge highlighted by higher K/Al, lower Ca/Ti ratio values and increases in reworked coccoliths. However, from 2.3 ky BP upwards the evidence of enhanced continental runoff during positive NAO phases (i.e., drier winters) could be attributed to anthropogenic pressure.

Bond G. et al. (2001) - Persistent Solar Influence on North Atlantic Climate during the Holocene. Science 294 (5549), American Association for the Advancement of Science, 2130–2136, https://doi.org/10.1126/SCIENCE.1065680/SUPPL_FILE/SUPP.DATATABLE1.XL.XLS.

Cascella A. et al. (2021) - The Response of Calcareous Plankton to the Sapropel S1 Interval in North Ionian Sea. Global and Planetary Change, 205, 103599, https://doi.org/10.1016/j.gloplacha.2021.103599.

Checa H. et al. (2020) - High Resolution Paleo-Environmental Changes during the Sapropel 1 in the North Ionian Sea, Central Mediterranean. Holocene, 30(11), 1504–1515, https://doi.org/10.1177/0959683620941095.

Smith A.C. et al. (2016) - North Atlantic Forcing of Moisture Delivery to Europe throughout the Holocene. Scientific Reports, 6, 24745, https://doi.org/10.1038/srep24745.

Benthic foraminiferal response to anthropogenic impact in the North Adriatic Sea during the last two centuries

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Keywords: benthic foraminifera, North Adriatic Sea, anthropogenic impact.

The temporal distribution of benthic foraminifera was studied in a marine sediment core EL-C01 collected 7 km south of the Po di Goro outlet at a 21.5 m water depth. Integrated geochemical and sedimentological data with trace metal concentrations allow us to document the response of benthic microfauna to anthropogenic influence during the last two centuries. Taxa occurring primarily in natural, oligotrophic conditions (*sensu* Jorissen et al., 2018), dominate the interval from 1840 (base of the investigated core) to ca. 1880, then they are progressively replaced by stress tolerant species toward the first half of the 1900. The observed benthic foraminiferal change is associated to sudden modifications in the Po sedimentary regime (Riminucci et al., 2022). Starting from ca. 1945, the assemblage became characterized by the dominance of taxa related to low oxygen and eutrophic condition (e.g., *Bulimina marginata, Bolivina gr., Nonionella stella*) with episodes of severe anoxia between 1960-1990 induced by the increase of primary production at the surface and high sedimentation of particulate organic matter. This pattern results time associated to socio-economic development and industrialization after the World War II as documented by the Pb and Zn profiles. The increasing biodiversity and decreasing dominance among benthic foraminifera from the second half of the 1980 is probably the effect of the Italian Law 319/76 and anti-pollution environmental policies concerning industrial and urban emitters.

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Riminucci F. et al (2022) - Trace metals accumulation on modern sediments from Po river prodelta, North Adriatic Sea. Marine Pollution Bullettin, 1175, https://doi.org/10.1016/j.marpolbul.2022.113399.

Response of particular taxa to climatic and environmental variations during the evolution of the Mediterranean Sea: from the Messinian Salinity Crisis to Zanclean normal marine conditions

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Keywords: Mediterranean, Messinian, Zanclean, Bioevents,

During the late Miocene and the early Pliocene, the Mediterranean Sea was devastated by a series of natural disasters that at the acme of the Messinian Salinity Crisis culminated into the complete desiccation, causing drastic changes in marine biota. Despite the over 1400 publications there is no unanimous agreement onto the dynamics that led to the biological revolution with extinctions and appearance of new taxa, as well as on the desiccation and the consequent Pliocene reflooding (Roveri et al., 2014; Caruso et al., 2020).

The exploration of the oceans in the late sixties and early seventies of last century brought important, largely unexpected, discoveries that contributed to recovery of evaporites in the deepest Mediterranean basins (Balearic, Tyrrhenian, Ionian and Levantine) originated the unorthodox deep-basin desiccation model. In the last 30 years the Neogene was investigated in great detail using interdisciplinary approach (i.e. litostratigraphy, biostratigraphy, geochemistry, magnetostratigraphy, astrocyclostratigraphy). The astrocyclostratigraphy permitted to correlate land outcrops with deep marine successions obtaining astronomical ages for the major events. Thanks to this approach, astronomical ages of 7.241 and 5.333 Ma were obtained, respectively for the Messinian and Zanclean GSSPs (Hilgen et al., 2012). Thus, the onset of the Messinian Salinity Crisis (MSC) has been astronomically calibrated, although with some slight differences, at ~5.971-6.04 Ma. Further, from Messinian to Zanclean the climate was not stable, several glacial periods alternated to warmest phases (Herbert et al., 2016) contributing strong changes in marine biota and favouring evaporation phenomena. In this work, some examples are discussed focussing on particular taxa

Caruso A. et al. (2020) - The late Messinian “Lago-Mare” event and the Zanclean reflooding in the Mediterranean Sea: New insights from the Cuevas del Almanzora section (Vera Basin, south-eastern Spain). Earth-Science Reviews, 200, 102993, https://doi.org/10.1016/j.earscirev.2019.102993.

Herbert T.D. et al.. (2016) - Late Miocene global cooling and the rise of modern ecosystems. Nature Geoscience, 9(11), 843-847, https://doi.org./10.1038/ngeo2813.

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Distribution pattern of macrobenthic assemblages along the Ideale Section of the Montalbano Jonico succession (southern Italy)

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Keywords: climate change, macrobenthic assemblages, mid-Pleistocene transition.

The Ideale Section (Montalbano Jonico Basin, Matera, Italy) is a Standard Auxiliary Boundary Stratotype for the Middle Pleistocene (Marino et al., 2024). This section provides a valuable opportunity to investigate the past macrobenthic dynamics in open marine environments in relation to climate change.

We analyzed the effect of long-term climate and sea-level changes on marine macrobenthic assemblages using 29 samples (about 4,000 fossil remains) from the 80 m-thick clayey succession of the Ideale Section that accumulated between Marine Isotope Stage (MIS) 20 and MIS 18 (Marino et al., 2015). Paleobathymetric reconstructions based on ordination analyses of macrobenthic assemblages indicate inner shelf environments during cold periods (glacials and stadials), which alternated with deeper settings (mainly outer shelf) during warmer phases of the MIS 19, reflecting the orbitally-driven climate shifts also registered by stable oxygen isotopes.

Thus, investigated macrobenthic assemblages have shifted in composition over long-term climate oscillations spanning the Calabrian-Chibanian transition (~810 to 750 ky). Cold climate periods are dominated by macrobenthic taxa indicators of environmental disturbance, such as turbidity exemplified by *Ditrupa arietina*. In addition, such periods are characterized by lower species richness and depressed abundance of species exclusive of Mediterranean to Lusitanian regions (Spalding et al., 2007) compared to warmer interstadials of MIS 19 (see Scarponi et al., 2022). Indeed, samples from warm climate periods show assemblages with higher species richness and equitability, suggesting more stable environments. In addition, the median relative total abundance of Lusitanian and Mediterranean specimens is around ten times higher than during cold climate intervals.

Thus, the high similarity between assemblages from cold climates (glacials and stadials) and their distinct composition and abundance from those from warmer phases of MIS 19 suggest that, over geological timescales, shelf benthic assemblages have been primarily structured by environmental forcing. As for cold climate intervals, the recurrence of macrobenthic assemblages with similar taxonomic structures points toward either remarkable resilience or persistence in the face of major, long-term environmental, and climatic perturbations.

Lastly, as MIS 19 is a climate analog for near-future climate warming, the result presented here could allow us to define baselines for macrobenthic structure and dynamics regarding climate changes in a context of null anthropogenic impact. Thus, the recent fossil record can help us identify important changes that occurred in present-day ecosystems before ecological monitoring that might have otherwise gone unnoticed.

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Spalding M.D. et al. (2007) - Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. BioScience, 57, 573-583, https://doi.org/10.1641/B570707.

Climate variability at around the 4.2 event based on novel $\delta^{18}O$- $\delta^{13}C$ speleothem data from Sardinia (Italy, Western Mediterranean)

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Keywords: 4.2 event, Holocene, paleoclimate.

The Holocene is distinguished by a multitude of climatic oscillations. The Mediterranean region serves as a significant site for exploring such a climate variability because of its geographical location and diverse geological, geomorphological and orographic characteristics. Among the oscillations that characterize the Holocene, the event known as "4.2 event" holds particular significance. Identified as one of the most cooling/drying abrupt events, it is widely recognized as a period of dry and cold conditions and is often termed a "megadrought". This event is implicated as a primary factor in the decline of ancient civilizations (such as the Akkadian Empire, Ancient Egyptian Culture, Mesopotamian Culture, and Ancient Indian Culture). The nature of the event is at times elusive, as it is not recorded in some sites and appears to be out of sequence in others. Therefore, it is necessary to study and understand the timeframe of this change, collocated at 4.2 ka but possibly spread over a much broader time interval. Indeed, other oscillations at times of greater magnitude with respect to the 4.2 event have been somehow underexplored because the "main" 4.2 event often takes all the importance. The aim of this study is to present new isotopic data ($\delta^{18}O$ and $\delta^{13}C$), obtained from a carbonate stalagmite SARM2 located in the S'Armidda Cave (Sardinia, Italy, Western Mediterranean), to enhance the knowledge about climate variability in the area pre, during and post 4.2 ka. Due to the cave's geographical location, the $\delta^{18}O$-climatic signal of SARM2 is primarily interpreted as reflecting the rainfall amount effect, while $\delta^{13}C$ is driven by the vegetation activity. SARM2 U-Th based chronology demonstrated that the speleothem deposition occurred from 5.6±0.14 to 3.3±0.14 ka. The average proxy chronological resolution is about 16 years. Centered at ca. 4.7 ka, $\delta^{18}O$ and $\delta^{13}C$ demonstrate a centennial long deterioration of climate characterized by lower rainfall and vegetation activity. While SARM2 is mostly composed of calcite, during this period there is an evident layer of aragonite. The presence of aragonite in speleothems is usually associated with particularly dry conditions. From ca. 4.6 ka $\delta^{18}O$ and $\delta^{13}C$ support an increase in rainfall that peaks at ca. 4.35 ka. Then, at around 4.2 ka there is another event of climate deterioration, which appears of minor magnitude with respect to the one found at ca. 4.7 ka. After 4.2 ka, $\delta^{18}O$ and $\delta^{13}C$ decouple, pointing to stable rainfall conditions but increasing vegetation activity. Contrary to previous interpretations that represented the 4.2 event as a single continuous dry period, our findings suggest a scenario in which the 4.2 event is formed by two arid phases framing a wetter period, as other records near the area suggest. This calls for a better climate investigation of the around of this event, with proxy timeseries with adequate resolution (i.e decadal or less).

Impact of the genus *Amphistegina* on the benthic foraminiferal association of the Pelagian Islands, an example of invasion in the Central Mediterranean Sea

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Keywords: benthic foraminifera, non-indigenous species, Amphistegina lobifera.

Irecent years the Mediterranean Sea is increasingly subject to colonization by non-indigenous marine organisms, many of which migrate through the Suez Canal. Its opening, which took place in 1869, connected two different biogeographical provinces after millions of years, facilitating the migration of over 600 non-indigenous species, some of which are seriously threatening the native biodiversity.

This study shows the results of benthic foraminiferal analyses carried out on algal and sediment samples collected in 2014 around the Pelagian Islands (Lampedusa and Linosa). These islands, starting from 2005 (the year of the first report), are undergoing the invasion of the non-native Indo-Pacific species *Amphistegina lobifera* Larsen.

The obtained data have been compared with those of previous sampling carried out in 2005 and 2009 (Caruso & Cosentino, 2014). This comparison highlights how, in most cases, *A. lobifera* is increasing its abundance dominating the assemblages with percentages over 50% and causing the drastic decrease of the native species. Its carbonatic tests, accumulated on the Linosa seabed are progressively changing the composition of marine sediments and for the first time are also giving rise to accumulations in the coastal environment, inside pools filled during storm surges, as happens in the Indo-Pacific atolls.

These results show how, in just a few years, some non-indigenous foraminifera are capable of massively colonize new environments, modifying native biodiversity and influencing sedimentary processes.

Caruso A. & Cosentino C. (2014). The first colonization of the Genus Amphistegina and other exotic benthic foraminifera of the Pelagian Islands and south-eastern Sicily (central Mediterranean Sea). Mar. Micropal., 111, 38-52, https://doi.org/10.1016/j.marmicro.2014.05.002.

Paleohydrological changes during the early Holocene through the study of an isotope record from stalagmite of Bossea Cave (NW Italy)

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Keywords: Early Holocene, paleoclimate, speleothems.

Within the Quaternary period, the Holocene emerges as a notably stable climatic phase. Yet, upon closer examination, it becomes evident that Holocene climate records exhibit greater temporal and spatial variability than the broad generalizations imply. Indeed, notable climate shifts occurred frequently and sometimes abruptly over relatively short timescales. Indeed, over the span of several decades to centuries, intervals characterized by relatively stable and warmer climates were occasionally interrupted by multiple cold episodes, particularly within the extra-tropical regions of the Northern Hemisphere. For example, Wanner et al. (2011) identified six cold events within the Holocene period (at approximately 8200, 6300, 4700, 2700, 1550, and 550 years BP). Nevertheless, these events did not exhibit clear cyclical patterns, and there was considerable spatiotemporal variability in temperature and humidity/precipitation. Similarly, focusing on the Western Mediterranean region, Magny et al. (2002) recognize intervals of declining river activity on a century scale, which correspond to glacier retreat in the Northern Alps and a decrease in lake levels in the Jura (approximately occurring at 11,500, 10,500, 9,000, 7,000, 4,000, 3,000, 2,000, and 800 cal. years BP). Even though the phases at 11500, 9000, and 7000 cal. years BP have not been identified as aridification phases by Jalut et al. (2000). In this context, we present an isotopic record from speleothem of Bossea Cave, which is located in the Ligurian Alps (Southern Piedmont, Italy). By examining of Bossea Cave's $\delta^{13}C$ and $\delta^{18}O$ records, where the $\delta^{18}O$ record is related to humidity changes, and based on several climate records from the Western Mediterranean, we provide an estimate of atmospheric conditions during the early Holocene. Furthermore, leveraging the high temporal resolution of this inorganic archive dated with U-Th, we can attempt to identify various climatic anomalies that occurred throughout this period.

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Michel M. et al. (2000) - Assessment of the impact of climate and anthropogenic factors on Holocene Mediterranean vegetation in Europe on the basis of palaeohydrological records. Palaeogeography, Palaeoclimatology, Palaeoecology, 186, 47-59

Wanner H. et al. (2011) - Structure and origin of Holocene cold events. Quaternary Science Reviews, 30, 3109-3123.

Terrestrial and marine palynomorphs from Holocene deposits and mosses samples in the Mar Piccolo semi-enclosed marine basin (Taranto, Southern Italy)

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Keywords: pollen, dinoflagellate cyst, Gulf of Taranto, Quaternary.

Palynological investigations on pollen and dinocysts are currently underway in a sedimentary core (S05B), surface sediments, and moss samples collected from and around the Mar Piccolo (MP; Central Mediterranean). This shallow, semi-enclosed marine basin, located between the Ionian Sea and the Apulia region, is surrounded by extensive wetlands consisting of both fresh and salt marshes. The palynological research conducted as part of the PhD theses of Degl'Innocenti and Niccolini (2024) at the University of Bari is integrated into a geomorphology project. The aim is to reconstruct paleoenvironmental and paleoclimatic changes as well as human impacts over the last 12,000 years in Southern Italy. Thanks to the exceptional preservation of palynomorphs, it was possible to create iconographic documentation showcasing the most intriguing and distinctive taxa identified during the palynological analyses. A total of 143 pollen taxa from local (freshwater marsh: e.g., *Sparganium*, *Typha latifolia*; saltmarsh: e.g., Amaranthaceae, *Armeria*), regional (e.g., *Quercus pubescens*-type, *Corylus),* and extra-regional sources (e.g., *Abies*, *A. cephalonica*, *Cedrus*, *Picea*) have been identified (Niccolini & Bertini, 2024). Furthermore, a high abundance of anthropic taxa, e.g., *Olea*, *Juglans*, *Vitis,* and Cerealia groups, along with the occurrence of e.g., *Citrus medica,* have been observed. Moreover, pollen analyses in surface sediments and moss samples reveal the presence of numerous alien taxa (e.g., *Aloe,* Arecaceae, ornamental Cactaceae, and *Eucalyptus),* suggesting a nowadays highly anthropized vegetation around MP. A total of 60 dinocyst taxa have been detected, including 2 belonging to Gymnodiniales (e.g., cyst of *Polykrikos kofoidii*), 30 to Gonyaulacales (e.g., *Operculodinium centrocarpum*), and 28 to Peridiniales (e.g., *Lejeunecysta oliva*). Dinocyst assemblages include 34 phototrophs (e.g., *Spiniferites* spp.) and 26 heterotrophs (e.g., *Brigantedinium* spp.). Estuarine/lagoonal (e.g., *Lingulodinium machaerophorum*), neritic (e.g., *Spiniferites mirabilis, S. hyperacanthus*), and full-oceanic (e.g., *Impagidinium patulum*, *I. strialatum*) taxa have been observed, highlighting a quite diversified association. Several taxa also provide information on surface water parameters such as temperature (e.g., *I. aculeatum*, *Bitectatodinium tepikiense*), salinity (e.g., *S. pachydermus*), and nutrients (e.g., *Lejeunecysta oliva*). The finding of *Peridinium ponticum*, whose discovery in the Mediterranean area is typically restricted to the Black Sea and Marmara Sea, is particularly noteworthy. *Alexandrium* spp., a toxigenic cyst known for causing harmful algal blooms, has also been identified. This comprehensive palynological documentation lays the groundwork for future palaeoenvironmental and palaeoclimatic reconstructions of the MP, as well as expanding the regional database of pollen and dinocyst taxa.

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Updates on the middle and late Villafranchian large mammal faunal turnovers

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Keywords: biochronology, faunal renewal, large mammals.

Large mammals are widely used for biochronological correlations and palaeoecological reconstructions. A most influential contribution on Plio-Pleistocene large mammal biochronology of Europe was offered by Azzaroli (1983), who, alongside summarizing the then available data, provided an important conceptual framework on large mammal "dispersal events". Azzaroli (1983) defined these events as "short periods of rapid intercontinental migrations and faunal replacements"; often named after some representative species but denoting a major faunal renewal. He further related them to substantial climatic and environmental changes, and with relevant geological transitions. Basically, the so-defined dispersal events had multiple dimensions, including geochronological and paleoecological aspects, which made them prominent concepts in Quaternary large mammal biochronology, especially of western Europe.

Here, we present updated considerations on two of the dispersal events recognized by Azzaroli (1983), the "Elephant-*Equus* event" and the "Wolf event". The Elephant-*Equus* event was regarded as denoting the spread of open environments linked to the onset of cold and dry conditions in the Northern Hemisphere and correlated with the Gauss-Matuyama reversal, today corresponding to the Pliocene-Pleistocene transition and the beginning of the Quaternary (~2.6 Ma). Current evidence indicates that early *Mammuthus* (i.e., the "elephant") spread in Europe at least ~3.2 Ma, while the arrival of monodactyl equids (i.e., the "*Equus*") from North America still coincides with the Pliocene-Pleistocene transition and it is part of the broader middle Villafranchian faunal turnover. In brief, we endorse the use of the "*Equus* event" as a valid alternative for the Elephant-*Equus* event, as most of the meanings associated with this concept are still valid, except for the inclusion of *Mammuthus* in its constitutive bioevents (Iannucci & Sardella, 2023). The Wolf event was considered to denote the late Villafranchian faunal turnover and to approximately coincide with the Gelasian-Calabrian transition (~1.8 Ma). Although it became soon clear that the appearance of *Canis etruscus* (i.e., the "Wolf") and other large mammals pre-dated the age assumed for the Wolf event, the term was still used and associated to the late Villafranchian, focusing on the "massive expansion" of the species involved, rather than their first appearance in the European fossil record (Azzaroli et al., 1988). However, current evidence highlights that the large mammal dispersal occurred in the late middle and early late Villafranchian had a rather diachronic nature, revealing a complex scenario and pushing to critically evaluate the biochronological, paleoecological, and paleobiogeographical significance of each bioevent (Iannucci et al., 2023). For instance, *Hippopotamus* spread from Africa into Europe at ~2.2 Ma, while, roughly at the same time, several species arrived from Asia.

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New insights on MIS 9e and MIS 5e sea-level highstands from Infreschi Cave and Cilento Coast (Central Italy)

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Keywords: MIS 5e e MIS 9e highstand, speleothems, Cilento.

Interglacial highstands have left several morphological and sedimentological traces worldwide, which are utilized for the reconstruction of the past relative sea level (RSL, e.g., Shennan et al., 2015; Rovere et al., 2016) and to constrain geophysical models and fingerprinting ice cap melting and cryosphere response to climate (Dutton et al., 2015; Rohling et al., 2019). Mediterranean coasts, according to variable tectonics and glacial– and hydro–isostatic adjustment, preserve many evidence of these features found at different elevations. A revaluation of the RSL indicators in the Baia di Infreschi (Cilento, Southern Italy) supported by new 30 U/Th dating on speleothems indicates that the upper limit of *Lithophaga* burrows at ~9 m a.s.l. can be correlated to the highstand of the MIS 9e, whereas the local RSL for the highstand of the LIG is reassessed at ~ 5.3 m a.s.l. The upper level of the *Lithophaga* marker can be followed for ~12 km along the coast suggesting a substantial absence of significant relative tectonic movements. In the Baia di Infreschi additional marine indicators (e.g., *Lithophaga* burrows, notches), sealed by a flowstone dated >110 ka indicates several phases of RSL stationing below the maximum highstand of the LIG of ~5.3 m a.s.l. The presence of flowstones as low as 2 m a.s.l. dated to the MIS 7 indicated that the highstand of MIS 7 probably was below the present sea level. All these evidence implies the need to reassess the stratigraphy of some archaeological caves in the area indicating that the sedimentary successions preserved there are older than previously believed.

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Last glaciation Dansgaard-Oeschger events in speleothems from Central Italy

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Keywords: speleothems, Dansgaard/Oeschger events, last glaciation.

Greenland ice cores exhibit significant and rapid millennial-scale fluctuations during the last glacial epoch, identified as Dansgaard-Oeschger (DO) events. These events are characterized by periods of relatively warmer and moister conditions called Greenland Interstadials (GI), alternating with intervals of colder and drier climate known as Greenland Stadials (GS, Lowe et al., 2008). While the precise mechanisms governing these cycles remain elusive, prevailing theories emphasize fluctuations in the Atlantic Meridional Overturning Circulation (AMOC), which transports surface and upper-level water masses northward and subsequently returns them southward into the deep ocean. To deeply investigate the mechanism of the DO pattern and the global teleconnections, new proxies with accurate and precise chronologies are essential in different parts of the globe. Here, we present two stalagmite records from Stiffe Cave in Central Italy (Apennine mountain chain) that continuously cover the last deglaciation (from 36 to 10 kyr BP). These speleothems offer high precision, enabling the resolution of millennial-scale events, and an accurately dated chronological framework. The stable O isotope compositions of both stalagmites show a strikingly similar pattern indicating calcite deposition under equilibrium conditions. Interstadial warming and stadial cooling led to an increase and decrease, respectively, in the $\delta^{18}O$ value of calcite. This is in contrast with other speleothem records in Central Italy and the Mediterranean area, which are characterized by a decrease in the $\delta^{18}O$ during interstadial warming and vice versa, due to their strong correlations with fluctuations in humidity.

Stiffe speleothems closely resemble the temperature variations observed in high-latitude regions, such as in Alpine speleothem records (Boch et al., 2011), where, oxygen isotope values are more strongly correlated with air temperature than with the composition of regional meteoric precipitation.

The similarity in shape and magnitude of the interstadials seen in the Stiffe speleothems and the Greenland ice core suggests that the speleothems isotope signal is dominated by atmospheric temperature variability. The Central Apennines appear highly sensitive to stadial-interstadial oscillations during the last glacial period, and the response to Dansgaard/Oeschger events was probably synchronous with Greenland ice core data.

This correspondence offers valuable insights into the dynamics of the last deglaciation period in the Northern Hemisphere and investigates the mechanism of the DO cycles.

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Survey on *Pinna nobilis* associated benthic biocenosis with a paleoenvironmental approach in terraced marine deposits of the Last Interglacial period (Taranto, Italy)

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Keywords: paleoecology, biological archives, benthic communities.

Indigenous species are nowadays seriously threatened by the current global climate change and environmental instability. The loss of biodiversity in the Mediterranean Sea is due to increasing temperatures and the consequentially introduction of alien fauna. Therefore, the Mediterranean Sea's "tropicalization" involves a change in environmental parameters and a faunal biodiversity shift from temperate to tropical and sub-tropical species. Nevertheless, there are similar scenarios in the Earth's history during which tropical species inhabited the Mediterranean Sea. This is a typical phenomenon of many interglacial warm periods. Indeed, it is common to find in the Mediterranean Sea typical Senegalese fauna characterized by the presence of *Thethystrombus latus* (Gmelin, 1791) dating back to interglacial periods. In particular, the scientific community focuses on the Last Interglacial (LIG) as analogous to the current one. It allows us to understand the natural climate forcing in a period with temperatures similar to today without the presence of the human footprint. Thus, it could be considered a possible scenario for climate change to predict future climatic conditions. The traces of past climate features are recorded in some biological archives such as the bivalve *Pinna nobilis* (Linnaeus, 1758) and the coral *Cladocora caespitosa* (Linnaeus, 1767) (Freitas et al., 2005; Silenzi et al., 2005). The description of fossil benthic communities could contribute to better describe past climate and environmental conditions. The study of ecological features of faunal assemblages associated with biological archives might reveal paleoenvironmental features. The present work is a paleoecological survey about benthic infauna communities associated with *Pinna nobilis* in coastal deposits of the LIG arranged into widespread marine terraces in the area of Taranto (Puglia, Italy). The survey on fossil fauna assemblages associated with the biological archive allows the reconstruction of fossil biocoenosis of the study site highlighting environmental features that are not recorded in climate proxies.

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The climatic and oceanographic setting during the Messinian: what can be learned for present and future deoxygenation dynamics?

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Keywords: anoxia, eutropication, thermohaline circulation.

During the Messinian, the Mediterranean Basin became highly sensitive to environmental changes due to the gradual restriction of water exchange with the Atlantic Ocean. This led to the widespread deposition of organic-rich layers known as sapropels, indicating significant disturbances in the carbon and oxygen cycles. These sediments formed under conditions of oxygen depletion, likely due to periodic weakening of the thermohaline circulation. Understanding the causes and extent of this circulation weakening in the past is crucial for predicting present and future deoxygenation trends in the Mediterranean amidst current climate warming.

For this purpose, we investigate a Messinian sapropel-bearing succession cropping out at Monte dei Corvi (Ancona, central Italy) with mineralogical, petrographic, micropaleontological and stable carbon and oxygen isotopic analyses. Our findings reveal that sapropel deposition occurred due to increased sea surface buoyancy, which inhibited the thermohaline circulation, consequently reducing bottom-water oxygen content and impacting bioturbating organisms. Within the lithological cycle, the recovery of an efficient thermohaline circulation is recorded by thin packstone layers underlying the marly limestone/marlstone, which record intense bottom currents activity. The accumulation of marly limestone/marlstone during periods of high primary productivity and organic carbon export to the seafloor led to bottom hypoxia but not organic matter preservation. These lithological changes were likely influenced by variations in the Adriatic Deep Water formation system driven by precession-driven climatic and oceanographic changes. Integration of previously published sea surface temperature (SST) data with our new isotopic data indicates that variations in sea surface salinity (SSS) primarily controlled sapropel deposition, with the SSTs of sapropel deposits aligning closely with projected SST in the Eastern Mediterranean at the end of this century under climate warming. In this future scenario, warming will be coupled with an SSS increase, which likely counteract the density loss provided by temperature, making the bottom deoxygenation in the Eastern Mediterranean abysses unlikely. However, we caution that additional factors such as winter heat waves and eutrophication could exacerbate Mediterranean oxygen depletion and should be considered in model-based projections.

Climatostratigraphy through a standard auxiliary boundary stratotype for the Middle Pleistocene subseries of the Quaternary System (Montalbano Jonico, southern Italy)

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Keywords: climatostratigraphy, Middle Pleistocene SABS, Montalbano Jonico.

The ideale section (IS) at Montalbano Jonico (southern Italy), is a standard auxiliary boundary stratotype (SABS) for the global boundary stratotype section and point (GSSP) of the Middle Pleistocene Subseries/ Subepoch, following the voting members of the International Commission on Stratigraphy's Subcommission on Quaternary Stratigraphy (SQS) on July 8th, 2023 (Marino et al., 2024). The 74 m thick IS, belonging to the Argille subapennine unit of the Quaternary southern Apennine Foredeep and outcropping in the Regional Special Nature Reserve of Montalbano Jonico badlands (Gallicchio et al., 2023), continuously spans the marine isotope stage (MIS) 20-18 interval. The IS provides a detailed stratigraphical record based on multiple chronologically well constrained marine and terrestrial proxies for outlining the paleoclimatic evolution through the Lower-Middle Pleistocene transition (Ciaranfi et al., 2010). The high-resolution carbon and oxygen isotope stratigraphy evidences glacial-interglacial and stadial-interstadial phases as well as the sub-millennial-scale features of Termination IX and the onset of MIS 19c. The sapropel layer equivalent to insolation cycle 74 (784 ka) occurs in early MIS 19c describing distinct centennial-scale paleoceanographic conditions during a $\delta^{13}C$ minimum. A prominent peak in the $^{10}Be/^{9}Be$ record at the MIS 19c-19b transition identifies the low geomagnetic dipole moment associated with the Matuyama-Brunhes boundary interval (Nomade et al., 2019). Two tephra layers (V3 and V4) relevant to boundary interval are $^{40}Ar/^{39}Ar$ dated. The V4 layer, occurring at the MIS 19c-b transition and in the middle of the $^{10}Be/^{9}Be$ peak, has an age of 774.1±0.9 ka, corresponding to the age of the Middle Pleistocene GSSP at the Chiba section (Japan). A high-resolution alkenone sea-surface temperature combined with total C37-alkenones and several paleobiological records enrich the chronological and paleoenvironmental dataset from MIS 20 to the inception of MIS 18. The GSSP boundary interval in the IS is represented from 35.50 to 39.50 m, which corresponds to the interval of the highest values of the $^{10}Be/^{9}Be$ ratio (~776.35-771.87 ka) and includes the V4 tephra layer and the MIS 19c-MIS 19b transition. This SABS is particularly relevant because it extends the correlation potential of the Middle Pleistocene Subseries/Subepoch GSSP interval to the Mediterranean region where most of the Neogene and Quaternary GSSP are historically and formally represented.

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Palaeoenvironmental reconstruction of the lower levels of Grotta Romanelli (Apulia, southern Italy) based on the mammal record

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Keywords: vertebrate record, Mammals, Mediterranean Europe, terrestrial ecosystems.

Grotta Romanelli is a costal cave located in southern Italy, in the heart of the Mediterranean. Since its discovery, the cave has been recognized as a pivotal site for the Late Pleistocene European stratigraphy, with its basal level attributed to the Last Interglacial (MISs 5e). The extremely abundant archaeological and palaeontological findings collected during the early decades of 20th century immediately established the cave a reference locality for the environmental reconstruction during the last ca. 130 ka.

The recent reassessment of chronostratigraphical setting Grotta Romanelli reveals a late Middle Pleistocene age for the lower levels of the cave, while the record of the ISU3 (level G) can be referred to early Late Pleistocene (MIS 5). By redefining the age of Grotta Romanelli implies that the oldest human frequentation of the cave occurred long before MISs 5e.

Here, selected museum collections from the lower levels of Grotta Romanelli (ISU1-ISU3) and fossils recovered from excavations between 2015 and 2022 are reviewed. Our results will offer new insights into the terrestrial ecosystems of Mediterranean Europe between the late Middle Pleistocene and early Late Pleistocene, as the three main mammal assemblages identified here are associated with three different interglacials occurring over the last ca. 350 ka. The mammal assemblages present here also indicate landscapes that are no longer present in the southern part of the Apulia.

Portable X-ray fluorescence and Milankovitch cycles in coeval marine and continental Upper Pliocene deposits from the Valdelsa Neogene Basin (Southern Tuscany, Italy)

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Keywords: cyclostratigraphy, Upper Pliocene, Southern Tuscany

Portable X-ray fluorescence (p-XRF) is a powerful tool for cyclostratigraphy investigations and for detecting paleoclimate indicators in the sedimentary record. This contribution presents a case study of p-XRF cyclostratigraphy applied to marine and coeval continental Pliocene deposits located in the central-eastern sector of Valdelsa Basin (Southern Tuscany), one of the wider and most important Neogene basins of the hinterland of the Northern Apennines. The p-XRF data acquisition has been performed on selected sections, mainly composed of mudstone, deposited during the Piacenzian, including the mid-Pliocene Warm Period (from 3.3 to 2.9 Ma, according with Lisiecki & Raymo, 2005). Geochemical data, acquired with equal spacing samplings on cleaned sediment surface, have been integrated with paleomagnetic and calcareous plankton biostratigraphic data. To identify orbital frequencies recorded by geochemical data series, power spectral analysis has been performed first in the space domain. The astrochronological tuning has been realised considering a preliminary age model of the studied section based on correlation between geochemical data and insolation curve (La2004 solution according to Laskar et al., 2004). The studied successions respond to the precession periodicity as for other Southern Tuscany Pliocene sections (Riforgiato et al., 2011). Geochemical, facies and micropaleontological data, all combined together, allow us to define changes in the depositional environment and their relationship to climate forcing driven by the orbital configuration. The high-resolution calibration of the studied successions, allowed to outline of an evolutive paleoclimatic, paleoenvironmental and paleogeographical model of the studied area. The results show the high potential of the pXRF analysis for the cyclostratigraphical application integrated with other paleoclimatical and paleoechological proxy data and the efficacy in detecting changes in depositional conditions.

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Messinian, Pliocene and Pleistocene ostracod events in the Atlantic-Mediterranean area

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Keywords: Ostracoda, palaeobiogeography, Atlantic-Mediterranean area.

Global climate and environmental changes during the Late Neogene and Quaternary influenced the distribution of biota in the shallow marine environments. In particular, the ostracod assemblages of the Proto-Mediterranean and northwestern Atlantic Africa were under the influx of a discontinuous cooling, leading to extinctions, range shifts or speciation events. Well-preserved, abundant and diversified ostracod infralittoral assemblages have been studied from the late Neogene Ashtart-1 well (Bonaduce et al., 1992), located in the Gulf of Gabès, in the south-eastern part of the Mediterranean basin, and from Messinian assemblages from the Atlantic section of Oued El Kell (OK), in northwestern Marocco (Aiello et al., 2024). The ostracod assemblages revealed an important relationship between Atlantic and Proto-Mediterranean biota, in tropical, subtropical and warm temperate waters and a complex scenario consisting of different paleoecoregions in the Atlantic-Mediterranean area, with tropical conditions persisting in the southeastern part of the Proto-Mediterranean basin. Tropical and subtropical ostracods such us *Carinovalva* and *Ruggieria*, that were able to enter in the Mediterranean with the Zanclean Flood, at the end of the Salinity Crisis, disappeared during the Late Pliocene and Early Pleistocene (Ruggieri, 1980). After the Salinity Crisis, the Pliocene shallow water subtropical-temperate temperatures in the area of the Strait of Gibraltar prevented the genus *Chrysocythere* to recolonize the Mediterranean waters. Several Miocene Proto-Mediterranean tropical genera (*Syrtica, Okadaleberis, Dallonella*) went completely extinct during the Messinian Salinity Crisis. The ostracod assemblages act as proxies for palaeoclimatic and palaeobiogeographic reconstructions, highlighting the intricate interplay between climate and biogeography.

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Ecosystem dynamics, climate change and glacial-interglacial cycles from Quaternary ostracod assemblages in the Corinth Gulf, Greece

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Keywords: palaeoenvironment, Ostracoda, Glacial-interglacial transitions.

In the Gulf of Corinth, glacial–interglacial cycles are associated with changes in sedimentary processes and environment that are well recorded by microfossils (McNeill et al., 2019). During the International Ocean Discovery Program (IODP) Expedition 381 in the Gulf of Corinth, three sediment cores were drilled in two different sectors: M0078 and M0079 in the center of the Corinth Gulf and M0080 in the eastern part of the Gulf of Alkyonides. The analysis of ostracod assemblages has allowed the reconstruction of a detailed history of climatic changes during the Quaternary, specifically focusing on the glacial and interglacial transitions and their associated sea-level changes. Mazzini et al. (2023) found that the ostracod assemblages from the last 20 ka from core M0080 showed complex temporal changes not simply explained by the alternation between marine and freshwater environments during the late Quaternary. Here, we present new data from core M0078 for the last 300 ka (Gawthorpe et al., 2022), encompassing several glacial-interglacial cycles. This allows us to better understand environmental changes that include palaeoenvironmental reconstructions in a setting where global sea-level oscillations connect and disconnect the Corinth Gulf to the Mediterranean and to the global oceans. The ostracod assemblages identify two different types of environments repeatedly following one another along the whole core M0078: Mediterranean marine (*Bosquetina tarentina*, *Cytheropteron* spp., *Henryhowella sarsi*, *Microcythere* spp.) and brackish with Black Sea influences (*Amnicythere* spp., *Euxinocythere virgata*, *Tuberoloxoconcha atlantica*, Candonidae). These ecosystem shifts documented by changes in the ostracod assemblages reflect the rapid nature of glacial to interglacial transitions, from deep-shallow marine environments to marine semi-isolated and brackish lake environments with different degrees of confinement and salinity.

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The interplay between sedimentary supply, sea-level rise and tectonics from the last glacial maximum onwards: insights from the Sant'Eufemia continental shelf (Offshore Calabria, Italy)

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Keywords: paleoenvironmental reconstruction, sea-level change, prograding wedges.

New high-resolution, multichannel seismic data, acquired in the Sant'Eufemia Gulf, provide constrains on the architecture of submarine depositional features (e.g. prograding wedges) formed since the last glacial maximum (LGM). Sedimentological and quantitative micropaleontological analyses of gravity cores integrated with calibrated radiocarbon age of samples allow us to calibrate the seismic profiles, constrain the sedimentation rate and reconstruct the paleoenvironmental evolution of the study area since the earliest Bølling-Allerød. Five sediment grain size intervals and benthic foraminifera assemblages outline the evolution of the sea-bottom environment. Basal coarse sand grains along with shallow water and epiphytic benthic foraminifera (e.g. genus *Asterigerinata, Elphidium*) point to an infralittoral environment. After that, we record a progressive grain size reduction culminating at the top core, where dominant silt, clay and benthic foraminifera assemblages point to a muddy bottom circalittoral environment. A reduced organic matter flux is observed in benthic foraminifera after 5.5 ka, supporting the evidence from calcareous plankton. Sedimentation rates vary from 4.9 to 12.9 cm/kyr.

The prograding wedges formed at distinct water depths at which the sea level was stationed or lowered during the relative sea-level rise from the LGM to the basal Holocene. The erosional surfaces and marine terraces result from wave action above the depth of closure. Therefore, the above features are suitable for reconstructing a relative sea-level curve. The error bar includes uncertainties due to the a) seismic velocities used for the time-to-depth conversion of profiles, b) water depth related to the formation of depositional and erosional features, and c) tectonics. The reconstructed sea-level rise curve shows a step-like trend, starting from the Heinrich stadial 1, followed by sea level rise during the warm and ice-melting period of Bølling-Allerød, with a peak of the rising rate during the Melt Water Pulse 1-A. Subsequently, it shows evidence of sea level still standing during the cold stadial Younger Dryas, followed by a rapid increase in sea level during the Melt Water Pulse 1-B. The obtained curve of relative sea-level rise was compared with the a) eustatic sea-level curve proposed by Lambeck et al. (2014) corrected for the Glacial Isostatic Adjustment (GIA), b) relative sea-level curve by Lambeck et al. (2011) for Briatico, seven eustatic sea level curves plus one calculated in the Mediterranean, all corrected for the GIA. The best overlap was obtained with the high-mantle-viscosity from the GIA correction model of the Australian National University (ANU14-HV). It is noteworthy that the eustatic sea-level curve proposed by Lambeck et al. (2014) overlaps our relative sea-level curve throughout the analyzed time interval.

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The Mid-Pleistocene transition in the Eastern Mediterranean: a multi-proxy approach to reconstruct its impact at the southern margin of the Central Anatolian Plateau (CAP)

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Keywords: Mid-Pleistocene transition, Eastern Mediterranean, calcareous nannofossils.

The Earth experienced notable influences on both biota and physical environment during the Mid-Pleistocene Transition (MPT). The MPT (~1.25 to 0.77 Ma) corresponds to a time of a progressive increase in the amplitude of climate oscillations from a 41-kyr to quasi-100-kyr rhythm, which resulted in increasing long-term average global ice volume (Head & Gibbard, 2005). In the Mediterranean region, the MPT is recorded in several offshore successions mainly located in the central and western parts of the basin. However, the eastern part of the Mediterranean has received less attention regarding the MPT. We aim to extend knowledge about the eastern part of the Mediterranean and compare the records of MPT in both on-land and offshore successions.

The CAP southern margin hosts Neogene marine sedimentary basins at high elevations (up to 2 km). In the Mut Basin, Middle Pleistocene deposits, reaching up to 1.5 km in elevation, unconformably overlie the Meso-Cenozoic succession of the Central Tauride (Öğretmen et al., 2018). We present the preliminary results on a marine succession cropping out in the Mut Basin (~1.1 km a.s.l.) (TOL 1). The studied section is roughly 71 m thick and is predominantly made up of marls, clayey marls, and calcarenite layers, showing a shallowing-up trend. We collected samples, with one-meter sampling resolution, for micropaleontological, isotopic and geochemical analyses. Although a strong presence of reworked specimens dilutes the concentration of the in-situ species, our preliminary results, based on the calcareous nannofossils biostratigraphy, show two important biostratigraphic events: *Gephyrocapsa omega* First Occurrence (FO), calibrated at 0.95 Ma (Maiorano et al., 2004), which occurs at the basal part of the sampled section, and *Emiliana huxleyi* FO, calibrated at 0.26 Ma (Rio et al., 1990), close to the top of TOL 1. Unfortunately, it was not possible to detect the Top common (Tc) of *Reticulofenestra asanoi*, probably due to interference from reworking.

These biostratigraphic events provide a clear hint that the TOL 1 section records the Mid-Pleistocene Transition. Quantitative biostratigraphic investigations on calcareous nannofossils, planktonic and benthic foraminifera assemblages are currently in progress. To define how the climatic changes that occurred during the MPT are recorded in the TOL 1 section, analyses on stable and clumped isotopes, and Mg/Ca ratio on foraminifera shells are still in progress, as well as magnetostratigraphic and calcimetry analyses.

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Late Holocene breakdown of antagonistic interspecific interactions in the western Adriatic Sea

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Keywords: Po Delta, Ecosystem functioning, Anthropic impacts.

Antagonistic interspecific interactions are crucial in shaping the diversity of marine ecosystems (Ricklefs, 2015). However, we often lack long-term data to see how these interactions may have changed during the last few thousand years due to increasing human impacts on ecosystems. Here, we explored the most recent fossil record of biotic interactions archived in mollusk shells. We analyzed the late Holocene mollusk record in two important and laterally coeval depositional settings of the western Adriatic Sea (shoreface and prodelta deposits) to focus on parasite-host (trematode-bivalve) and predator-prey (gastropod-bivalve) interactions, respectively. We specifically targeted the shoreface bivalve *Chamelea gallina* and trematode traces present in the internal part of its valves (Huntley & Scarponi, 2021), to evaluate changes in parasitic dynamics in relation to increasing anthropogenic pressures recorded in the area during the last millennia (Lotze et al., 2011). For predator-prey interactions, we examined the predation traces of naticid or muricid gastropods (Sawyer & Zuschin, 2010) on their mollusk prey across different mollusk species from prodelta deposits. The results of our analysis indicate that parasitic prevalence in the western Adriatic Sea has decreased by an order of magnitude over the late Holocene. Parasite intensity and aggregation have also been reduced significantly signaling a substantial decrease in the effective population size of digenean trematodes. Similarly, predator-prey interactions have also decreased by a factor of four with respect to the late Holocene baseline, mainly due to the loss of predatory gastropods, decreased abundance of preferred prey, and increased abundance of less-preferred prey organisms.

Combined, these results indicate the collapse of antagonistic interspecific interactions among marine invertebrates in concert with increasing human influence on the Adriatic and its transition to an Urban Sea.

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Paleoenvironmental remarks on the Early-Middle Pleistocene site of Contrada Monticelli (Apulia, Southern Italy)

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Keywords: paleoenvironmental, Early-Middle Pleistocene transition, Mediterranean Europe.

The transition between the Early and Middle Pleistocene marks an important change in the Earth's climate system, when the periodicity change of glacial-interglacial cycles from 41,000 to 100,000 years, influenced the distribution and typology of terrestrial vegetation and fauna. This period, characterized by major ecological transitions and profound reorganization of terrestrial ecosystems, is known as the Early-Middle Pleistocene Transition (EMPT) and occurred during the ~1.4–0.4 Ma interval. In general, the mammal communities proved to be very sensitive to climate and environmental changes of this crucial time.

Discovered during the spring of 1978, the karst infilling deposit of Contrada Monticelli (CM) revealed to be very rich in terrestrial mammals, with over 150 fossil remains discovered. The faunal assemblage has been attributed to the Isernia Faunal Unit (early Middle Pleistocene, ca 0.6-0.55 Ma), and this biochronological placement is of particular interest, representing one of the few sites referred to as early Middle Pleistocene in Mediterranean Europe. The mammal assemblage found at CM mostly includes herbivores turned out to be composed of mixed and highly flexible feeders such as *Palaeloxodon antiquus*, *Stephanorhinus hundsheimensis*, *Bison* cf. *schoetensacki*, *Dama* cf. *roberti*, in addition to *Equus* sp. considered a typically grazing species. Carnivorans are exclusively represented by the isolated and poorly preserved cranium of *Canis mosbachensis*.

In addition to the known paleoecological characteristics, analyzes carried out on the size and relative length of long bones of some species found at CM seem to suggest adaptations to relatively warm and heterogeneous environments, characterized by a mosaic of wooded covers alternating with more open grazing spaces. The recent discovery of micromammals, which have never described before, within the sediment incorporating some mammal remains could further enhance our understanding of the paleoenvironmental conditions at the CM site.

Hydrological variability during the Roman and Medieval periods in the Balkan Peninsula using speleothems

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Keywords: Middle Age Climate Anomaly, speleothems, stable isotopes

The most recent European summer droughts have fueled a debate as to whether they are within the range of natural variability or related to anthropogenic warming. This debate is within the more general question if previous climatic change periods (before pre-industrial Era) during the last thousandth of years are globally coherent in terms of chronology or not (Neukon et al., 2019). This uncertainty largely arises because the instrumental records are intrinsically short and sparse and are unlikely to include the full range of natural variability. Historical, archaeological and proxy records supply additional information to be used to reconstruct past summer droughts and more in general on hydrological variability. Southern Europe and the Mediterranean region are particularly vulnerable to drought events and there is evidence that hydrological changes are increasing even if a long-term (millennial-scale) perspective is still at least incomplete. Therefore, to identify regional drought in the last thousands of years of warmer periods has important implications within the current debate on climatic changes and their potential impact (e.g. Zanchetta et al., 2022). The climate during the Roman Age and the Middle Ages has attracted the attention for its potential to be an important analogue for the present warming. However, regionally well-dated records are still sparse. We present two new, well-dated stable isotope (δ18O, δ13C) records of speleothems from Galubarnica and Momicek caves in the North Macedonia Republic. Specifically, δ18O is here considered a good tracer of the hydrological variability (e.g. amount of rainfall during the recharge seasons. They show a prominent aridity during the first century BCE, the beginning of the CE, and during the Middle Ages. These drier periods found some important similarities with regional lake level reconstruction and δ18O from lacustrine carbonates, indicating their severity and regional impact.

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The deformational mega-structures of the Pianico-Sellere Basin (Iseo Lake, Lombardy) which evidence for their origin?

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Keywords: glaciotectonics, Pleistocene, lacustrine basin.

The spectacular mega-structures of the Early to Middle Pleistocene Pianico-Sèllere lacustrine sediments (Moscariello et al., 2000; Pinti et al., 2001; Ravazzi 2013) are well known since the XIX century and caught the attention of many scientists who visited the site. Despite the quality of the exposures, the interpretation of the deformation structures is controversial, as different mechanisms may be proposed for their origin (deformation induced by slope movements, glaciotectonics, seismic-induced events, neotectonics). Casati (1968), who favoured a glaciotectonic genesis for these phenomena, gives a significant contribution to the analysis of these structures. The occurrence of deformational structures has been mentioned in recent papers but no detailed descriptions have been reported so far.

The deformation structures observed in the basin consist of reverse faults, thrusts, folds and overturned folds, often formed in hydro-plastic conditions suggested by liquefaction and dewatering occurring in close association with some of the largest structures. Normal faults are only present as secondary accommodation structures. Some of the described phenomena can represent slumpings, deforming beds along the slopes of the paleo-basin before diagenesis or during sedimentation, whereas the largest ones seem to be related to other phenomena due to different features.

Oedometric tests performed on the fine-grained lacustrine clays attest a strong overconsolidation of these sediments, possibly due to a significant glacial overload. Based on these results, we suggest a glaciotectonic origin for most of the contractional structures, which may be related to the push of a lateral tongue of the main Oglio Glacier, overriding the lacustrine deposits of the Pianico-Sèllere basin during multiple glaciation episodes (Ravazzi, 2013).

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A petrologic journey through the lithosphere

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Reactive melt percolation in spinel mantle harzburgites from the Wadi Tayin Massif (Oman ophiolite)

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Keywords: mantle rocks, melt reactive porous-flow, olivine CPO.

The Oman ophiolite shows a complete sequence of oceanic lithosphere providing direct sampling access to understand processes ruling lithosphere accretion in a fast spreading-ridge oceanic setting. Our research aims at studying the composite recrystallization and melt migration history recorded in the Oman lithospheric mantle from spinel- to plagioclase-facies conditions, poorly constrained to date, in spite of a large number of studies devoted to the Mantle Transition Zone.

Here, we provide evidence of reactive melt percolation at spinel-facies conditions, combining microstructural and petrological investigations on harzburgite samples from the upper mantle of the Wadi Tayin massif.

The studied harzburgites display a porphyroclastic association of (Ol+Opx±Cpx±Spl), and granoblastic aggregates of (Opx+Cpx±Spl) that partially replace Opx porphyroclasts. The granoblastic association is formed by the progressive cooling of the harzburgite at subsolidus conditions (T= 900-1000°C). Both pyroxene porphyroclasts and neoblasts show lobated contacts with interstitial olivine crystals, suggesting a melt reactive porous-flow process that involved pyroxenes dissolution and crystallization of new reactive olivine from the migrating and reacting melt. Both pyroxene generations (porphyroclasts and granoblasts) exhibit similar major element compositions and their Crystallographic Preferred Orientations (CPO) is clear and characteristic of upper mantle deformation under high-T and dry conditions. On the other hand, the olivine CPO varies from axial-[100] pattern, coherent with olivine from upper mantle peridotite deformed under high T and dry conditions (Tommasi et al., 2000), to axial-[010] pattern, indicating deformation in the presence of melt (Zimmerman et al., 1999). Such CPO transition is correlated with olivine modal contents ranging overall from 70% to 85%. Harzburgites with lower modal olivine contents show weak axial-[100] olivine CPO patterns, whereas samples with higher modal olivine abundances have well defined axial-[010] olivine CPO. Both harzburgite modal composition and CPO evolution are related to the melt-rock ratio integrated through time and to the deformation accumulated in presence of melt (Higgie & Tommasi, 2012). Accordingly, samples preserving lower olivine modal amount and axial-[100] CPO are representative of harzburgite recording lower melt-rock ratio over time, compared to those characterized by only axial-[010] CPO symmetry and high olivine modal contents. Preliminary results of this study evidence that reactive melt percolation at spinel-facies depth involved the Oman lithospheric mantle after its conductive cooling at subsolidus conditions. Such event, although not causing evident major element changes in minerals, is clearly documented by modal and microstructural evolution of spinel harzburgites, likely reflecting micro-scale variations in melt-rock ratio through the mantle section.

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Geochemical and petrological study of eastern limb of Rustenburg Layered Suit (Bushveld mafic complex)

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Keywords: Bushveld mafic complex, mafic-ultramafic rocks, cumulates.

South Africa's Bushveld Complex is the most significant and important example of layered mafic complex in the world. It is an iconic geological site, where many generation of geologists were ventured to understand the phenomenology of intrusive magma crystallization process. The interst in Bushveld Compelex expanded since the discovery (Merensky, 1925) of the world's large reserve of platinum (and platinum elements group).

The Complex comprises four exposed sectors - the eastern limb, the western limb, the far western limb and the northern limb, with a fifth limb, the southeastern Bethal limb, obscured by younger sediments. These sectors are formed by mafic-ultramafic layered suite at the base, a granite suite and a sequence of heterogeneous predominantly felsic volcanic rocks of the Rooiberg Group. Both extrusive and intrusive Bushveld magmatism occurred with a time span of a few million years around 2057±3 (Mungall et al., 2016). The majority of the ore deposits are, however, restricted to the intervening group of ultramafic-mafic rocks, or Rustenburg Layered Suite. The Rustenburg layered Suite comprises a package of rocks which range in composition from dunite to diorite. This layered suite is subdivided into marginal, lower (LZ), critical (CZ), main (MZ) and upper (UZ) zones, although their exact boundaries have been the subject of much debate (e.g. Kruger, 2005). Despite the countless published papers since the Twenties of the previous century, there is no consensus yet on the details of its mode of formation. However, it is generally assumed that the layered rocks represent an upward-aggrading pile of crystals deposited on the floor of a vast, long-lived and repeatedly replenished magma chamber (e.g. Mungall et al., 2016).

In 1998 the field excursion poposed by the programme of four-yearly International Vocanic Congress (IAVCEI), held in Cape Town (SA), was focused on the eastern limb of the Rustenburg Layered Suite. Petrologists of the Unviersity of Ferrara (Luigi Beccaluva and Franca Siena) attended the field excursion and collected 31 samples representing all the main rock types of each zone (dunites, orthpyroxenites, pyroxenites, anorthosites). This rock collection remained unworked for many years and just recentely were resumed by the authors of this contribution. Here, the initial stage of a geochemical and petrological study of eastern limb of Rustenburg Layered Suite is presented. On the basis of preliminary bulk geochemistry (major and trace elements) and mineral modal distribution, the majority of the samples are cumulates: dunites, orthopyroxenites, peridotites norite, anorthosites, gabbros; a few metasedimentary rocks of the Transvaal basement are also included. The general order of appearance (and disappearce) of cumulus minerals suggests a multiple a crystallization processes in an open melt-filled chamber.

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Pyroxenite generation via high-pressure crystallization of a MORB-type basalt: an experimental study at 1-2.5 GPa

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Keywords: pyroxenite, crystallization experiments, upper mantle.

Pyroxenites are widespread lithological heterogeneities found in the upper mantle in various geodynamical settings. They are often observed as veins or layers embedded within mantle peridotites in ophiolitic or orogenic ultramafic massifs and found out as lithospheric mantle xenoliths. The origin of pyroxenites can be attributed to different magmatic or metamorphic processes or a combination of them (Bodinier & Godard, 2003). Many mantle pyroxenites are believed to result from segregation of mantle-derived melts with varying degrees of evolution at high-pressure conditions (P ≥ 1 GPa). In this study, we performed piston cylinder experiments at 1-2.5 GPa and 1100-1350°C to investigate the mineralogy and the composition of mineral phases in pyroxenites formed through high-pressure crystallization of a MORB-like basalt. Our starting material was a natural tholeiitic glass with the composition of moderately evolved basalts (XMg = 0.60, SiO_2 = 48.6 wt.%, Na_2O = 3.48 wt.%, K_2O = 0.81 wt.%). High temperature (T > 1200°C) isothermal experiments revealed that clinopyroxene is the liquidus phase at 1-2.5 GPa. We also conducted experiments that experienced cooling down to 1100 and 1150°C to simulated close-system crystallization following high-pressure melt segregation. During cooling, garnet precipitated from the basaltic melt at P ≥ 1.5 GPa, in association with rutile at P ≥ 2 GPa after significant extents of crystallization (residual glass < 20 wt.%). At 1 GPa, low-fosterite olivine (Fo_{76-79} at 1200°C and Fo_{65-68} at 1100°C) was observed in all runs in assemblage with a plagioclase An_{45-48} at 1100°C. Upon cooling, XMg in clinopyroxene decreases (down to 0.66) accompanied by a slight decrease in Ca and an increase in Ti. At higher pressure, clinopyroxenes exhibit progressively higher Na and Al contents (with Jadeite content up to 0.25 at 2.5 GPa) with decreasing Ca and Cr concentrations. Garnets record upon cooling increase of Grossular and Pyrope contents combined with a decrease of Almandine. By assuming that late residual melt is expelled through compaction, the modal abundances determined in cooling experiments can be used to estimate the final mineralogy of the rock. Pyroxenites generated through infiltration and crystallization of MORB-type basalt at P ≥ 1.5 GPa are garnet clinopyroxenites having garnet modal abundance increasing with pressure from 22 to 38 wt.%. Olivine-bearing clinopyroxenite, with a low abundance (< 5 wt.%) of Ab-rich plagioclase, forms at 1 GPa. Mineral compositions and modal abundances are employed to estimate the bulk compositions of pyroxenites formed through high-pressure crystallization. Preliminary calculations suggest that the reconstructed bulk compositions are similar to those of some mantle pyroxenites observed in natural settings.

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Alkaline MORBs mark low-T domains along Mid Ocean Ridges

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Keywords: alkaline MORB, Mid Ocean Ridge, mantle heterogeneity.

Mid Ocean Ridge basalts are generated during decompressive partial melting of the suboceanic asthenosphere under variable PT conditions controlled mainly by the local spreading rate. Once obducted onto ophiolitic sequences MORBs are typically identified by their distinctive chemical systematics, which reveal a significant depletion in incompatible elements in comparison to alkaline lavas generated at hot spots, where fertile mantle material melts at high T-P conditions. Recently, we sampled a suite of alkaline MORBs at the Romanche eastern intersection (Maia et al., 2020), characterized by high K/Ti, steep REE patterns and nepheline normativity. These MORBs are generated at slow spreading conditions in regions of starved magmatic production due to local depression of the mantle potential temperature. They compositionally pair extremely enriched MORBs recovered along ultra-slow spreading ridges, which have been attributed to aggregation of melts from low-degree partial melting of fertile lithological heterogeneities (Standish et al., 2008). Contextually, alkaline MORBs have been identified at the EPR 8 °N along a seafloor spreading flow line at the ridge axis tip, possibly generated in the thinned wings of the subaxial melting region (Anderson et al., 2020). The same source can be postulated for alkaline basalts sampled in intra-transform domains extracted during pressure release of transpressive systems at the St. Paul FZ, MAR (Klein et al., 2024).

All these occurrences are suggestive of partial melting of heterogeneous mantle sources controlled by heat diffusion into low-solidus components. They pose a challenge once retrieved in ophiolitic sequences due to their apparent similarity with hotspot-generated alkaline melts in all compositional systematics, including isotopes.

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Variability in Platinum Group Elements enrichments in supra- and sub-Moho ophiolite chromitites: case studies from the Dinarides-Hellenides belt

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Keywords: ophiolites, chromitites, platinum group elements.

Platinum Group Elements (Os, Ir, Ru, Rh, Pt and Pd) are listed as Critical Raw Materials by the EU. The main producing countries are South Africa and Russia, where the main mineralization are associated to mafic-ultramafic layered intrusions and magmatic Ni-Cu-PGE deposit respectively.

PGE are also enriched up to subeconomic grades within ophiolites, in particular in mantle chromitites, where they are hosted within Platinum Group Minerals. Due to the PGE geochemical behaviour, mantle chromitites are enriched in Os, Ir and Ru (IPGE) with respect to Rh, Pt and Pd (PPGE), with concentrations rarely exceeding hundreds of ppb.

Some studies, however, report PGE enrichments, in the order of some ppm, in chromitites within the ultramafic cumulates above the Moho, even though enriching mechanisms are still largely unknown. The Dinarides-Hellenides belt hosts numerous ophiolitic outcrops, along with past and active chromite mines. Most of the ophiolites are Jurassic and occur in the Vardar Zone in Greece and in the Inner and Outer Ophiolite Belt in Albania. Older, more scattered occurrences have been dated to Early Triassic and are associated to the Serbo-Macedonian Massif in Greece.

Supra-Moho and mantle chromitites were collected in the Tropoje Massif, Northern Albania, and in the Chalkidiki Peninsula, Northern Greece.

Mantle chromitites in Tropoje show dominantly massive textures. Chromite rims are altered into ferrian-chromite, and the silicate matrix is mainly serpentinitic. Platinum Group Minerals (PGM) were not detected. Base Metal Minerals (BMM) are mainly native Bi and awaruite (Fe-Ni alloy).

Supra-Moho chromitites are small occurrences of massive and disseminated chromitites located in exploration trenches. Chromites show alteration into ferrian-chromite at the rims, and primary silicates are all replaced by serpentine. PGM are relatively abundant and show a high mineralogical diversity. The most abundant PGE is Pt, hosted in Pd-free isoferroplatinum (Pt_3Fe) and ferronickelplatinum (Pt_2FeNi). Pd was detected only as a minor element in isoferroplatinum. Undetermined PGM are: Rh-Ir-Ru-Os sulfosalts and Rh-Ni-Fe-Ir arsenides. The only sulfides are rare laurites $(Ru,Os)S_2$.

Mantle and supra-Moho chromitites in the Chalkidiki Peninsula show disseminated to massive textures. Chromite rims are altered into ferrian-chromite and the silicate matrix is replaced by chlorite. Mantle chromitites (average PGE content: 380 ppb) host rare laurite, while supra-Moho chromitites (PGE content: 3516 ppm) show higher PGM variability, with laurite, erlichmanite $(Os,Ru)S_2$, and undetermined Rh sulfides. Unlike typical ophiolite PGE patterns, supra-Moho chromitites show a positive Rh anomaly (Bussolesi et al., 2022). The variability of the PGM suite in two different supra-Moho chromitites leaves us with important issues regarding the formation mechanisms, the PGE geochemical behaviour and the preferential partitioning into sulfides, alloys, arsenides and sulfosalts.

Bussolesi M. et al. (2022) - Chromite compositional variability and associated PGE enrichments in chromitites from the Gomati and Nea Roda ophiolite, Chalkidiki, Northern Greece. Miner. Deposita., 57, 1323-1342, https://doi.org/10.1007/s00126-022-01109-z.

Using olivine trace elements content as a tool to reconstruct the chemical log of the sub-cratonic lithospheric mantle and the evolution of kimberlite melts

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Keywords: peridotite xenoliths, sub-cratonic lithospheric mantle, kimberlites.

Mantle-derived xenoliths and diamonds brought to the surface by kimberlites in cratonic areas provide the best insights onto the deepest realms of the lithosphere. However, a comprehensive understanding of the nature and evolution of the sub-cratonic lithospheric mantle is still hindered by the geochemical similarities between the metasomatic melts-fluids and the xenoliths' host kimberlites. Indeed, mantle xenoliths witness repeated overprint by kimberlitic-like fluids and melts, which induce cryptic to modal metasomatism, but at the same time kimberlite melts also evolve through progressive reaction with/assimilation of the lithospheric mantle.

In this study, chemical-textural characterization of on spinel- to garnet-bearing peridotite xenoliths from the Udachnaya-East kimberlite (Siberian craton) and thermobarometric modelling were coupled to high-precision EPMA analyses of olivine crystals in both peridotite xenoliths and host kimberlites. Results showed that the distribution of elements such as Cr, Al, Ca, Mn, Ti and P in olivine from peridotite xenoliths is variable, and generally increases from the 10s ppm to the 100s ppm level from spinel- to garnet-bearing rocks. We will discuss how the incorporation of the different trace elements in olivine can be dependent on either temperature, nature of co-existing mineral assemblage (presence/absence of clinopyroxene, spinel *vs.* garnet), and/or melt extraction/metasomatic processes. Concomitantly, olivine grains inside kimberlites display marked zoning in trace elements, which dramatically increase from the xenocrystic, mantle-derived cores to the magmatic-derived overgrowth formed in equilibrium with kimberlitic melts.

Altogether, our results demonstrate how trace elements in olivine determined through high-precision EPMA are an extremely powerful tool to: i) unravel the nature and evolution of the lithospheric mantle; ii) understand the provenance depth of mantle-derived cargo in kimberlites; and iii) reconstruct the liquid line of descent of the ascending kimberlitic melts.

MORB melt - harzburgite interaction at 1-2 GPA: experimental constraints on oceanic mantle refertilization

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Keywords: melt-peridotite reaction, experimental petrology, trace elements.

Earth's upper mantle is characterized by wide compositional variability, mainly caused by partial melting processes and interactions between migrating melts and peridotites. After oceanic partial melting, refractory peridotites may be modified via reaction with migrating MORB melts at the flanks of melting regions, thus affecting the chemical and isotopic evolution of large lithospheric mantle sectors. This work aims to investigate by high-pressure experiments the effect of Enriched-MORB - peridotite reaction on major and trace elements composition of mantle phases at oceanic asthenosphere-lithosphere boundary (1-2 GPa; 1150-1400°C). We present the results of reaction experiments on a modeled harzburgite, made by depleted orthopyroxene (LaN/YbN = 0.004) and San Carlos olivine (Fo_{90}), homogeneously mixed to tholeiitic basaltic glass (XMg = 0.60, Na_2O = 3.48 wt.%, K_2O = 0.81 wt.%) with E-MORB signature (LaN/YbN = 5.40). Melt-peridotite reaction is simulated by isothermal experiments performed at high temperature (1200-1350°C). In a separate set of experiments, after high temperature step, runs have been cooled at 1150-1200°C to enhance reacted melt crystallization. Isothermal experiments mostly result in orthopyroxene dissolution coupled to olivine dissolution and reprecipitation. In cooling experiments, we observed new orthopyroxene and clinopyroxene crystallized from reacted melt, associated with few modal garnet (2 GPa) or plagioclase (1 GPa). Rims of partially dissolved orthopyroxene and newly crystallized orthopyroxene tend to acquire high TiO_2 and Al_2O_3, and low Cr_2O_3 contents with respect to initial orthopyroxene composition. Clinopyroxenes (XMg = 0.83-0.88) have moderate Al (up to 0.49 a.p.f.u.) and Ti (up to 0.07 a.p.f.u.). Olivines compositions are correlated with temperature and show high XMg (up to 0.95), high Ca and low Ni concentrations in high-T isothermal experiments, whereas cooling experiments have lower XMg (up to 0.84), coupled to moderate Ca and variably Ni contents. Newly formed orthopyroxenes show variable enrichments in LREE (LaN/SmN = 0.83-1.38) coupled to slightly lower HREE contents (SmN/YbN = 0.24-0.33), compared to initial orthopyroxene (LaN/SmN = 0.04, SmN/YbN = 0.10). Such unusual enrichment in orthopyroxenes has been documented in abyssal peridotites metasomatized by variably melts. Several rims of orthopyroxenes relicts are modified and show relatively high incompatible element concentration likely due to REE diffusion during the reaction. Clinopyroxenes show high convex upward LREE patterns at marked MREE/HREE fractionation. Reacted glasses show slight LREE/HREE fractionations at variable absolute REE concentrations as a function of temperature and extent of interstitial phases crystallization. This study provides a set of "reaction" partitioning coefficients (KdREE = CREEsolid/CREEliquid) that allows us to estimate the trace element redistribution in mantle minerals due to reactive percolation of basaltic melts.

Petrographic and structural study of a lower crustal mafic-ultramafic sequence from the Sesia Valley (Ivrea-Verbano zone, Italy)

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Keywords: garnet-bearing metagabbros, lower continental crust, virtual outcrop models

The factors and dynamics governing the processes in lower continental crust have long been a source of vigorous debate, due to the lack of direct access to such lithologies on the Earth's surface. The Ivrea-Verbano zone (IVZ) represents a geological unit in the western Southern Alps that offers the possibility to investigate an exhumed quasi-complete section of the continental crust, including the roots of a completely exposed fossil magmatic system (Quick et al., 2009). In addition, there is an active debate about whether the contact between the Balmuccia peridotite and the Mafic Complex in the IVZ might represent a continental crust-mantle transition zone (Ryberg et al., 2023).

The focus of this work is a petrographic-structural study of a mafic-ultramafic sequence within the Upper Zone of the Mafic Complex, cropping out near the Sassiglioni village (Sesia Valley, IVZ; Rivalenti et al., 1984). The study involved collecting field and remotely sensed data, including primary magmatic intrusions, foliations, faults, and fractures. To enhance our understanding of these structures and the chemical-physical processes at a micro-scale, a petrographic and micro-structural analysis on selected samples is also being conducted. The remote sensing part of the study was based on capturing drone images that were used to construct a virtual outcrop model (VOM) of the site. This VOM facilitated the analysis of structures at a macro-scale and enabled the mapping of the outcrop, free from perspective distortion, using orthorectified photomosaics.

The lithological sequence is mainly composed of metagabbros with variable amounts of garnet, olivine and/or hornblende. Foliation varies from sub-vertical to less than 45° dipping toward E-SE or W-NW. Occasionally, the sequence includes anorthosites and pyroxenites layers, pseudotachylytes (PST) and mafic pegmatites. The cm-to-m sized PST, which range in color from black to brown and occasionally include plagioclase-pyroxene grains, are found as I) shear planes, II) injection veins, and III) network of melt surrounding metagabbro blocks. The mafic pegmatite is composed of cm-sized pyroxene-plagioclase crystals and can be observed in direct contact with the metagabbro. Clasts of this pegmatite are also included within the PST. The layers of anorthosite and pyroxenite are found in contact with each other with sharp boundaries. Finally, several dm-sized enclaves of fresh garnet-rich metagabbro were identified near the fracture zones within the main body of garnet-free metagabbro. Contact between the enclaves and the main body is marked by apparent reaction rims. All lithologies and their associated foliations were found to be overprinted by a later tectonic event, consistent with literature data (Quick et al., 1994). This event is characterized by top-to-SE brittle shear deformation, evidenced by a Riedel shear assemblage. It represents the most recent deformational event in the area.

Quick J.E. et al. (1994) - Emplacement dynamics of a large mafic intrusion in the lower crust, Ivrea-Verbano Zone, northern Italy. J. Geophys. Res., 99, 21, 559-21, 573, https://doi.org/10.1029/94JB00113.

Quick J.E. et al. (2009) - Magmatic plumbing of a large Permian caldera exposed to a depth of 25 km. Geology, 37, 603-606, https://doi.org/10.1130/G30003A.1.

Rivalenti G. et al. (1984) - The layered series of the Ivrea-Verbano igneous complex, Western Alps, Italy. Tscher. Miner. Petrog., 33, 77-99, https://doi.org/10.1007/BF01083065.

Ryberg T. et al. (2023) - 3-D imaging of the Balmuccia peridotite body (Ivrea-Verbano zone, NW-Italy) using controlled source seismic data. Geophys. J. Int., 234, 1985-1998, https://doi.org/10.1093/gji/ggad182.

The Se-Te-bearing VMS deposits of Tuscan ophiolites

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Keywords: VMS deposits, ophiolites, Northern Apennine.

Several Jurassic, ophiolite-hosted Cu-Zn Volcanogenic Massive Sulphide deposits (VMS) occur in Tuscany (Klemm & Wagner, 1982). They are hosted by tectonic units of oceanic affinity (Ligurian Units), such as the well-known deposits of nearby Liguria. Industrial production was small and definitively ceased from the 1960s. Locally, massive ore (chalcopyrite-bornite-chalcocite) having exceptionally high grade was found. The Montecatini Val di Cecina mine exploited the largest "bonanza" and, for few decades in XIX century, became one of the most profitable copper mines in Europe.

This study is part of the PRIN-MUR 2017AK8C32 project, funded by the Italian Ministry of University and Research. It was aimed to make a reappraisal of the Tuscan VMS Cu-Zn deposits and define: i) their structural setting, ii) their potential for precious-critical metals and iii) the reactions involving their sulphides and gangue silicates. It provides an updated review of these deposits (Dini et al., 2024).

Tuscan Cu-Zn VMSs mostly occur in proximity of the contact between the serpentinite-gabbro basement and the overlying basalts. Chalcopyrite-pyrite stockworks occur in serpentinite-gabbro cut by dolerite dykes, while the largest massive sulphide bodies are hosted by polymictic-monomictic breccias at the base of pillow basalts. The early chalcopyrite ores were mechanically-chemically reworked and upgraded to bornite-rich nodular ore embedded in a chlorite, calcic amphibole, Fe-rich serpentine, quartz, andradite, ilvaite and xonotlite assemblage. The bornite-rich ore contains substantial amount of sphalerite and pyrite and ubiquitous grains of clausthalite, hessite, tellurium and gold/electrum. The concentration of selenium, tellurium in bornite-rich ore is extremely high, up to 100,000 times the average for the Earth's crust.

They represent a prime example of the sub-seafloor portion of a hybrid mafic-ultramafic oceanic hydrothermal system formed in an OCC along the slow spreading ridge of the Jurassic Piedmont-Ligurian Ocean (Dini et al., 2024). The peculiar mineralogical-textural character of the bornite-rich ore was driven by an interface coupled dissolution-precipitation process mediated by fluids. Despite their small size, Tuscan ultramafic- and hybrid mafic/ultramafic-hosted VMS deposits provide valuable information for the ongoing definition of a genetic model for this sub-group of VMSs (Patten et al., 2022). This is a potentially relevant mineral resource worldwide not only for base metals, but for possibly recovering energy-critical metals like Co, Ni, Te and Se from mafic/ultramafic-hosted deposits in orogenic and oceanic settings.

Dini A. et al. (2024) - The ophiolite-hosted, Cu-Zn VMS deposits of Tuscany (Italy). Minerals, 14, 273, https://doi.org/10.3390/min14030273.

Klemm D.D. & Wagner J. (1982) - Copper deposits in ophiolites of Southern Tuscany. Ofioliti, 2-3, 331-336.

Patten C.G.C. et al. (2022) - Ultramafic-hosted volcanogenic massive sulfide deposits: An overlooked sub-class of VMS deposit forming in complex tectonic environments. Earth Sci. Rev., 224,103891, https://doi.org/10.1016/j.earscirev.2021.103891.

Exploration of natural hydrogen in the Northern Apennines, Italy

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Keywords: natural hydrogen, northern Apennines, ophiolites.

In the energy diversification scenario, natural or geological hydrogen (H_2) may represent a clean and cost-effective option. Although it is still poorly studied, its exploration is already a reality. In Mali, a field of H_2 has been in production since 2012. In other countries, such as Australia, U.S.A, France, Oman and Poland, H_2 exploration activities are already allowed.

One of the main H_2-generating process is the alteration of iron-rich rocks. During serpentinization, oxidation of minerals containing Fe^{2+} (e.g. olivine) into Fe^{3+} (e.g. serpentine + magnetite) generates H_2. Therefore, mantle rocks occurring in ophiolite sequences can represent suitable H_2-generating rocks.

In the Northern Apennines, the presence of ophiolites including ultramafic rock bodies is noticeable, and, associated to the multiphase structural framework and gas manifestations, makes the region a favorable place to H_2 occurrences.

Our study aims to evaluate the potential for H_2 occurrence and investigate the H_2-forming processes in the NW sector of the Northern Apennines. The study is conducted through i) measurements of H_2 content in the soil and dissolved in the water, ii) rocks chemistry, and iii) assessment of subsurface geological-geophysical data.

Three study areas were selected for investigation: two in Emilia-Romagna, namely Monte Prinzera (Parma Province) and Bobbio (Piacenza Province), and one in Liguria (Bracco-Levanto).

Located in the External Ligurian domain, Monte Prinzera corresponds to an ophiolitic body primarily composed of serpentinized peridotites and breccias. The presence of a hyperalkaline spring water, containing H_2 and CH_4 reported by Boschetti et al. (2013) encouraged our further H_2 measurements in the soil and dissolved in the water. Additionally, petrographic, and bulk analyses of major elements in peridotites are being carried out to evaluate the potential for H_2 production.

The Bobbio region corresponds to a structural window where deformed sediments of the Tuscan domain are tectonically overlain by ophiolitic bodies from the External Ligurian units. Bubbling gas manifestations previously observed (Scicli, 1972) have led us to investigate the region. We found that two bubbling springs, despite they are not hyperalkaline, contained H_2. Seismic reflection, magnetometric and gravimetric surveys integrated with published geological surveys are currently used to investigate the origin of H_2. The Bracco-Levanto is an ophiolitic massif of the Internal Ligurian domain where a hyperalkaline spring water was reported (Fantoni et al. 2002). However, no dedicated H_2 study was carried out so far. H_2 measurements in dissolved gas in water are being conducted in the area, and if H_2 is found, we plan to conduct rock analysis to investigate its potential to form H_2. According to the results obtained to date, the NW part of Northern Apennines hosts H_2-generation processes, and it deserves further studies to better assess H_2 origin and potential accumulations.

Boschetti T. et al. (2013) - Boron, lithium and methane isotope composition of hyperalkaline waters (Northern Apennines, Italy): Terrestrial serpentinization or mixing with brine? Appl. Geochem., 32, 17-25, https://doi.org/10.1016/j.apgeochem.2012.08.018.

Fantoni D. et al. (2002) - Natural hexavalent chromium in groundwaters interacting with ophiolitic rocks. Environ. Geol., 42, 871-882, https://doi.org/10.1007/s00254-002-0605-0.

Scicli A. (1972) - L'attività estrattiva e le risorse minerarie della Regione Emilia-Romagna. Poligrafico Artioli, 728 pp.

Tests for implementing ophiolitic chromite concentrates from Albania mines to chromite foundry sands quality parameters

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Keywords: ophiolite chromite, chromite foundry sand, silicate mineralogy.

Chromite is the best performing of the refractory materials used by foundries for casting. Chromite foundry sands form the mould in which molten metal is contained until it solidifies in the desired shape. Chromite is used because of its resistance when exposed to heat and its good heat conductivity. It is chosen when a higher casting temperature is required or for a complex shape of the mould; in these cases it has no substitutes and hence its high economic importance.

To be used for casting, chromite sands must be as pure as possible as small amounts of low-T melting gangue minerals can damage the binding resins. Moreover, a very narrow sand grain size range is required to provide the correct permeability to the sand.

In refractory industry acid demand test (ADT), a titration method that keeps into account the amount of acid consumed at three different pH levels, is used as a proxy of the sand-resin reaction potential, while for grain-size the fineness index (FI) test is used. A third parameter usually determined is the SiO_2 content that should be as low as possible.

The present work reports the first results obtained on testing several chromite sands produced by different gravity enrichment plants at Albanian chromite mines.

Firstly, the sands were checked, together with two samples from commercial South African chromite foundry sand, for all the three quality parameters and compared with foundry industry thresholds. As expected, all Albanian sands did not meet the parameters. Some of the sands meet the FI range but all of them are too high in SiO_2. The worst results were anyway obtained for the ADT value, always quite far from the thresholds. A selection of the Albanian sand closer to the quality thresholds were chosen for further depuration tests aimed to meet all three parameters.

The mineralogy of Albanian and South African chromite gangue minerals strongly differs. Albanian sand derives from metamorphosed ophiolite-hosted deposits, typically enriched in serpentine, while South African ones come from the major layered intrusion of Bushveld and their typical gangue minerals are olivine and orthopyroxene. The presence of serpentine negatively affects the ADT value as it is much more reactive than olivine or pyroxene (Bussolesi et al., 2020).

The first depuration tests were designed with the aim to reduce serpentine content of sands by cooking them in an oven at 800°C for one hour. The results were partially positive as the ADT value was reduced of about 30%, due to transformation of serpentine into a new phase as confirmed by XRD data. This result is not enough to decrease the ADT below the commercial threshold.

To further implement sands quality a separation through a Franz magnetic separator has been conducted. Preliminary results are positive, and it is possible that a combination of cooking and magnetic separation could lead to the production of chromite foundry sands starting from Albanian chromite concentrates.

Bussolesi M. et al. (2020) - Ophiolite chromite deposits as a new source for the production of refractory chromite sands. Sustainability, 12, 7096, https://doi.org/10.3390/su12177096.

Serendipity-driven discovery of a new UHP slice in the southern Dora-Maira Massif

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Keywords: petrological discovery, new UHP unit, southern Dora-Maira Massif.

The first worldwide report of coesite (Chopin, 1984) in the continental crust of the southern Dora-Maira Massif (DMM), western Alps, is one of the best examples of how petrological discoveries can revolutionize geological and geodynamic paradigms, suggesting that even the relatively light continental crust can reach previously unsuspected mantle depths. Since that discovery, the small Brossasco-Isasca Unit (BIU) has been the subject of an incredibly high number of studies, becoming the archetype of ultra-high pressure (UHP) metamorphic terranes; currently, most geodynamic models seeking to explain the subduction and exhumation processes of crustal rocks from mantle depths are calibrated on this tectonic unit. However, despite all these studies, the interpretation of the BIU in the framework of the southern DMM and, more generally, of the Western Alps, remains controversial.

Progress on understanding UHP metamorphism in the BIU inevitably depends also on our knowledge of adjacent units, which - together with the BIU - define the nappe stack of the southern DMM. After preliminary studies dating back to more than 30 years ago, a new impetus in this direction has recently been given (e.g., Groppo et al., 2019; Bonnet et al., 2022), allowing to reconstruct the lithostratigraphic and tectonic setting, the metamorphic evolution and the ages of Alpine metamorphism for all the units stacked in the DMM tectonic "sandwich".

Although one might think that the southern DMM has no more secrets and that everything has already been said in this small area extending over less than 200 km^2 between the Po and Varaita valleys in the Piedmont region of Italy, serendipity can sometimes lead to new discoveries even in the best-known areas. And serendipity is the basis of this study: while observing under the microscope an apparently common metagranite sample we noticed unexpected microstructures which led us to critically re-examine samples collected more than 30 years ago. Here we report petrological evidence that the tectonic unit overlying the BIU (formerly known as Rocca Solei Unit), so far considered as a high pressure (HP) unit, is actually divided in two sub-units, one of which (the lowermost Rocca Solei Unit s.s.; RSU*) experienced "cold" UHP conditions, while the other (the uppermost unit, here renamed as Grimbassa Unit, GU) reached HP conditions. Therefore, a "new" slice needs to be added to the southern DMM sandwich; this new unit experienced UHP metamorphism, but at significantly different P-T conditions compared to the underlying BIU. Interestingly, the structural position, thickness and metamorphic evolution of the UHP RSU* inferred in this study are very similar to those defined for the Chasteiran Unit, recently discovered in the northern DMM (Manzotti et al., 2022). This new discovery encourages everyone not to cease the quest for petrological novelties and to be prepared to take advantage of serendipitous events.

Bonnet G. et al. (2022) - Protracted subduction of the European hyperextended margin revealed by rutile U-Pb geochronology across the Dora-Maira Massif (Western Alps). Tectonics, 41, e202TC007170, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021TC007170.

Chopin C. (1984) - Coesite and pure pyrope in high-grade blueschists of the western Alps: a first record and some consequences. Contrib. Mineral. Petrol., 86, 107-118, https://doi.org/10.1007/BF00381838.

Groppo C. et al. (2019) - What's in the sandwich? New P-T constraints for the (U)HP nappe stack of southern Dora-Maira Massif (Western Alps). Eur. J. Mineral., 31, 665-683, https://doi.org/10.1127/ejm/2019/0031-2860.

Manzotti P. et al. (2022) - A journey towards the forbidden zone: a new, cold, UHP unit in the Dora-Maira Massif (Western Alps). Contrib. Mineral. Petrol., 177, 59, https://doi.org/10.1007/s00410-022-01923-8.

Subcontinental lithospheric mantle stratigraphy in the SW margin of São Francisco Craton: insights from xenocrysts and xenoliths trapped in the Três Ranchos kimberlite (APIP, Brazil)

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Keywords: thermal structure, chemical zoning, subcontinental lithospheric mantle.

The petrographic and chemical (major and trace elements) characteristics of garnet and clinopyroxene xenocrysts and of peridotite xenoliths entrained in the Três Ranchos kimberlite have provided valuable insights into the subcontinental lithospheric mantle (SCLM) beneath the Alto Paranaíba Igneous Province (APIP, Brazil) with respect to: (i) the thermal structure and heat flow; (ii) the pristine composition and metasomatic events undergone by the lower SCLM sector; (iii) the nature of the shallow fertile, lherzolite layer. These observations, combined with a re-evaluation of the petrochemical data of the Brazilian SCLM, allow to shed light on the stabilization and evolution processes of the São Francisco Craton (Guarino et al., 2024).

The present-day thickness of the Brazilian SCLM is similar in the Três Ranchos, Canastra, and Osvaldo França areas (~170-180 km depth), and the estimated temperatures and pressures indicate a typical cratonic geotherm, with a surface heat flow of ~40 mW/m^2 slightly hotter than that at the São Francisco Craton margin (35-36 mW/m^2), suggesting lateral heterogeneities in the geothermal gradients, in agreement with geophysical studies.

A deep mantle portion (160 km) is recorded by a lherzolite xenolith (5 GPa and 1200°C). This portion has undergone pervasive interstitial melt percolation of an ultra-alkaline silicate melt and late injection of small silicate melt fractions similar to the host carbonated kimberlite. This pervasive migration extended into shallower SCLM sectors at 124-100 km (3.9-3.1 GPa and ~940-810°C) as evidenced by metasomatized (± phlogopite) peridotite identified by sinusoidal REE garnet compositions. At 120-110 km depth (3.7-3.3 GPa and ~850°C) strongly depleted peridotites also occur, which show garnet and clinopyroxene compositions extremely impoverished in moderately incompatible elements, as a result of extreme, ancient melt extraction. Above the metasomatized and depleted peridotites, at 100 km depth, a layer of fertile lherzolite is identified by garnet xenocrysts, with 'normal', HREE-enriched, steadily fractionated LREE-depleted patterns.

This study highlights the occurrence in the São Francisco Craton of i) a deeper sector (>100 km deep beneath Três Ranchos) originally formed by extremely depleted peridotites, that were largely metasomatized by pervasive melt migration of ultra-alkaline silicate melts and/or LILE-enriched fluids; ii) and a shallower sector of the São Francisco Craton composed of fertile lherzolites unrelated to ultra-alkaline magmatism. Similar fertile lherzolites are found in the uppermost sectors of the Siberian and Kaapvaal SCLM, suggesting that they may be a ubiquitous, primary feature, possibly related to the stabilization of the Archean cratons.

Guarino V. et al. (2024) - Stabilization and evolution of the Brazilian subcontinental lithospheric mantle: insights from garnet xenocrysts and peridotite xenoliths of Três Ranchos kimberlite (APIP, Brazil). Gondwana Res., 130, 18-35, https://doi.org/10.1016/j.gr.2024.01.005.

HT-LP extensional shear zones in the GHS (E Nepal): preliminary data on P-T-D conditions and timing

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Keywords: Himalata, Greater Himalayan Sequence, petrochronology.

The medium-to high-grade metamorphic core of the Himalaya belt is represented by the Greater Himalayan Sequence (GHS). Facilitated by its 3D good exposure, the GHS is regarded as a proxy for investigating the structure of the middle-lower crust in orogenic settings. For a long period of time, the GHS has been regarded as single, tectonically coherent, unit. Recent findings (Carosi et al., 2010; Montomoli et al., 2013; 2015), starting from field mapping, down to the microscale analysis, challenges this view. Indeed, nowadays most of the focus on the tectono-metamorphic evolution of the GHS is aimed to characterize how strain is accommodated within this "composite" unit, over the time in response to the P-T evolution.

Here, we present preliminary data, combining field observations, microtectonics analysis, pseudosection modelling, iterative thermodynamic modelling and monazite petrochonology, on the activity of high-temperature / low-pressure ductile shear zones, affecting garnet-sillimanite-bearing and cordierite-bearing anatectic paragneiss, in Eastern Nepal. Field and microstructural data highlighted how these shear zones are associated to a normal (both top-to-the-S and top-to-the-N) sense of shear. Mylonitic shearing developed under upper amphibolite facies (c. 700°C) metamorphic conditions, as testified by syn-kinematic mineral assemblage and by quartz and feldspar dynamic recrystallization microstructures. Phase equilibria modelling (i.e., with the aid of P-T-X pseudosections) and iterative thermodynamic modelling, highlighted how sheared rocks experienced a "peak" pre-mylonitic stage in the medium-pressure, upper amphibolite-to granulite facies melt present conditions. This stage is followed by the mylonitic stage, associated to decompression and minor cooling.

Our multidisciplinary investigation highlights how strain was progressively localized within migmatitic terrain, following melt extraction, from the Oligocene down to Miocene. Possible consequences on the role of the detected HT-LP extensional shear zones on the exhumation and thinning of the GHS are presented.

Carosi R. et al. (2010) - Late Oligocene high-temperature shear zones in the core of the Higher Himalayan Crystallines (Lower Dolpo, Western Nepal). Tectonics, 29, TC4029.

Montomoli C. et al. (2013) - Tectonometamorphic discontinuities within the Greater Himalayan Sequence in Western Nepal (Central Himalaya): insights on the exhumation of crystalline rocks. Tectonophysics, 608, 1349-70.

Montomoli C. et al. (2015) - Tectonometamorphic discontinuities in the Greater Himalayan Sequence: a local or a regional feature? Geol. Soc. London, Sp. Publ., 412, 25-41.

Carbonatitic and related alkaline to ultralkaline melts in the Quaternary Eifel Volcanic Province, Germany

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Keywords: carbonatite, phonolite, ultralkaline.

Nearly 80% of carbonatite outcrops are associated with cogenetic silicate magmas, characterised by compositions ranging from ultrabasic (nephelinites and ijolites) to intermediate (phonolites, trachytes and syenites; e.g., Woolley & Kjarsgaard, 2008). The eastern sector of the Quaternary Eifel Volcanic Province (EVP) hosts abundant evolved compositions (mostly phonolite-syenite) occasionally associated to carbonatites and rare mafic lithologies. On the other hand, the western sector of the EVP comprises abundant basic-ultrabasic mafic lithologies, rarer evolved compositions, and even rarer carbonatites.

The largest volcano of the eastern sector of EVP is Laacher See volcano, characterized essentially by strongly explosive phonolite eruptions associated to the formation of a large caldera, plus very rare ultrabasic low-volume potassic lava flows. Plutonic ejecta, with a size up to 20 cm and compositions spanning from mafic to felsic, are common within the thick phonolite pyroclastic deposits. Less than ~5% of these plutonic ejecta contain a carbonate component that can reach more than 50% of the nodule.

A detailed petrographic, mineral chemical, geochemical and isotopic study on such carbonate-bearing plutonic ejecta from Laacher See volcano (sövite and syenite-carbonatite mixed rocks), as well as on the rare leucitite lavas has been carried out to infer the origin of this igneous association. The geochemical compositions are extremely variable, from nearly SiO_2-free and CaO-rich terms to strongly ultrabasic and mildly CaO-rich rocks and to SiO_2-rich CaO-poor compositions.

The relatively high $^{87}Sr/^{86}Sr$ ratios for composite and silico-carbonatite samples overlap quite well, highlighting a genetic link, possibly associated with assimilation of Devonian country rocks by the phonolite magma. Samples from the eastern district of EVP plot in the enriched isotopes field, also for the $^{143}Nd/^{144}Nd$ ratios, while the $^{143}Nd/^{144}Nd$ for carbonatite belonging to the western district is slightly above ChUR. EVP rocks exhibit uniform $^{207}Pb/^{204}Pb$, coupled with a negative correlation between $^{206}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$, and between $^{208}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$.

The origin of the carbonatitic and silico-carbonatitic rocks can be explained with a two-step model. Magma evolution started from a CO_2-bearing leucitite magma, which, after prolonged fractionation of olivine + clinopyroxene + Fe-Ti oxides ± melilite, evolved towards CO_2-enriched phonolite compositions. These melts experienced magma unmixing, with the separation of SiO_2-rich and CaO-CO_2-poor liquids (represented by syenites) and SiO_2-poor and CaO-CO_2-rich melts (represented by Ca-carbonatites). Silico-carbonatites are interpreted as the consequence of the entrapment of small portions of carbonate liquids in the strongly evolved silicate magma, during the unmixing process, whereas composite samples would represent the result of the mechanical mixing of the two unmixed melts.

Woolley A.R. & Kjarsgaard B.A. (2008) - Paragenetic types of carbonatite as indicated by the diversity and relative abundances of associated silicate rocks: evidence from a global database. Can. Mineral., 46, 741-752, https://doi.org/10.3749/canmin.46.4.741.

The redox state of heterogeneous mantle: clues from C-S-bearing clinopyroxenites

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Keywords: clinopyroxenite, oxygen fugacity, mantle.

Fossil subduction zones are key locations to study the deepest geochemical cycles of C, O, S and H. In non-cratonic areas C-bearing mantle rocks were reported for the orogenic peridotite massif of Beni Bousera - Moroccan Rif belt (Pearson et al., 1994), where graphite occurs in garnet pyroxenite layers as pseudomorphs after diamond. Montanini et al. (2010) found high-temperature graphite as flakes in garnet pyroxenite layers from the External Ligurides (Northern Apennine, Italy). Both sample sets show sulphides in equilibrium with carbon. These pyroxenite layers are proxies of deep recycling of subducted crust and may have formed by crystallisation of mafic melts induced by C-S-related redox processes. We analysed the redox state of garnets and clinopyroxenes associated with C and S, related to a liquid segregated from the melting of a recycled eclogite. Transmission Electron Microscopy coupled with Electron Energy-Loss Spectroscopy and synchrotron micro-Mossbauer analyses were performed to check the $Fe^{3+}/\Sigma Fe$ distribution heterogeneities, in relation to its partitioning among mineral phases and/or to the occurrence of fluid fluxes at different redox conditions.

Our results indicate a strong partitioning between garnet and clinopyroxene at high temperature in samples from Beni Bousera, with $Fe^{3+}/\Sigma Fe$ in clinopyroxene reaching up to 0.30, vs. garnets with values up to 0.07. Interestingly, graphite-bearing clinopyroxenites from External Ligurides show two generations of clinopyroxene. The first included in garnet has higher values of Fe^{3+}/SFe with respect to high temperature clinopyroxenes in the rock matrix (0.23-0.38 vs. max 0.08). Garnet shows homogeneous values (up to 0.07). This variation in clinopyroxenes may therefore records a variation of redox conditions, likely related to the interaction and evolution of C-S-bearing liquids, corresponding to an average ΔFMQ (Fayalite-Magnetite-Quartz buffer) from -0.25 to -5. These values correspond to redox conditions slightly above the CCO (Carbon-CO_2 buffer) to below the CCO, indicating a variation in the carbon speciation.

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The Monte Pagliano Unit in the southern Dora-Maira Massif (Western Alps): a preliminary petrologic study

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Keywords: southern Dora-Maira Massif, petrologic investigations, forward thermodynamic modelling.

Located at the mouth of the Varaita and Maira valleys (Western Alps), a few km south-east of the worldwide renew ultra-high pressure Brossasco-Isasca Unit of the southern Dora-Maira Massif, the Monte Pagliano relief, is mostly unknown from a geological point of view, the most recent detailed study being dated to the end of the 19th century (Stella, 1899). However, understanding its geological-structural setting and its metamorphic evolution is crucial for interpreting the whole tectonic architecture of the southern Dora-Maira Massif.

In the study area, we have recognized a new tectonostratigraphic unit, named Monte Pagliano Unit (MPU), which is bounded at its bottom by a several hectometers thick shear zone (i.e., the Valmala Shear Zone, Balestro et al., 2020). Here we present the results of a detailed petrographic study aimed at recognizing the lithostratigraphic succession of the MPU and defining its peak metamorphic assemblages.

The monometamorphic metasedimentary succession of MPU consists of three lithological units: (i) chloritoid- and tourmaline-bearing graphitic micaschist at the bottom; (ii) kyanite- and chloritoid-bearing micaschist with meters-thick levels of paragneiss and metabasite; (iii) quartzitic micaschist at the top.

The paragneiss shows a peculiar mineral assemblage consisting of quartz, kyanite, chloritoid, muscovite, Fe-hydroxide and rutile. The preliminary petrologic investigation of this paragneiss allowed us to provide an estimate of the peak P-T conditions experienced during Alpine subduction.

The obtained results open new questions on the tectonic architecture of this portion of the Dora-Maira Massif and stimulate further petrologic investigations in the adjacent areas.

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Chemistry of sulfides in the Earth's mantle: insights from magmas, mantle xenoliths and inclusions in diamonds

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Keywords: sulfur, sulfide, mantle.

Sulfur (S) is one of the main volatile elements occurring on Earth, both in its reducing (S^{2-}) and oxidized (S^{2+}, S^{4+}, S^{6+}) form. The abundance of S in the bulk silicate Earth has been proposed to be 250 (±50 ppm; McDonough & Sun, 1995), whereas cosmochemical constrains indicates that more than 97% of the bulk Earth S is hosted in the core (Palme & O'Neill, 2003). As a chalcophile element, sulfur binds with Cu, Se, Cd, ln, Sn, Te, Pb and Hg as well as with siderophile elements like Ni, Au, Ag, Co and PGEs.

Sulfides are the main S-bearing minerals and are present as an accessory phase in the Earth's mantle (< 1% of bulk), often occurring as mineral inclusions in lithospheric diamonds. Interestingly, solidus curves of the principal sulfide end-members indicate that these are likely molten or partially molten in almost the mantle (Zhang & Hirschaman, 2016). Studies of natural mantle sulfides reveal significant heterogeneities in terms of both chemical composition and isotopic signatures. However, the reasons for these heterogeneities are not yet fully understood.

In this work, we review the chemistry of sulfides from mantle-derived samples including melts, peridotites, eclogites and inclusions in (sub-)lithospheric diamonds, metamorphic rocks and experimental works at the aim of shedding light on the controversy between the composition of sulfides in nature and those from quenched laboratory experiments with particular emphasis on the role of pressure, temperature and oxygen fugacity.

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Zhang Z. & Hirschmann M.M. (2016) - Experimental constraints on mantle sulfide melting up to 8 GPa. Am. Mineral., 101, 181-192.

New geochemical and age constraints on forearc intrusive rocks from the New Caledonia ophiolite (SW Pacific): diversity of melts generated at hot subduction inception

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Keywords: New Caledonia ophiolite, forearc magmatism, subduction inception.

The New Caledonia peridotite nappe is crosscut by orthopyroxenites, amphibole-bearing websterites, clinoenstatite boninites and hornblende gabbro/diorite dykes intruded between 55.5 Ma and 50 Ma (U-Pb zircon and $^{40}Ar/^{39}Ar$ hornblende ages, Cluzel et al., 2024). Dolerite dikes with tholeiitic affinity were subsequently emplaced between ca. 50 and 47 Ma. Hornblende-gabbro/diorite-forming melts have a broad adakitic affinity, whereas contrasting parental melts with boninitic and Mg-adakitic composition may be inferred for the pyroxenite dikes. Production of slab melts was modelled by moderate degree (20-40%) of partial melting of the HT garnet amphibolites of the metamorphic sole. End-member compositions of the dikes, hornblendites and anorthosites, resulted from solid-state phase segregation of crystal mush within tectonically active magmatic conduits. Residual mantle source re-enriched by slab melt inputs during the Eocene subduction successively formed clinoenstatite-boninite magmas. The youngest magmas of tholeiitic affinity, appeared about 6 Ma after subduction inception when the cooler subducting slab plunged more steeply. Incipient slab retreat allowed corner flow, triggering low pressure hydrous melting of the uplifted asthenosphere. The early stages of forearc magmatism were closely associated with transcurrent shear zones, now testified by HT mylonitic deformation in the peridotites, which recorded oblique subduction inception. The lower Eocene tectonic and magmatic features of the New Caledonia ophiolite witness the existence of a north- or northeast-dipping hot (forced) subduction zone in the Southwest Pacific, which appears notably distinct from the slightly younger west-dipping Izu-Bonin-Mariana cold (spontaneous) subduction system (e.g. Reagan et al., 2013). Our results support the notion that compositional variability of the early forearc products may be a hallmark of subduction inception.

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Kyanite trace element zoning as a method for unravelling migmatite petrological evolution

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Keywords: anatexis, kyanite trace element zoning, thermodynamic modelling.

Trace element zoning in kyanite can preserve information about the growth history of this phase, particularly in anatectic metapelites (Kendrick & Indares, 2018; Phillips et al., 2023). There, kyanite can grow (i) at sub-solidus conditions through metamorphic reactions involving other aluminous phases as reactants (i.e., sub-solidus kyanite), (ii) through muscovite dehydration melting reaction (i.e., peritectic kyanite), and (iii) during cooling and melt crystallisation either through back-reactions between melt and solid phases (e.g., garnet, K-feldspar) or crystallising directly from the melt (i.e., back-reaction overgrowth or magmatic kyanite). Thermodynamic modelling successfully reproduces these reactions, allowing a more robust interpretation of the observed features based on predicted reactants and products.

In this study, we integrate cathodoluminescence (CL) microscopy (optical CL and SEM-CL), LA-ICP-MS mapping and forward thermodynamic modelling to unravel the anatectic history of biotite + kyanite + garnet migmatites from the Lower-Greater Himalayan Sequence exposed in eastern Nepal Himalaya. Changes in kyanite CL colour intensity appear mostly related to different concentrations of Fe, Cr and V (hundreds to thousands of ppm; Müller et al., 2016). Three main generations of kyanite revealed by CL and LA-ICP-MS maps have been identified, consistent with the three main kyanite-producing reactions predicted by forward thermodynamic modelling. Trace element zoning patterns and relative concentrations have been related to kyanite growth (i) at sub-solidus conditions, (ii) during the dehydration melting of muscovite and (iii) during the following decompression and cooling.

The major implications of this study concern the interpretation of the melt extraction processes in anatectic rocks and the understanding of the Cr and V partitioning between minerals and melt. On a broader perspective, our work highlights how minerals characterised by simple chemistry, investigated with a multi-methodological approach coupled with thermodynamic modelling, can reveal important information about metamorphic processes occurring during the evolution of continental crust undergoing partial melting.

Kendrick J. & Indares A. (2018) - The reaction history of kyanite in high-P aluminous granulites. J. Metamorph. Geol., 36,125-146, https://doi.org/10.1111/jmg.12286.

Müller A. et al. (2016) - Trace element composition and cathodoluminescence of kyanite and its petrogenetic implications. Contrib. Mineral. Petrol., 171, 70, https://doi.org/10.1007/s00410-016-1280-6.

Phillips S.E. et al. (2023) - Kyanite petrogenesis in migmatites: resolving melting and metamorphic signatures. Contrib. Mineral. Petrol., 178, 10, https://doi.org/10.1007/s00410-022-01991-w.

Quantitative isopleth thermobarometry for determination of optimal P-T conditions from Perple_X models

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Keywords: quality factor, statistical solution, Python script.

Forward thermodynamic modelling is ubiquitously used in modern metamorphic petrology. Phase diagrams calculated using this technique allow users to determine the pressure (P) and temperature (T) conditions of mineral assemblage formation for a given bulk composition (*X*). Traditionally, isopleth thermobarometry involves manually tracing the field of maximum isopleth overlap, which can be considered a qualitative method (Powell & Holland, 2008; Lanari & Duesterhoeft, 2019). In the last decade, several software solutions have provided more quantitative approaches where optimal P-T conditions can be calculated from a statistical point of view, resulting in a more accurate interpretation of forward model results (Lanari et al., 2017; Duesterhoeft & Lanari, 2020). However, these approaches are based on Theriak-Domino, and/or require quantitative compositional maps (e.g., Bingo-Antidote routine in XMapTools; Duesterhoeft & Lanari, 2020).

We present an application of statistical quantification of the quality of fit starting from the Perple_X WERAMI output, testing different statistical approaches: (i) a least squares approach, which minimises the difference between the observed and modelled compositions, referred to as the residue; (ii) a weighted least squares approach, which adds a weighting factor using analytical uncertainties (Lanari et al., 2017); and (iii) a quality factor approach, which assesses the quality of fit between the modelled and the observed compositions (Duesterhoeft & Lanari, 2020). The calculation shows that a quality factor approach, as implemented in Bingo-Antidote (Duesterhoeft & Lanari, 2020), can be applied to Perple_X results, allowing the propagation of uncertainties in the measured mineral composition. This work and the code will help to improve the quality of interpretation when using isopleth thermobarometry.

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Powell R. & Holland T. J. B. (2008) - On thermobarometry. J. Metamorph. Geol., 26, 155-179, https://doi.org/10.1111/j.1525-1314.2007.00756.x.

2D vs. 3D rock investigation comparison and possible influences for thermodynamic modelling estimates

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Keywords: mineral distribution, quantitative microstructural analysis, bulk rock composition.

Despite the rise of innovative approaches and high-resolution techniques in Earth Sciences, the reconstruction of the tectono-metamorphic history of crystalline basements is mostly based on a two-dimensional (2D) thin-section investigation. Forward thermodynamic modelling requires the definition of a bulk rock composition, which can be obtained from a three-dimensional (3D) rock volume by whole-rock geochemical analysis (e.g., X-ray fluorescence, XRF). Nevertheless, most petrological contributions consider a 2D local bulk rock composition (Palin et al., 2016; Lanari & Duesterhoeft, 2019), obtained by combining the modal abundance of phases with their chemical compositions (e.g., via a weighted calculation using different software, combining mineral proportion of a thin section with their representative compositions and densities). Similarly, textures, grain size, shape, and orientation of different mineral phases in polymineralic rocks are mostly investigated only in 2D, leading to a potential loss of information.

On the other hand, 3D investigations, despite being computationally intensive and requiring specialised tools and expertise, offer a more comprehensive and realistic representation of metamorphic features than traditional 2D thin-section observations (e.g., Corti et al., 2019). Different sample sectioning directions can influence the mineral modal proportions of strongly heterogeneous and anisotropic samples, and 2D thin-section observations risk to oversimplify complex textures. Thus, this work focuses on the comparison between 2D and 3D approaches to understand possible mismatches.

We compared microstructural evidence, modal abundances, local bulk rock compositions and thermodynamic modelling results using a 2D thin section and a 3D volume analysed through X-ray computerised axial microtomography (μCT). Moreover, three different cuts from the 3D volume have been extrapolated (XZ, YZ, XY planes of the finite strain ellipsoid of deformation), and results have been compared. Despite differences in the modal distribution in the 2D thin section, 3D volume, and different-oriented cuts, the mismatches in the local bulk rock composition estimates are very small, with no major implications for the derived thermodynamic modelling. We quantitatively corroborate the reliability of the thin section approach, still emphasising that 3D analysis is complementary for a complete understanding of microtextures and a better representation of the complex geological reality.

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The origin of melilitites: an experimental study

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Keywords: mantle, melilitite, carbonatite.

Melilitites are ultramafic magmas characterized by normative Ca_2SiO_4, larnite, high FeO* and TiO_2. Melilitite primitive lavas (Mg# 67-77) occurs in ocean island as well in alkaline volcanic districts on rifted continental crust. Liquids compositionally close to melilitites were experimentally reproduced in the model system CaO-MgO-Al_2O_3-SiO_2-CO_2 at 3.2-3.3 GPa, approx. 1500°C, at relatively high melt proportions. In complex compositions, MORB-eclogite derived, carbonated, partial melts reacted with a fertile peridotite were proposed at the origin of melilitites. The experimental reconstruction of phase relationships on the liquidus of carbonated natural melilitites reveal that clinopyroxene and olivine or garnet are stable phases, suggesting that carbonated wehrlites are potential sources for the genesis of melilitites.

Here, we explore phase relationships on the high pressure melting of a model wehrlite, initially composed of a mechanical mixture of San Carlos olivine, diopside, aegirine, dolomite, rutile and kyanite. Starting materials were loaded in graphite capsules, inserted in sealed platinum capsules. Vitreous carbon spheres and synthetic diamond grains were adopted for liquid traps.

A first set of experiments performed at 3.2 GPa from 950 to 1450°C reveal that the solidus for the model wehrlite composition is located at temperatures in the order of 1050°C. In all experiments, an orthopyroxene-rich layer, with polygonal microstructure, forms at contact with aggregates resulting from quenched liquids, its thickness increasing with increasing temperature, i.e., increasing melt fraction. Estimates of liquid composition are melilititic at 1150-1200°C, with TiO_2 approx. 2.5 wt.% on a volatile free basis.

A second set of sandwich experiments is devoted to verifying the modification and equilibration of liquids produced by a natural aphyric melilitite from Alaotra district (central-northern Madagascar) interbedded with wehrlite.

Currently available experiments suggest that the melting reaction producing a melilitite liquid is dolomite + olivine + clinopyroxene + garnet = orthopyroxene + liquid. This is feasible only if the primary phase field of orthopyroxene on the liquidus surface extends on the Ca-rich portion of the volume forsterite-enstatite-nepheline-larnite in the presence of CO_2.

Compositional variability of the oceanic crust as a function of spreading rates: insights from the ultra-slow spreading Gakkel Ridge (Arctic Ocean)

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Keywords: mid ocean ridges, lower gabbroic crust, mineral chemistry.

Gakkel Ridge runs for ~1,800 km in the Artic Basin, and features a long spreading segment without transform faults, expanding nearly perpendicular to the North America-Eurasia opening. It is currently the slowest spreading ridge on Earth, its full spreading rate decreasing from 14.6 mm.yr-1 near the Lena Trough in the west to 6 mm.yr-1 towards the active rifting in the Laptev Sea in the east. The composition of Gakkel ridge lower gabbroic crust is undocumented to date. Bathymetric and gravity data display variation in crustal thickness, suggesting the occurrence of three distinct tectono-magmatic provinces along its length: i) the Western Volcanic Zone (WVZ), ii) the central Sparsely Magmatic Zone (SMZ), and iii) the Eastern Volcanic Zone (EVZ). Extensive sampling during the AMORE expedition in 2001 allowed for the recovery of gabbroic lower crustal rocks from all these provinces, therefore allowing for a detailed assessment of the composition of the lower gabbroic crust at the worldwide end-member of slow-spreading ridges. We here report the very first data of the petrography and mineral major and trace elements of the lower gabbroic lithotypes sampled during the HLY0102 and PS59 expeditions. The sampled gabbros show strong compositional variability, representing the whole crystallization sequence of oceanic melts, ranging from troctolites to oxide gabbros and felsic vein. Furthermore, gabbroic rocks from the central SMZ show widespread occurrence of Fe-Ti oxides and amphiboles even in the most primitive lithologies such as troctolites. Important textural differences characterise the lower gabbroic crust from the central SMZ and WVZ, where clinopyroxene presents habitus from vermicular to subequant and the olivine shows habitus from rounded anhedral to interstitial, respectively. On the other hand, the different gabbroic lithologies from the EVZ were mostly sampled as variably altered veins associated with basaltic intrusions and peridotites. As a whole, these lower gabbroic sections show a correlation between modal and chemical compositions, showing higher Mg-numbers in olivine and clinopyroxene and Anorthite contents in plagioclase in the most primitive lithotypes such as troctolites and troctolitic gabbro, and lower contents in the most evolved lithotypes such as gabbronorites and oxide gabbros, forming after progressive compositional evolution of the magmatic system. Low Anorthite contents are most likely correlated with minor extents of melting, suggesting that the lower oceanic crust of the Gakkel Ridge is compositionally distinct from that of the Mid-Atlantic Ridge. The systematic analysis of the compositions in major and trace elements of gabbroic lithologies from the Gakkel Ridge will allow us to broaden the compositional spectrum of oceanic ridges worldwide and provide better constraints between the composition of the oceanic crust and its spreading rate.

Quantitative analysis of sulfur volatile species generated from HP-HT experiments: a novel approach

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Keywords: sulfur, HP-HT experiments, subduction zones.

Subduction zones serve as crucial sites for chemical exchanges between the Earth's surface and its deeper reservoirs. Within these zones, slab dehydration facilitates elemental transfers from the subducting slab to the mantle wedge, initiating hydrous melting and melt production. The introduction of slab-derived oxidizing material is often proposed to account for the higher oxidation state observed in arc magmas compared to magmas formed in other geological settings, such as mid-ocean ridges. However, the specific agents responsible for oxidation and the mechanisms underlying chemical transfer remain enigmatic, necessitating further exploration.

Among the most controversial components, sulfur plays a pivotal role in regulating mantle redox conditions. Diverse perspectives on sulfur behavior within subduction zones primarily stem from petrological analyses of mantle xenoliths, HP sulfide-bearing rocks, and thermodynamic models (Schwarzenbach et al., 2018; Piccoli et al., 2019). However, the lack of experimental works significantly limit our understanding of sulfur release and speciation in slab-derived fluids.

To bridge this knowledge gap, we have developed a novel methodology enabling accurate and high-sensitivity determination of sulfur volatile species (H_2S and SO_2) in HP-HT dehydration experiments. A series of experiments was performed at conditions of geological interest (P = 3 GPa and T = 700°C , ~ to subarc regions) under controlled oxygen fugacity and using different runtimes, from six hours to up one week. The volatiles produced were analyzed using a capsule-piercing device connected to a quadrupole mass spectrometer (Tiraboschi et al., 2016), using gas mixtures of known composition as calibration standards.

Our study not only validates predicted thermodynamic models but demonstrates for the first time that chemical equilibrium between the sulfide and fluid phase is reached quite quickly, typically within hours. Remarkably, the sulfide phase remains relatively inert even under relatively oxidizing conditions.

We expect that this technique will offer valuable insights into sulfur behavior within subduction settings. By identifying the predominant sulfur species under fixed pressure, temperature, and redox conditions, we will be able to gather crucial constraints into the role of sulfur as effective oxidizing agent of the mantle wedge.

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Tiraboschi C. et al. (2016) - Quantitative analysis of COH fluids synthesized at HP–HT conditions: an optimized methodology to measure volatiles in experimental capsules. Geofluids, 16, 841-855, https://doi.org/10.1111/gfl.12191.

Sulfide mineralization in the Lower Crust of the Bay of Islands Ophiolite, Canada

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Keywords: sulfide mineralization, lower crust, Bay of Islands Ophiolite.

The Bay of Islands Ophiolite Complex (BOIC) in southwestern Newfoundland has significant exposures of mafic-ultramafic rocks, both crust and mantle. Parts of the lower crust in North Arm Massif (NAM) contains sulfide concentrations. The ultimate origin of the sulfur remains unclear due to the complex nature of the BOIC crust. In order to better understand how Sulfur was transported and concentrated in lower crustal sections of the NAM, we analyzed siderophile elements from whole rocks and minerals. At NAM, lower crustal peridotitic and pyroxenitic intrusions of boninitic affinity intrude and assimilate host gabbros derived from the overlying tholeiitic crust, many of which were previously affected by greenschist-grade hydrothermal metamorphism and deposition of subordinate pyrite. Field evidence and mineral chemistry show that the feldspathic facies associated with gabbro-peridotite contacts are hybrid rocks, containing gabbroic xenoliths and xenocrysts. Cm-scale sulfide lenses are locally present, and the reaction zones show a wide range of siderophile element abundances, ranging up to 58,000 ppm S and up to 538 ppb ΣPGE. Enrichment of PGEs in feldspar peridotite and pyroxenite indicates high siderophile element concentrations associated with sulfide mineralization in hybrid rocks. Petrological indicators, such as sulfide inclusions in chromite, pyroxene and olivine, and drop-like pyrrhotite-pentlandite-chalcopyrite blebs, indicate that sulfides behaved immiscibly and concentrated chalcophile elements by high-temperature magmatic processes. This is consistent with in-situ laser ablation analyses from individual sulfide phases, which shows a magmatic range, comparable to the mantle range (~ 2000-6000 ppm). However, boninitic melts are generally poor in sulfur, and do not show sulfide immiscibility until very late in their crystallization history. One way to add sulfur and trigger early immiscibility is by assimilation of previously altered, sulfur-enriched, gabbroic host rocks. This is supported by the wide chalcogenic element variations observed, with S/Se varying from ≤ 2000 ppm up to 23000 ppm, the highest ratios being found at contact zones between peridotite and gabbro. This suggests that the Sulfur was previously concentrated by hydrothermal circulation in the deep gabbroic crust, and that assimilation of these S-enriched hosts triggered sulfide saturation in the intrusive boninite.

From cold to hot mantle: exploring new concepts for migration of alkaline melts and perspective on critical minerals

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Keywords: volatile-rich alkaline melts, heterogeneous mantle, Hawaiian plume, critical minerals.

Alkaline melts and related volatile-rich melts are derived from a compositionally heterogeneous mantle. There is a long-standing debate not only about their composition, but also about migration of alkaline melts and their mantle temperature in different geological settings. Based on an integrated approach combining results from petrology, geophysics and modeling, we propose models to explain the origin of volatile-rich alkaline melts in the middle-Alpine-Himalayan orogenic belt and the Hawaiian plume, representing two contrasting cold and hot mantle temperatures, respectively. Our synthesis of recent seismic tomography images shows the presence of a large set of low-velocity, 100 km elliptical bodies called 'compaction pockets' in the middle Alpine-Himalayan orogenic belt (Soltanmohammadi et al., 2018). The compaction pocket model shows that the low velocities result from percolation and concentration of volatile-rich melts. The volatile-rich melts interact with a surrounding mantle that is 100°C cooler than the normal adiabatic mantle. It is argued that this leads to the precipitation of hydrated and carbonated mineral phases (at 8-6, 5 GPa and < 4 GPa, respectively). As the top of the compaction pocket successively crosses these critical depths, different types of alkaline melt extraction via dykes occur. In contrast, the hot mantle plume model is composed of four types of "filaments" as the main components (Soltanmohammadi et al., 2022). Our plume model shows that the filaments melt at depths ≥ 5 GPa. The mantle flow is split into two flow lines. Each line consists of different filaments. The dykes formed at the top of each type of cold and hot flow line carry different melt compositions, from tholeiitic picrite to kimberlite/carbonatite, respectively. The key is that alkaline melts are known as fertile melts that host critical minerals. Our primary synthesis shows that our models imply in world-class metallogeny domains hosting alkaline rocks. The fact offers new observation to track melt trajectories for a systematic investigation on critical minerals.

Soltanmohammadi A. et al. (2018) - Transport of volatile-rich melt from the mantle transition zone via compaction pockets: implications for mantle metasomatism and the origin of alkaline lavas in the Turkish-Iranian plateau. J. Petrol., 59, 2273-2310, https://doi.org/10.1093/petrology/egy097.

Soltanmohammadi A. et al. (2022) - Melt percolation, concentration and dyking in the Hawaiian mantle plume and overriding lithosphere: links to the evolution of lava composition along the volcanic chain. J. Petrol., 63, 1-24, https://doi.org/10.1093/petrology/egab101.

When modern petrology meets advanced microstructural analysis

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Keywords: migmatites, clogged melt channels, garnet coalescence.

Petrology and microstructural analysis are inextricably linked together. The recent paper of Festa et al. (2024) on garnet growth to large ellipsoidal crystals by coalescence within residual migmatitic metapelites is a proof for the successful interaction of modern petrological modelling and advanced microstructural analysis. The whole set of data (phase equilibrium thermodynamic modelling, EBSD analysis, EDS and BEX mapping, micro-Raman analysis) obtained by this combined approach fit together like a puzzle. It defines a model showing that melt extraction in a dynamic system stops when melt channels become clogged by coalescence of peritectic phases carried along in anatectic melt migrating towards pull-apart structures, where the melt with entrained garnet pooled as it was progressively squeezed out. The importance of deformation for melt extraction is known since the basic work of Brown et al. (1995). The amount of decompression associated with formation of extensional sites within rocks undergoing ductile deformation has been documented quantitatively by Spiess et al. (2012).

Coalescence of garnet aggregates to large single crystals is invariably related to deformational rotation and surface energy reduction of individual grains (Spiess et al., 2001). Whether coalescence finally results in large single crystals or not depends on several factors. Of prime importance is the presence of a grain boundary wetting fluid/melt. Static experiments conducted in a piston cylinder apparatus at 3 GPa confining pressure and 1100°C show that any attempt to epitaxially grow single garnet crystals in platinum capsule, using a fine pyrope powder surrounding a polished pyrope rod acting as seed, fails. The absence of a fluid-saturated system prevents surface energy from becoming a driving force strong enough to crystallographically isorient the garnet crystals growing around the seed.

In the migmatite studied by Festa et al. (2024) rotation of coalescing garnet grains is documented by EBSD mapping. EBSD mapping also shows that during coalescence quartz did not activate dislocations that accommodated geometric incompatibility as a consequence of garnet rotation. Instead, quartz became dissolved in contact along melt decorated grain boundaries. Internal deformation within quartz during coalescence is essentially limited by activation of dauphiné twinning. This contrasts with local activation of dislocations in garnet along presumed boundaries of coalesced garnet grains. Activation of dislocations within garnet most reasonably happened once melt channels were clogged, and a rheological change accompanied ongoing deformation within the residual migmatites.

Brown M. et al. (1995) - Melt segregation in migmatites. J. Geophys. Res., 100, https://doi.org/10.1029/95jb00517.

Festa V. et al. (2024) - Garnet coalescence clogs melt extraction channels in migmatite. Lithos, 472-473, https://doi.org/10.1016/j.lithos.2024.107581.

Spiess R. et al. (2001) - Development of garnet porphyroblasts by multiple nucleation, coalescence and boundary misorientation-driven rotations. J. Metamorph. Geol. 19, 269-290, https://doi.org/10.1046/j.0263-4929.2000.00311.x.

Spiess R. et al. (2012) - Depressurized Cavities within High-strain Shear Zones: their Role in the Segregation and Flow of SiO2-rich Melt in Feldspar-dominated Rocks. J. Petrol., 53, 1767-1776, https://doi:10.1093/petrology/egs032.

Potential mineral resources in historically dismissed volcanogenic massive sulfide (VMS) deposits of the Emilia Romagna region (Italy): petrological and geochemical study for Critical Raw Materials (CRMs) exploration and exploitation

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Keywords: critical raw materials, VMS deposits, Emilia Romagna ophiolites.

The last update on the Critical Raw Materials Act (2023) drawn up by the European Union identified 54 Critical Raw Materials (CRMs), i.e., minerals, elements, or materials that are fundamental to supply for technology and strategic for the green transition, but subjected to fickle supply, e.g., for the fragile geopolitical contest (Kiss et al., 2023). This led many European countries, including Italy, to focus on the metal recovery from dismissed mines, mine wastes, and landfills to accomplish the circular economy politics. Italy has more than 100 historically dismissed mining sites just in the North, and, among them, the ones in the Emilia Romagna region are now under investigation for the various volcanogenic massive sulfide (VMS) deposits (Zaccarini & Garuti, 2008). These are a type of metal sulfide ore deposits that occur as a result of underwater volcanic eruptions, associated with hydrothermal events in submarine environments, and are divided based on ore composition (Cu, Cu-Zn, Cu-Zn-Pb group) and environment formation (Cyprus, Kuroko, Besshi, as mentioned by Zaccarini & Garuti, 2008). In the Emilia Romagna region, these deposits occur as pods within small bodies of ophiolitic basalts cropping out as olistoliths in the Northern Apennine External Ligurian units and owe their origin to the metal-rich hydrothermal circulation which developed quartz-sulfide veins when mixed with seawater through a fissures network (Saccani, 2015; Kiss et al., 2023). These ophiolites represent Jurassic Alpine Tethys oceanic crust fragments obducted in the continental crust (Zaccarini & Garuti, 2008). The stratigraphy of the area is characterized by sequences of pillow lavas associated with serpentine and gabbro breccias, radiolarian cherts, limestones, and abundant serpentinized subcontinental mantle peridotites (Kiss et al., 2023). Basalts, then, show Ocean Continent Transition Zone (OCTZ) chemical features with transitional-MORB affinity and a garnet signature (Dyn/Yb0: 1.2-1.4, Saccani, 2015), in agreement with Cyprus-type VMS deposits (Zaccarini & Garuti, 2008). Major and trace elements bulk rock geochemical analyses were performed in a group of basalts of the Boccassuolo ophiolite and compared with the previous results (e.g., Barrie & Hannington, 1999; Zaccarini & Garuti, 2008; Kiss et al., 2023): the VMS deposits in the Emilia Romagna region belong to the Cu and Cu-Zn types (Cu up to 5818 ppm, 200 times Upper Continental Crust, UCC, composition; Zn up to 7941 ppm, 118*UCC), low to very low Pb contents (< 1 ppm, max. 0.42*UCC). These preliminary results provide the first relevant geochemical information to map trace metal enrichment distribution in the main rocks of the area. Radiogenic (Sr-Nd-Pb) and stable (S-C) isotopic analyses, as well as mineralogical and in-situ analyses, will provide additional information on the enrichment and distribution of VMS deposits in the Region.

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Kiss G.B. et al. (2023) - Tracing the Source of Hydrothermal Fluid in Ophiolite-Related Volcanogenic Massive Sulfide Deposits: A Case Study from the Italian Northern Apennines. Minerals, 13, 8.

Saccani E. (2015) - A new method of discriminating different types of post-Archean ophiolitic basalts and their tectonic significance using Th-Nb and Ce-Dy-Yb systematics. Geosci. Front., 6, 481-501, https://doi.org/10.1016/j.gsf.2014.03.006.

Zaccarini F. & Garuti G. (2008) - Mineralogy and chemical composition of VMS deposits. Mineral. Petrol., 94, 61-83, https://doi.org/10.1007/s00710-008-0010-9.

Exploring a garnet-bearing pegmatoid pyroxenite in the Ivrea Verbano Zone (northwestern Italy): petrography and phase equilibrium modelling

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Keywords: crust-mantle transition, ultramafic cumulates, thermodynamic modelling.

The Ivrea-Verbano Zone (IVZ, northwestern Italy) is recognised worldwide for exposing a complete section of a lower - and possibly its transition to the upper - continental crust. Along the Sesia river, the lower part of this section consists of a km-sized mantle peridotite body (i.e., Balmuccia peridotite) and a sequence of websterites, pegmatoid clinopyroxenites, cumulus peridotites and gabbros (Rivalenti et al., 1984). New detailed field mapping and petrography have revealed a previously unrecognised presence of garnet, together with spinel and plagioclase, within the pegmatoid pyroxenitic bodies. Here we present the first results and observations on this unusual garnet-bearing ultramafic lithology.

Petrography and scanning electron microscope analyses showed a main magmatic assemblage consisting of pegmatoid clinopyroxenes with variable occurrence of exsolution lamellae of orthopyroxene ± garnet ± spinel ± plagioclase. A secondary assemblage made of garnet, plagioclase, spinel, and ortho ± clinopyroxenes, occurs as veins and pockets within the main pegmatoid texture.

Pegmatoid clinopyroxenes are augites with 7.4 to 8.1 wt.% Al_2O_3 and 0.86 to 0.87 Mg#. Garnets in the exsolution lamellae contain 22.1 to 22.9 wt.% Al_2O_3 and 0.45 to 0.49 Mg#. In the secondary assemblages, garnets are geochemically similar to those in the exolution lamellae, orthopyroxenes contain 2.9 to 7.2 wt.% Al_2O_3 and Mg# from 0.76 to 0.80, while An content in plagioclase varies from 61 to 83.

The initial results suggest that the secondary assemblage might have formed from the percolation of melts within the pre-existing pegmatoid pyroxenite. The texture of the garnets in this secondary assemblage suggests a metamorphic origin and may be related to high bulk aluminium content or high equilibration pressure, or a combination of both. Further work is being devoted to the garnet-bearing exsolution lamellae in the pegmatoid clinopyroxenes, as these will potentially provide insights into the P-T path that the original assemblage has undergone. We are investigating these aspects through phase equilibrium calculations using a set of bulk compositions assumed to represent the original pegmatoid clinopyroxenite and the secondary assemblage. We use the thermocalc software (Powell & Holland, 1985) and an internally consistent thermodynamic model (Holland et al., 2018) to generate pseudosections for each calculated bulk composition. Altogether, the results are aimed to shed light on the petrological history of this pegmatoid clinopyroxenite and bring new insights into the geothermal evolution of IVZ.

Holland T.J.B. et al. (2018) - Melting of peridotites through to granites: a simple thermodynamic model in the system KNCFMASHTOCr. J. Petrol., 59, 881-900, https://doi.org/10.1093/petrology/egy048.

Powell R. & Holland T.J.B. (1985) - An internally consistent thermodynamic dataset with uncertainties and correlations: 1. Methods and a worked example. J. Metamorph. Geol., 3, 327-342, https://doi.org/10.1111/j.1525-1314.1985.tb00324.x.

Rivalenti G. et al. (1984) - The layered series of the Ivrea-Vervano igneous complex, Western Alps. Italy. Tscher. Miner. Petrogr., 33, 77-99, https://doi.org/10.1007/BF01083065.

Investigating isotopic signatures of CO_2 produced by coccolithophore algae in subduction zones: experimental insights and modeling approach

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Keywords: carbon stable isotopes, arc volcanism, high pressure.

This experimental study investigates the isotopic signature of CO_2 emissions from coccolithophore algae within subduction zones, elucidating the complex isotopic exchange mechanisms among CO_2, $CaCO_3$, and graphite. Coccolithophore algae, characterized by their calcium carbonate plates, serve as a dual source of organic and inorganic carbon, significantly impacting the isotopic composition of volcanic arc CO_2. The research aims to unravel the influence of subducted oceanic sediments on the isotopic signature of volcanic arcs.

High-pressure and temperature experiments were conducted (T = 700°C and P = 3 GPa), simulating conditions conducive to peak CO_2 production resulting from the oxidative dissolution of graphite in subduction zones. Cultivated coccolithophore algae were utilized as starting materials, supplemented with green algae or ooze sediment to modulate the graphite/$CaCO_3$ ratio across a spectrum of organic matter percentages.

Chemical and isotopic analyses, facilitated by a capsule-piercing device coupled with a quadropole mass spectrometer and other Isotope Ratio Mass Spectrometers (IRMS), quantified CO_2 in the experimental fluid phase and $\delta^{13}C$ values of CO_2, $CaCO_3$ and organic matter/graphite. Experimental findings were compared with the model proposed by Tumiati et al. (2022), correlating $\delta^{13}C$ CO_2 with experimentally determined CO_2/$CaCO_3$ ratios, while considering the isotopic signature of starting materials.

Results underscored the recrystallization of coccolithophore calcite into aragonite and the graphitization of organic matter. Isotopically, $\delta^{13}C$ values of CO_2 and $CaCO_3$ exhibited convergence with model predictions, particularly evident for experiments with low CO_2/$CaCO_3$ ratios. Conversely, experiments with high CO_2/$CaCO_3$ ratios demonstrated a notable divergence, likely due to kinetic issues when carbonate is present in minor or trace amounts.

Experimental observations highlighted the exclusive association of CO_2 isotopic signatures with the CO_2/$CaCO_3$ ratio under consistent pressure-temperature-oxygen fugacity conditions, aligning with previous research demonstrating similar dependencies in ^{13}C-doped systems. Graphite emerged as the primary source of aqueous CO_2 through oxidation, with isotopic exchange occurring solely between CO_2 and $CaCO_3$ during dissolution and reprecipitation processes. This sheds light on the isotopic dynamics of CO_2 emissions from coccolithophore algae within subduction zones, providing crucial insights into the isotopic evolution of volcanic arcs influenced by subducted oceanic sediments.

Tumiati S. et al. (2022) - Subducted organic matter buffered by marine carbonate rules the carbon isotopic signature of arc emissions. Nat. Commun., 13, 2909, https://doi.org/10.1038/s41467-022-30421-5.

It's getting hot, depleted, dense and dry: evolution of garnet-sillimanite restites from Catena Costiera (northern Calabria, Italy)

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Keywords: restites, extraction of melt entraining peritectic minerals, chemical potentials.

In granulite-facies terranes, rocks of the middle-lower crust undergo different degrees of partial melting, depending on their fusibility. It is well known that pelites, after greywackes, are the most prone lithologies to melt, producing anatectic magmas of granitic composition. These anatectic magmas are mainly produced by incongruent melting reactions that continuously take place and involve hydrous minerals, forming peritectic minerals and melt. At this point, there is a fork in the road: (i) melt production exceeds melt extraction rates or (ii) melt with entrained peritectic and residual minerals is extracted from the source, leaving behind a depleted, dense and dry residue. The Variscan garnet-sillimanite residue from Catena Costiera (northern Calabria), which is the subject of this contribution, is derived from migmatitic metapelites that followed the second route, experiencing high degrees of partial melting and melt extraction. Garnet in the residue exceeds 50 vol.%, the rest of the mineral assemblage consisting of sillimanite and ilmenite and very little quartz, with complex cordierite-spinel-corundum symplectites occurring between garnet and sillimanite. Inclusions of biotite, rutile, quartz and sillimanite are found in the garnet, indicating that the garnet-sillimanite residue resulted from biotite dehydration melting. K-feldspar was not found in the residual mineral assemblage and the reaction is thus unbalanced. We show, supported by phase equilibrium thermodynamic modelling, that melt entraining K-feldspar (and possibly some reactants) was extracted from the source during heating up to ~930°C at 0.90-1.05 GPa. The A/AFM ratio of the residue obtained from modelling extraction of melt entraining peritectic K-feldspar is indeed more adherent to that measured when compared to the A/AFM obtained by simply modelling melt extraction at the melt connectivity threshold. Finally, the dry residue underwent a progressive shrinkage of the equilibration volume and an increase in the μFeO, μMgO and μSiO_2 chemical potential gradients, leading to the formation of cordierite-spinel-corundum symplectites during cooling from peak temperature conditions at 0.5-0.6 GPa. Our results allow refinement of the commonly used method for modelling melt extraction in open systems and illustrate the microstructural evolution of the equilibration volume during cooling of residual rocks.

Neoproterozoic serpentinites from the Bou Azzer ophiolite (Central Anti-Atlas - Morocco): exploring the geodynamic changes and mantle processes beneath the boundaries of the West African Craton

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Keywords: partial melting, ultramafic massifs, Inguijem-Aït Ahmane.

The West African Craton (WAC) originated during the Archean period and underwent significant development around 2 billion years ago during the Paleoproterozoic Eburnean orogeny (Ennih & Liégeois, 2008). Following this, a relatively quiet period during the Mesoproterozoic era, approximately 1.7-1.0 billion years ago, marked the beginning of craton formation. In the early Neoproterozoic, the WAC experienced widespread extension, suggesting the potential fragmentation into separate continents, followed by convergence towards the end of the Neoproterozoic. Around 760 to 660 million years ago, the WAC was involved in the accretion of island arcs along its northern and eastern margins (e.g., the Moroccan Anti-Atlas) (Hefferan et al., 2014). Subsequently, during the primary Pan-African orogeny, the WAC encountered convergence along all its boundaries, leading to the subduction of Pan-African oceanic crust beneath various oceanic arcs. These collision events induced partial mobilization of other craton regions within the peri-Gondwanan terranes, resulting in the recycling of water and volatile-rich fluids. This process led to subsequent melting, metasomatism, and serpentinization of mantle peridotites (Wafik et al., 2015). Understanding the alterations in peridotites and their mineral compositions is crucial for interpreting the extent of melting and metasomatic influences within the mantle. Chromite minerals, commonly found in chromitites or serpentinites within ophiolites, are significant indicators of their origin. Being the first mineral to crystallize from ultramafic magma and highly sensitive to the primary magma's composition, chromite serves as a valuable petrogenetic marker (Kang et al., 2022). Moreover, residual Cr-spinel minerals are often used to estimate the melt rate in upper mantle peridotites due to their resistance to alteration compared to early-formed olivine and pyroxene. During partial melting, Cr-spinel minerals become depleted in Al and enriched in Cr. This geochemical tool is increasingly utilized to reconstruct the magmatic and geodynamic context of depleted ophiolites formed in supra-subduction zones (SSZ) as a result of partial melting processes and rock-fluid interactions.

In this contribution, we focus on the Inguijem-Aït Ahmane ultramafic complex situated in the central region of the Bou Azzer inlier (Moroccan Anti-Atlas). We aim to offer fresh insights derived from petrological, mineral chemistry, and geochemical analyses, aiming to characterize the processes of mantle melting and enrichment during the Neoproterozoic era. This is to gain a better understanding of the evolutionary dynamics of the Neoproterozoic mantle beneath the West African Craton (WAC) and to enhance the analysis of how this mantle reservoir influenced the Neoproterozoic geochemical cycle.

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Hefferan K. et al. (2014) - A reconsideration of Pan African orogenic cycle in the Anti-Atlas Mountains, Morocco. J. Afr. Earth Sci., 98, 34-46, https://doi.org/10.1016/j.jafrearsci.2014.03.007.

Kang J. et al. (2022) - Chromite geochemistry of the Jinchuan Ni-Cu sulBde-bearing ultramaBc intrusion (NW China) and its petrogenetic implications. Ore Geol. Rev., 141, 104644, https://doi.org/10.1016/j.oregeorev.2021.104644.

Wafik A. et al. (2015) - The Podiform Chromite and Platinum Group Elements in the Neoproterozoic Ophiolite Bou Azzer (Inlier Bou Azzer - El Graara, central Anti-Atlas). Eur. Sci. J., 11(36), 121-140.

The continental Moho from a geobarometric perspective

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Keywords: pressure, crust-mantle transition, peridotites.

Understanding the structure and composition of the Moho transition zone continues to be a long-standing goal in Earth science. Regarding anorogenic continental settings, there is no general consensus whether direct evidence of this transition can be obtained through surface sampling or drilling. A possible case could be the Ivrea-Verbano Zone (IVZ), Southern Alps, in which peridotitic bodies of mantle origin crop out in contact with lower crustal lithologies of Permian age. Another possible way to investigate the petrology of this transition is through the study of crustal and mantle xenoliths brought to the surface by alkaline magmas. Xenoliths are sporadic and cannot provide continuous sampling of the lithosphere. Yet, they can be used to get as much information as possible about the pathway(s) through which the magmas reached the surface, including the possible petrological and geophysical transitions of the lithosphere. In order to use xenoliths to constrain these transitions, we need good estimates of the depth of provenance, and therefore we need good geobarometers. This is easy to say, but difficult to put in practice. What is a good geobarometer for these settings? The uppermost mantle in continental settings is made up of spinel peridotites, and methods to retrieve accurate and precise pressure estimates are not available. Even when they might appear to be available (i.e., Ca-in-olivine barometry), they have strong temperature (T) dependence, and T cannot be determined with accuracy. An even more basic aspect is the need to determine when the accuracy becomes good enough to make the geobarometer useful to reconstruct the lithological structure of the lithosphere. This contribution will show some case studies with applications to xenolith suites, comparisons with the IVZ crustal section and the results of a new experimental and theoretical approach to quantify the limits of geobarometry for spinel peridotites.

S35.

New frontiers of Planetary Geology

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A second AlCu-bearing micrometeorite from Monte Gariglione (Italy): insights on the origin and growth conditions

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Keywords: micrometeorites, CuAl alloy, natural quasicrystals.

Recently, two remarkable extraterrestrial fragments, named FB-A1 and FB-A2 respectively, have been found at Monte Gariglione (Catanzaro, Italy). FB-A1 consists of a scoriaceous, elongated-, subspherical-shaped micrometeorite of about 400 μm in diameter, while FB-A2 is an irregular fragment of about the same size.

Preliminary non-destructive investigation, using micro-computed X-ray tomography and scanning electron microscopy, revealed that both particles exhibit extraterrestrial features, including forsteritic olivine crystals in a porous matrix of silicates, Fe-Ni metals, Fe-Ni sulfides, oxides and disseminated exotic CuAl alloys with variable stoichiometric ratios. This finding represents the third independent discovery of naturally occurring intermetallic Al-Cu alloys in meteorites, after the Russian Khatyrka meteorite (MacPherson et al., 2013) and the Sudan KT01 spherule (Suttle et al., 2019; Ma et al., 2023).

FB-A1 was yet deeply investigated by EPMA and EBSD and the analyses revealed that this micrometeorite contains naturally occurring quasicrystals. This is the second finding of quasicrystalline material, after Khatyrka meteorite, and the first case of quasicrystal with composition $Al_{52}Cu_{31}Fe_{10}Si_7$ (Agrosì et al., 2024).

The study of FB-A2 is currently in progress. Preliminary results reveal that the second fragment is quite different from FB-A1; actually, the irregular shape is associated to a different texture. The fragment can be described as composed of two main regions. The first consists of relict olivines, with forsteritic core and Fe-rich rim, orthopyroxenes (enstatite), clinopyroxenes with pigeonitic composition, oxides and sulfides disseminated in the silicate glass. Locally, intergrowths of partially melted olivines and pyroxenes are visible. The porosity is very low. The second region shows a high porosity and consists mainly of silicatic glass. In this region there is a big portion of Fe-poor AlCu-alloy. These alloys consist of worm-like intergrowths of nearly pure Al in khatyrkite ($CuAl_2$) and stolperite (CuAl). Sub-spherical Fe-Ni alloys of few micrometers in diameter are visible on the surface of the fragment at the contact between the CuAl alloy and the silicatic matrix. The presence of voids in the core suggests that these Fe-Ni bubbles represent the residual part of melting and degassing of precursor grains of sulfides.

Further studies of this fragment, and the comparison with data acquired on FB-A1, will be very helpful to shed light on the origin of these micrometeorites and to try to decipher the source of these materials and their growth conditions.

Agrosì G. et al. (2024) - A naturally occurring Al-Cu-Fe-Si quasicrystal in a micrometeorite from southern Italy. Commun. Earth Environ., 5, 67, https://doi.org/10.1038/s43247-024-01233-w.

Ma C. et al. (2023) - Al-Cu-Fe alloys in the solar system: Going inside a Khatyrka-like micrometeorite (KT01) from the Nubian Desert, Sudan. Meteorit. Planet. Sci., 58, 1642-1653, https://doi.org/10.1111/maps.14089.

MacPherson G.J. et al. (2013) - Khatyrka, a new CV 3 find from the Koryak Mountains, Eastern Russia. Meteoritics & Planetary Science, 48, 1499-514, https://doi.org/10.1111/maps.12170.

Suttle M.D. et al. (2019) - A unique CO-like micrometeorite hosting an exotic Al-Cu-Fe-bearing assemblage – close affinities with the Khatyrka meteorite. Scientific Reports, 9, 2426, https://doi.org/10.1038/s41598-019-48937-0.

Identification and characterization of Martian chips by non-destructive analyses

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Keywords: martian rock, X-ray micro-computed tomography, SEM-EDS analyses.

Returning sample missions have gained increasing attention in the last decades since the only way to know the planetary surface's composition and reconstruct the history of geological processes is to analyse samples using Earth-ground laboratory-based techniques.

In order to be ready to receive samples from returning missions (see https://science.nasa.gov/mission/osiris-rex/, https://science.nasa.gov/mission/mars-sample-return/, and https://global.jaxa.jp/projects/sas/hayabusa2/), the scientific community is working on protocols to carry out a comprehensive characterization, avoiding at first stages, methodologies that implies the sample modification and contamination.

With this aim, we are studying some unclassified chips of a supposed Martian rock sent to us in 2017 from Dr Abdeltif Mechaouguen, a Moroccan meteorite collector and dealer. To obtain the major amount of information on extraterrestrial materials following a non-destructive or minimally destructive protocol, we decided to use these chips as analogues of returned samples to test the methodology and the protocol to follow.

The samples (less than 0.5 cm in size and no fusion crust) characterized by a typical microstructure of basaltic shergottites with pyroxene laths in a transparent glassy-looking matrix are studied by X-ray micro-computed tomography (μ-CT) combined with chemo-mineralogical analyses by SEM-EDS. The results confirmed the typical internal microstructure of shergottite, which consists of intergrown laths of crystals with a high attenuation coefficient and grains characterized by a smaller absorption coefficient.

A preliminary non-destructive characterization of Tarda meteorite

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Keywords: Tarda, carbonacoues asteroids, returned samples.

The Tarda meteorite is a carbonaceous chondrite fallen in the locality of Tarda in Morocco on August 25th, 2020 (Chennaoui Aoudjehane, 2021). Since it was readily collected after the fall, it was exposed to desert weathering for very little time (few days) and therefore it should have preserved its original composition.

It consists of a bulk composition of clay minerals, plus chondrules, anhydrous silicates, Fe bearing sulphides, carbonates and amoeboid olivine aggregates. On the basis of the mineral chemistry, this meteorite shows a petrologic type 2 (Chennaoui Aoudjehane, 2021). Moreover, oxygen isotopic analyses plot this meteorite in two fields of carbonaceous chondrites corresponding to CI and CY. All these peculiarities are also typical of only one another meteorite similar in bulk mineralogy and oxygen isotopes, the Tagish Lake, also classified as a C2 ungrouped. Both meteorites could be from the parent body: the type D asteroid (Marrocchi et al., 2021; Hiroi et al., 2022). In the view of a comparison with the returned samples from another very similar carbonaceous asteroid, Bennu, thanks to the Osiris-REX NASA's mission, we are exploring the composition and structure of this kind very friable and light material using non-destructive techniques.

In this conference, we will show some preliminary results acquired combining multimethod non-destructive investigations of a crusted sample of Tarda. Chemical and mineralogical analyses by SEM-EDS, chemical mapping and SEM-BSE images were compared with 3D reconstruction by X-ray micro-computed tomography (μ-CT), a technique used to explore the whole sample without any manipulation.

The purpose of this investigation is the study of mineralogical composition with a particular attention to the rare phases, mineral distribution and association, texture and microstructures in order to provide further information on origin and evolution of this meteorite. The results obtained will be subjected to a comparison with same investigations carried out on Bennu fragment, to deeply investigate the similarity observed and to deduce further information about the parent body.

Chennaoui Aoudjehane H. (2021) - Tarda an unusual carbonaceous chondrite meteorite fall from Morocco. In: Jull A.J.T. (Ed), 84th Annual Meeting of the Meteoritical Society, Meteorit. Planet. Sci., 56, 6063, https://doi.org/10.1111/maps.13530.

Hiroi T. et al. (2022) - Tagish Lake is Still the Only Possible Meteorite Sample from D-Type Asteroids. 53rd LPSC, Abstract #1149.

Marrocchi Y. et al. (2021) - The Tarda Meteorite: A Window into the Formation of D-type Asteroids. ApJL, 913, L9, https://doi.org/10.3847/2041-8213/abfaa3.

FRESCO, a Python open source tool to democratize CRISM spectral data management, analysis, and mapping

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Keywords: Mars, CRISM, Python.

Remotely sensed hyperspectral data provide essential information on the composition of rocks on planetary surfaces. On Mars, these data types are provided by the CRISM instrument (Compact Reconnaissance Imaging Spectrometer for Mars) (Murchie et al., 2007), a hyperspectral camera that operated onboard the MRO (Mars Reconnaissance Orbiter) probe that collected more than 10 Tb of data. CRISM covers a spectral range going from 400 to 4000 nm, with a spectral resolution of 6.55 nm/channel and a spatial resolution of 18.4 m/px, from 300 km altitude. The most advanced CRISM data products are the MTRDRs (Map-Projected Target Reduced Data Records) (Seelos et al., 2016). These data are re-projected onto the Martian surface and are cleaned from the so-called ”bad bands”, noisy stripes. The two main CRISM MTRDR subproducts are the hyperspectral datacube and the spectral parameter datacube. The first contains the detected reflectance spectra, while the second is composed of 60 different spectral parameters, as defined in Viviano-Beck et al. (2014), usually to produce RGB maps emphasizing specific minerals within the scene. Usually, the creation of the RGB maps and the spectral analysis are conducted using the commercial software ENVI©, software not specifically meant for these dataset and which inherently implies some costs for the user. Here we present a free open-source tool completely written in Python called FRESCO (Flexible RGB Extraction and Spectra Comparison for Observations), which allows the use of CRISM MTRDR data. The software can create RGB maps and select Regions Of Interest (ROI) from which the user can extract and further analyze the spectral data available from the chosen CRISM scene. The possible types of analysis that FRESCO supports range from simple descriptive statistics (to obtain, for example, mean spectra of a ROI), and spectra-related pre-processing methods like continuum removal and/or smoothing, to analysis through more complex techniques, like machine learning for automatic detection of the absorption lines or ML-driven Multi Gaussian Models (MGM) for spectral unmixing. The machine learning models implemented are programmed as transparent as possible, to ensure that the performed analyses are as much reproducible and interpretable as possible (white-box). Moreover, with FRESCO it is possible to georeference the RGB maps, export them to ArcGIS©/QGIS software and to confront the processed and confront the processed spectra with either laboratory or other CRISM reference spectra. In support of the effectiveness of FRESCO, we also present a case study conducted on the CRISM target FRT00009B5A that covers the northern portion of Kai crater, located in Meridiani Planum. The choice of this particular case study is motivated by the morphological and compositional complexity shown by this specific target (Baschetti et al., 2023), demonstrating that FRESCO can be useful especially in complex scenarios that require a detailed analysis of the geological context, evolution, and processes.

Baschetti B. et al. (2023) - Interbedded clay and sulfate deposits in Meridiani Planum, Mars: a valuable insight on the planet’s ancient climate at the Noachian-Hesperian boundary. Biennial European Astrobiology Conference (BEACON).

Murchie S. et al. (2007) - Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on Mars Reconnaissance Orbiter (MRO). J. Geophys. Res.-Planet.,112, E05S03.

Seelos F.P. et al. (2016) - CRISM Hyperspectral Targeted Observation PDS Product Sets - TERs and MTRDRs. LPSC XXXXVII, Abstract 1783.

Viviano-Beck C.E. et al. (2014) - Revised CRISM spectral parameters and summary products based on the currently detected mineral diversity on Mars. J. Geophys. Res.-Planet., 119(6), 1403-1431.

Are there more out there? The possible prevalence of quasicrystals in the Universe

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Keywords: quasicrystals, meteorite, CuAl-alloys.

Until 2009, the only known quasicrystals - materials with a structure that is ordered but not periodic - were synthetic, having been formed exclusively in highly controlled laboratory experiments. Plausibly, the only quasicrystals in the Milky Way Galaxy or perhaps even in the Universe, are the ones manufactured by humans, or so it seemed. Then came the report that an icosahedral AlCuFe-quasicrystal had been discovered inside a small rock fragment from a remote stream in far eastern Russia. Later studies proved the rock to be extraterrestrial, a piece of a rare CV3 carbonaceous chondrite (known as Khatyrka). Few years later, a new quasicrystal was discovered in an Italian micrometeorite and few other occurrences of CuAl-alloys were described in other extraterrestrial bodies.

At present, only few examples of natural quasicrystals have been discovered. Does that mean that these exotic materials must be extremely rare in the Universe? During this talk, the author will accompany the audience on a cosmic-scale excursion going from presolar materials, through nuclear tests debris to recently formed fulgurites. Several reasons will be presented indicating that quasicrystals may prove to be among the most ubiquitous minerals found in the Universe.

Furthermore, based on the mineralogical and petrographic evidence as well as the triple oxygen isotope measurements on the silicates of all the CuAl-bearing objects, possible hypotheses about the provenance of these exotic alloys will be presented, including the fascinating scenario that they could come from another planetary system.

The author will also discuss how quasicrystals are an example of how sometimes being too uncritical of conventional wisdom may hinder research and progress in understanding the marvels of this world and beyond.

Geomicrobiology of the concretions of the Makgadikgadi pans (Botswana): an astrobiological perspective

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Keywords: Mars analogues, astrobiology, silica.

The Makgadikgadi Basin of central Botswana hosts one of the largest salt lakes (pans) system on Earth. These pans are characterized by strong evaporation rate, high salinity and pH and high UV radiation. For this reason, they are considered 'extreme environments' and analogues to playa environments on Mars. Playa environments on Mars, such as Meridiani Planum, present layered sedimentary deposits and hydrated minerals and opaline silica. These Martian deposits, for their direct link with liquid water, became targets for ongoing and future astrobiological missions.

Three types of concretions were identified in the Makgadikgadi pans: silica concretions, silcrete, with opal as primary cement; carbonate concretion, calcrete, with calcite as primary cement; gypcrete, with gypsum as cementing material. Here the focus is on the role of microbial organisms (e.g. extremophiles) in the precipitation of minerals within the silica concretions in the Makgadikgadi pans. The aim is to decipher microbe-mineral interactions and constraints the biomineralization processes in this extreme environment.

Most of the silcretes are quartzarenites and/or quarzitic breccias cemented by a complex paragenesis of quartz and calcite. Lithoclasts of flint, sand-sized quartz grains and ostracods are cemented by microcrystalline quartz (brown opal) and pore-filling spatic (coarse crystals) quartz cement. The fractures and larger pore space are filled by spherulitic chalcedony: fibrous microcrystalline quartz with botryoidal habit and characteristic wavy-extinction. The remaining pore space and the spherules are cemented by microcrystalline, isopachous carbonates(probably calcite) as a late product of pan diagenesis.

The silcretes are formed through direct precipitation of silica from groundwater within the pan system resulting in distinct silcrete morphologies e.g. nodules, massive, sub-outcrop, "scatter" or ellipsoidal. The complex paragenesis reflects fluctuation in the pH and water chemistry. It remains to be proven if the formation process was purely abiogenic or if there was also a biogenic component. In order to achieve this goal SEM analysis, looking for microbial fossils, and Raman spectroscopy, for identification of organic matter and biomarkers, will integrate the petrographic analysis of the Makgadikgadi silcretes.

This work, although at its preliminary stage, is bound to teach us how microbial communities of extremophiles interact with diagenetic products and what is the astrobiological potential of the Makgadikgadi silcretes.

Landslides on solid bodies in the Solar System

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Keywords: landslides, Solar System, extraterrestrial bodies.

Landslides affect almost all solid bodies in the Solar System, including planets, moons, asteroids and comets (Brunetti & Peruccacci, 2023). The rocky and icy surfaces of Solar System bodies are modified by a variety of processes, including tectonics, volcanism, impact craters, weathering and erosion, which overlap and interact to predispose slopes to landslides or to trigger landslides.

As on Earth, landslides observed in the Solar System are classified according to the mechanism of mass displacement and the material involved. This can be rock or soil (or both) mixed with water or ice. The types of movement are falling, toppling, sliding, spreading or flowing, and possible combination of these. Variability in landslide characteristics is reflected in their magnitudes (e.g., area, volume, fall height, length) that may vary by orders of magnitude. The effects of specific body properties such as surface gravity, atmospheric pressure (if present) or the presence of water (in different physical states) on the initiation and propagation of landslides can be deduced by comparing the observed mass movements of different bodies. This can be very important for manned and unmanned missions involving landings.

This contribution provides a brief overview of landslides observed in the extraterrestrial environment. The landslides are grouped by solid body type, including terrestrial planets, planetary moons, dwarf planets, asteroids and comets. For example, for the terrestrial planets, an inventory of large rockfalls in impact craters has been made on the Moon using high-resolution images from the Lunar Reconnaissance Orbiter (LRO) (Brunetti et al., 2015). On Mars, the giant landslides of the Valles Marineris (VM) canyon system have been mapped and classified using data from the Mars Reconnaissance Orbiter (MRO). Mass movements have been collected in a comprehensive geomorphological inventory (Brunetti et al., 2014). A global inventory of the planet's landslides was produced a few years later (Crosta et al., 2018). On the airless surface of Mercury, large rock slides in impact craters have been identified and mapped using images from the MESSENGER spacecraft (Brunetti et al., 2015).

This overview shows that landslides occur throughout the Solar System. They are evidence of the continuous dynamic evolution of the surface of solid bodies. Landslides are also one of the most interesting geological features because they expose fresh material, making it possible to study the subsurface composition of extraterrestrial bodies.

Brunetti M.T. & Peruccacci S. (2023) - Landslides in the Solar System. In: P. Read et al. (Eds), The Oxford Research Encyclopedia of Planetary Science, Oxford University Press, article #254, https://doi.org/10.1093/acrefore/9780190647926.013.254.

Brunetti M.T. et al. (2014) - Analysis of a new geomorphological inventory of landslides in Valles Marineris, Mars. Earth Planet. Sci. Lett, 405, 156-168, https://doi.org/10.1016/j.epsl.2014.08.025.

Brunetti M.T. et al. (2015) - Large rock slides in impact craters on the Moon and Mercury. Icarus, 260, 289-300, https://doi.org/10.1016/j.icarus.2015.07.014.

Crosta G.B. et al. (2018) - Introducing a new inventory of large Martian landslides. Earth Space Sci., 5, 89-119, https://doi.org/10.1002/2017EA000324.

Comparative studies on Martian landslides found in Craters of Noachian highlands: new perspectives for mass wasting phenomena

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Keywords: Mars, landslides, impact craters.

Noachian highland terrains on Mars preserve a large record of unnamed impact craters, representing the perfect study area to perform a new quantitative analysis on Martian landslides occurred within impact basins. The steepness of crater walls and the multiple weakness planes and fractures developed on the surroundings of the crater rim after a meteoritic impact could be the starting points for the generation of mass wasting phenomena (Crosta et al., 2018; Guimpier et al., 2021). The characterization and correlation of different landslides within impact craters located at different latitudes can help understanding the Martian climate and the underground conditions at the time of their formation (Guimpier et al., 2021). A comparative study between the nature of landslides found in impact craters has not been performed yet. Only a small percentage of the total amount of Martian landslides have been studied in detail (Valles Marineris, Tharsis region) (Roback & Ehlmann, 2020; Guimpier et al., 2021), thus it can be interesting to expand the knowledge about this topic through the analysis of landslides with size comparable with terrestrial analogs, to unveil new hints for constraining trigger mechanisms (still debated in many case studies).

A good satellite data coverage is mandatory to perform the research, and heavily influenced the selection of the targets. The workflow to perform the research can be divided into three main phases: i) the reconstruction of the geological frameworks in which landslides occurred (CTX, THEMIS, CRISM dataset), ii) formulation of reasonable hypotheses regarding their formation mechanism based on detailed quantitative analyses (HiRISE dataset), 3D models based on CTX-derived DEMs and comparisons with data on the literature, and iii) trace correlations between the selected landslides in terms of planetary evolution.

All the information collected during the research, including the total number and classification of proposed crater candidates and landslides, are summarize in a general catalog.

The expected results will give new perspectives and quantitative data to investigate the causes triggering Martian landslides in well-defined, specific environments (impact craters in Noachian highlands). This aspect could also support the study of terrestrial landslides through remote sensing techniques (Sosio et al., 2013). Moreover, the occurrence of a landslide, considered one of the active geological processes on the surface of Mars, can show geomorphological features potentially interesting even from the astrobiological point of view.

Crosta G.B. et al. (2018) - Introducing a new inventory of large Martian landslides. Earth Space Sci., 5, 89-119, https://doi.org/10.1002/2017EA000324.

Guimpier A. et al. (2021) - Dynamics of recent landslides (< 20 My) on Mars: Insights from high-resolution topography on Earth and Mars and numerical modelling. Planet. Space Sci., 206, 105303, https://doi.org/10.1016/j.pss.2021.105303.

Roback K.P. & Ehlmann B.L. (2020) - Controls on the Global Distribution of Martian Landsliding. ESS Open Archive, https://doi.org/10.1002/essoar.10504190.1.

Sosio R. et al. (2013) - Runout Prediction of Rock Avalanches in Volcanic and Glacial Terrains. In: Margottini C., Canuti P., Sassa K. (Eds), Landslide Science and Practice, Vol. 3, Springer, https://doi.org/10.1007/978-3-642-31310-3_38.

Mineralogical analysis and preliminary physical property results on Didymos/Dimorphos meteorite analogues

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Keywords: ordinary chondrites, porosity, asteroid analogues.

Meteorites, together with return mission samples, represent unique tools to investigate Solar System bodies. Unfortunately, planetary surface sampling is rarely possible and the attribution of a meteorite to a planetary body is tentatively done using reflectance spectroscopy techniques. Double asteroid 65803 Didymos/Dimorphos, supposed to be formed by stony material chemically affine to L/LL ordinary chondrites, was the object of the DART (Double Asteroid Redirection Test) mission (Michel et al., 2018), and it is planned to be visited by the next HERA mission, to investigate the subsurface and interior properties of impact site outcome materials exposed by the kinetic DART impactor. To support the HERA mission scientific activity, we have investigated 9 ordinary chondrites, i.e., Aba Panu (L3), Bruderheim (L6), Gueltat Zemmour (L4), Kheneg Ljouad (LL5/6), Loro (L6), Ouadangou (L6), Vinales (L6), Aldsworth (LL5) and Rio Negro (L4), which VNIR (visible and near-infrared) spectroscopic characteristics make them the best asteroid surface analogues. Usual petrographic and mineralogical characterization using SEM-EDS and EMPA allowed us to determine the exact modal mineralogy and mineral phase compositions necessary for a correct VIS-NIR-MidIR reflectance spectroscopy interpretation of the analysed materials. Alongside petro-mineralogical analyses, we obtained physical properties like bulk density and porosity. Using a structured light 3D scanner, we have calculated volume samples and mean bulk densities, resulting in the 3.21-3.33 gr/cm^3 range, in agreement with the literature data (Wilkinson et al., 2003). Only Gueltat Zemmour showed a lower density of 3.01 gr/cm^3, inferred by the high porosity found through SEM-EDS modal maps. The use of an X-ray microtomographer (µCT) allowed us to better constrain its high porosity value (15.8 vol%), while the remaining sample showed much lower porosity (less than 2-3 vol%). Forthcoming analyses will expand our samples dataset, and we will also perform nano-indentation tests using the AFM (Atomic Force Microscopy) technique, with the possibility to investigate in situ physical properties like Young's modulus, hardness and rigidity at the level of a single mineral grain, as already done for some grains sampled from the surface of the asteroid 25143 Itokawa (Tanbakouei et al., 2019). In addition to Young's modulus, hardness, and rigidity, it will also be possible to evaluate the cohesion forces, which, together with porosity, are the most important properties for modeling the mechanical/dynamic behavior of the regolith on the Dimorphos surface in microgravity (Stickle et al., 2023).

Michel P. et al. (2018) - European component of the AIDA mission to a binary asteroid: Characterization and interpretation of the impact of the DART mission. Adv. Space Res., 62, 2261-2272, https://doi.org/10.1016/j.asr.2017.12.020.

Stickle A.M. et al. (2023) - Impact Simulations Provide Important Constraints On Dimorphos's Material Properties And Estimates Of Crater Size From The Dart Impact. Asteroids, Comets, Meteors Conference, abstract #2541.

Tanbakouei S. et al. (2019) - Mechanical properties of particles from the surface of asteroid 25143 Itokawa. Astron. Astrophys., 629, A119, https://doi.org/10.1051/0004-6361/201935380.

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Interplanetary river classification: a geomorphological approach utilizing subjective and objective analysis through advanced statistical methods

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Keywords: drainage networks, AI, statistics.

This work introduces an innovative approach to river hydrographic basins classification within the River Zoo Survey project. Main goal of this project is to perform a statistical evaluation of the classification of terrestrial and extraterrestrial drainage networks by human experts to be subsequently used as base of knowledge to train supervised AI methods.

The idea is to analyze the degree of reliability of class assignment to drainage samples, driven domain expert decisions, based on visual inspection of images and the identification of the right pattern type. Through the analysis of Earth, Mars and Titan's rivers, experts were asked to classify rivers into one of ten distinct patterns, further categorized into two macro-classes: dendritic and non-dendritic.

The purpose of this study is to establish an objective classification system for rivers, improving the understanding of terrestrial and extra-terrestrial rivers drainage networks. Through the use of statistical techniques, the study explores methods to reduce noise in human based classification, thus providing a robust classification system for the automatic processing of river data with a detail much better (10 classes) than the current two class classification systems (dendritic and non-dendritic).

This work focuses on the methodology and objectives of the research, highlighting its interdisciplinary nature and potential contributions to a better comprehension of river morphologies across different planetary bodies.

Three-dimensional probabilistic slope stability analysis in lunar South Pole region

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Keywords: lunar south pole region, landslide, slope stability, 3D numerical modeling.

Landslides stand out as significant geomorphic events driving morphological changes across mountainous and hilly landscapes. These impactful phenomena, often occurring on steep slopes, have received extensive study on Earth, both in terrestrial and submarine environments. Similarly, various gravitational events have been observed on celestial bodies such as the Moon. This work aims to enhance our understanding of landslide on lunar surface, focusing on the lunar south pole region (LSPR) that has garnered increasing attention due to its geological features, including permanently shadowed regions (PSRs) and volatile deposits such as water ice. The study of slope stability in the LSPR is useful for the success of forthcoming space exploration missions such as NASA's Artemis planning to land the first woman and man near the Moon's south pole in 2024. In view of this and with the aim of contributing to ensure the safety of personnel and equipment, this study proposes a probabilistic three-dimensional slope stability analysis of LSPR using the RocscienceTM Slide3 software. Morphological data as 3D mesh, crucial for understanding the intricate lunar topography, was extrapolated using lunar orbiter laser altimeter (LOLA) digital elevation model (DEM), providing a detailed representation of LSPR surface. Geomechanical characteristics of lunar regolith, like unit weight, cohesion, and friction angle, was statistical analysed to determine their distribution and uncertainty. The statistical analysis was conducted by collecting data from various researches containing data from past different lunar missions (Huang et al., 2024). Differently from a deterministic analysis, where the above parameters are typically kept fixed and a single factor of safety (FoS) is provided, a probabilistic analysis was carried out yielding multiple FoS. This approach offered a more comprehensive view of lunar slope stability. In order to consider both, static and dynamic conditions, a contribution of seismic event produced by lobate thrust fault scarps movement, as proposed by Mishra & Kumar (2022) and Watters et al. (2024) was implemented. Specifically focusing on the LSPR, the analysis allowed to identify critical areas susceptible of potential instability phenomena and engineering-geological parameters which mostly influence the slope stability. Results from this research may be used for the formulation of strategic risk mitigation measures and meticulous planning of future lunar missions. This study effectively demonstrated the efficacy of employing three-dimensional numerical modelling techniques in addressing the unique geotechnical challenges inherent to the lunar environment. Furthermore, it underlined the critical importance of adopting a probabilistic approach to ensure safety and successful execution of future space exploration endeavours.

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Mishra A. & Kumar S.P. (2022) - Spatial and temporal distribution of lobate scarps in the lunar south polar region: Evidence for latitudinal variation of scarp geometry, kinematics and formation ages, neo-tectonic activity and sources of potential seismic risks at the Artemis candidate landing regions. Geophys. Res. Lett., 49, e2022GL098505, https://doi.org/10.1029/2022GL098505.

Watters T.R. et al. (2024) - Tectonics and Seismicity of the Lunar South Polar Region. Planet. Sci. J., 5, 22, https://doi.org/10.3847/PSJ/ad1332.

Reflectance spectra of mascagnite and salammoniac minerals with varying viewing geometry

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Keywords: reflectance, ammonium-bearing minerals, icy bodies.

Ammonium-bearing minerals have been observed on icy planetary bodies such as Comet 67/CG and Ceres (e.g. De Sanctis, 2016; Poch et al., 2020). The presence of NH^{4+}-minerals could be associated with upwelling of ice from possible subsurface oceans (e.g. Cruikshank, 2019). Given the presence of surface roughness, topography and variations in morphology, the surface reflectance spectra of all Solar System bodies are affected by observation geometries. In this work we analyse the effects of viewing geometry variations on the near-infrared reflectance spectra of mascagnite-$(NH_4)_2SO_4$ and salammoniac-NH_4Cl powder samples (Fastelli et al., 2023). These two samples could represent some of the most promising candidates as ammonium-bearing minerals on icy bodies. Bi-directional reflectance spectra are collected in the 1-4.2 µm range considering a set of 3 incidence (*i*) angles ($i = 0°$; 30°; 60°) and 9 emergence (*e*) angles between -70° and 70° at room temperature. The reflectance spectra analysed in this study were collected using the custom-made bidirectional reflectance spectro-goniometers SHINE (SpectropHotometer with variable INcidence and Emergence) at the Cold Surface Spectroscopy facility (CSS) of the IPAG laboratory (https://cold-spectro.sshade.eu) in the frame of the Trans-National Access program, project number 20-EPN2-081, of Europlanet 2024. The NH^{4+} absorption bands located at ~ 1.09, 1.32, 1.62, 2.04, 2.2 and 3.05 µm are experimentally investigated. Changing observation geometry, the absorption bands parameters (area, depth and FWHM), reflectance values and spectral slope show important variations in the bidirectional reflectance spectra. Bands' area and depth parameters show the highest variability for $i \geq 30°$ and *e* greater than ±40°. The area and depth parameters of these bands show a dual behaviour: (1) the weak to medium absorption bands below 2 µm have their area and depth that decrease as the phase angle increases, (2) however, the stronger absorption bands above 2 µm have their areas and depth that increase only at phase angles above 90°, but also at low phase angles for high incidences, $i \geq 30°$. We observe an important dependence of band depth and area on the incidence angle, up to 60°, compared to moderate variation with emergence angles. Furthermore, the ~3 µm absorption band becomes less saturated at ± 70° emergence angles. A general trend of spectral bluing with change in observation geometry is observed. The dataset reported here represents a contribution in the framework of present and future space missions focused on understanding the nature and quantification of NH^{4+}-bearing minerals on icy bodies. The NH^{4+}-minerals identification has a strong impact on understanding their thermal evolution and the construction of geophysical internal models providing information on ocean/brine compositions, possible explanations of geological phenomena, like cryovolcanism, and implications for biological activity.

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De Sanctis M.C. et al. (2016) - Bright carbonate deposits as evidence of aqueous alteration on (1) Ceres. Nature, 536, 54-57, https://doi.org/10.1038/nature18290.

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Poch O. et al. (2020) - Ammonium salts are a reservoir of nitrogen on a cometary nucleus and possibly on some asteroids. Science, 367, eaaw7462, https://science.org/doi/10.1126/science.aaw7462.

Highly reduced meteorites: a comparison with Mercury's surface through minero-petrological and spectroscopic investigation

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Keywords: aubrites, enstatite achondrites, Mercury's surface.

Compositional and spectroscopic data acquired by the NASA's MESSENGER (Mercury Surface, Space Environment, Geochemistry and Ranging) mission led to the hypothesis that planet Mercury formed from highly reduced materials, such as the asteroidal parent bodies of enstatite chondrite meteorites. The mineralogy of the planet surface is thought to be dominated by FeO-poor pyroxene and olivine, Na-rich plagioclase and Mg-Ca-Fe sulphides assemblage (Nittler & Weider, 2019). These characteristics suggest that the best analogues of the planet surface currently at our disposal are represented by highly reduced meteorites, in particular aubrites (Burbine et al., 2002) and enstatite chondrite impact melts (Udry et al., 2019).

We are conducting a minero-petrological and spectroscopic investigation on ten highly reduced meteorites: Rantila, Tiglit, NWA 14185, Peña Blanca Spring and Norton County (aubrites), Itqiy (EH7-an), Zakłodzie (enstatite achondrite ungrouped), NWA 13266 (enstatite achondrite), NWA 13210 (EL-melt rock) and NWA 4945 (EL6). The texture and modal mineralogy of every sample were investigated through SEM-BSE and SEM-EDS mapping and the mineral chemistry of the detected phases was obtained with EPMA analysis.

The samples, belonging to different meteorites groups originated by various processes, show some differences in their texture and modal mineralogy, while their mineral chemistry is quite similar. The main mineralogical phase (60-90%) in every sample is nearly FeO-free enstatite ($En_{96.9-99.8}Wo_{0.2-1.7}Fs_{0.0-0.6}$). Nearly FeO-free forsterite ($Fo_{99.6-99.9}$) and diopside ($En_{53.7-61.3}Wo_{38.7-46.0}Fs_{0.0-0.3}$) are present only in the five aubrite samples (up to 17% and 13%, respectively). Plagioclase covers a wide compositional range ($Ab_{60.3-97.2}Or_{0.2-13.8}An_{0.1-40.4}$) and is a minor constituent in the aubrites (max 5%) while it is more abundant in the other samples (up to 14%). Sulphides and metals are much more abundant in enstatite achondrites and melts (up to 19%) than in aubrites (max 2%). Metals are mostly represented by kamacite with variable Si content (max 0.4% in aubrites and up to 3% in enstatite achondrites and melts). The detected sulphides are: troilite, daubréelite/zolenskyite, alabandite, niningerite, keilite, oldhamite, heideite. Glass with albitic composition is found in some of the samples.

Reflectance spectra in the VNIR range show features typical of highly reduced materials (Burbine et al., 2002) with very weak absorption bands in spectra related to silicates and sharper absorption related to sulphides. The correlation between mineralogical data and VNIR reflectance spectra enable to have a complete suite of information about highly reduced materials that could be useful for future comparison with Mercury's surface data expected to arrive from SIMBIO-SYS/VIHI spectrometer onboard ESA's BepiColombo mission (Cremonese et al., 2020).

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Cremonese G. et al. (2020) - SIMBIO-SYS: Scientific Cameras and Spectrometer for the BepiColombo Mission. Space Sci. Rev., 216, 75, https://doi.org/10.1007/s11214-020-00704-8.

Nittler L.R. & Weider S.Z. (2019) - The Surface Composition of Mercury. Elements, 15, 33-38, https://doi.org/10.2138/gselements.15.1.33.

Udry A. et al. (2019) - Reclassification of four aubrites as enstatite chondrite impact melts: Potential geochemical analogs for Mercury. Meteorit. Planet. Sci., 54, 785-810. https://doi.org/10.1111/maps.13252.

Supporting the characterization of Atira surfaces with synthetic photometry of meteorites

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Keywords: asteroids, meteorites, NEOs.

The taxonomic classification of asteroids is important to gain insights on their composition and texture of their surfaces for those asteroids never explored by space missions. Nevertheless, a large number of interesting Near-Earth Objects (NEOs), such as Atiras, Earth co-orbitals and Earth Trojans, have orbital dynamics that limit their observability by ground-based telescopes only during challenging twilight conditions. These objects hold clues to the dynamical history of the inner solar system, as well as the physical evolution of asteroids in extreme environments.

For this reason, since 2021, a project is under way collecting data by using the Large Binocular Camera (LBC) at Large Binocular Telescope (LBT) in evening and morning astronomical twilight time to discover and physically characterize NEOs in the low solar elongation region using multiband photometry in g, r, i and z Sloan band (Giunta et al., 2021). The resulting data of these measurements will be used to allow the taxonomic classification of these objects, following the methodology described in DeMeo & Carry (2013) according to which strict boundaries in the overall spectral gri slope and depth of the one-micron band (i-z) are used to classify the targets into ten broad classes.

With the aim to address the problem of the gap in the mapping of Atira classification to meteorite groups, and trying to identify a possible parent body for those meteorites for which is still not clear the planetary bodies they may come, we are testing the approach that get “synthetic” Sloan values from reflectance spectra of meteorites and terrestrial analogues of planetary surfaces.

DeMeo F.E. & Carry B. (2013) - The taxonomic distribution of asteroids from multi-filter all-sky photometric surveys. Icarus, 226, 723-741, https://doi.org/10.1016/j.icarus.2013.06.027.

Giunta A. et al. (2021) - A twilight sky survey with LBT: catching near-Sun objects. LBT Prop. N. IT-2021B-044.

Structural analysis of wrinkle ridges in the region between Aristarchus plateau and Marius Hills in Oceanus Procellarum (Moon)

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Keywords: planetary geology, Moon, structural geology.

Tectonics on the Moon is expressed by two types of contractional landforms: the lobate scarps, which are surface-breaking thrust faults characterized by a global distribution and the wrinkle ridges, thrust propagating folds, both present in the lunar maria (Hauber et al., 2018).

The wrinkle ridges can follow: (i) a concentric distribution pattern related to the presence of thick sequences of mare basalts, which induced subsidence and flexure of the elastic lithosphere (Freed et al., 2001) or (ii) a non-concentric preferred orientation, the origin of which is still a matter of debate within the scientific community.

Not only the origin, but other aspects are investigated in this work such as: (i) the complex stress field behind their formation which is presumably a result of a combination of different factors (secular heating, cooling and orbital despinning); (ii) how the deformation of wrinkle ridges in a certain lunar basin is related to the volcanic and thermal evolution of the basin; (iii) the décollement depths of such structures which is in turn related to (iv) the mechanical layering of the crust.

Oceanus Procellarum is the largest mare basin on the Moon and it is located on the western lunar nearside. The study area of this work is located within this basin, between two big shield volcanoes: the Marius Hills complex and the Aristarchus plateau.

The best products to identify thrust faults and wrinkle ridges are Digital Elevation Models (DEM). We used the "High-resolution Lunar Topography (SLDEM2015)", with a vertical accuracy between 3 and 4 meters, and the SLN Terrain Camera DTM Map V2.0 (TCDTMM), with a vertical accuracy of 5 meters. In addition, we used KAGUYA (SELENE) TC Derived Data, SLN Terrain Camera Ortho Map Seamless V2.0 (TCORTS).

To perform this study, we used the following software: QGIS Desktop 3.28.1, Minitab, Microsoft Excel, and MATLAB. QGIS was used to map the wrinkle ridges within the study area and to calculate the maximum displacement (Dmax). For better constraining the dip of the thrusts, we followed the method developed by Galluzzi et al. (2015). This method uses displaced crater to calculate the fault geometries and kinematics. It is based on the assumption of a perfect- circular shape and constant rim elevation of the initial crater. Accordingly, from the present-day topography the displacement and fault dip can be derived. Subsequently we estimated the shortening and through a MATLAB code even the décollement depth of each mapped fault (Karagoz et al., 2022).

The results on the décollement depths and the Dmax/L values (maximum displacement-length) are in agreement with previous local scale studies, but here are expanded at the basin scale proving multiple weak layers within the basin.

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Galluzzi V. et al. (2015) - Faulted craters as indicators for thrust motions on Mercury. Geol. Soc. London, Spec. Pub., 401, 313-325, https://doi.org/10.1144/SP401.17.

Hauber E. et al. (2018) - Endogenic Processes. In: Rossi A.P. & Van Gasselt S. (Eds), Planetary Geology, Springer, 147-183, https://doi.org/10.1007/978-3-319-65179-8_8.

Karagoz O. et al. (2022) - Circum-Tharsis wrinkle ridges at Lunae Planum: Morphometry, formation, and crustal implications. Icarus, 374, 114808.

Lanzarote as suitable Mars analogue to test if recent Mars deposits could be dataed using luminescence

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Keywords: late Quaternary, alluvial fan, dunes.

Luminescence dating could be a reliable method to date the recent climate and sedimentological changes active, and that have been active, in the recent past on Mars. Luminescence dating uses the properties of quartz and k-feldspar to absorb and entrap radiation when buried from the sun light. The presence of k-feldspar minerals, derived from basalt alteration, has been documented on Mars, rising luminescence as potential suitable dating methodology. Moreover, the recent improving technology has been capable to realize a portable instrument to date with luminescence in the field. This could be eventually installed on a rover and remotely driven from Earth. To test this potentiality it is necessary to select a Martian analogue where validate luminescence dating protocols applicable to date the Martian recent sediments.

Lanzarote (Canary Island) has been chosen as the best Martian analogue where to perform the test. The geological features and climatic conditions are very similar to those occurring on Mars: basaltic surface, low quartz and k-feldspar concentrations, dry weather, and very low vegetation.

Aim of the work has been to reconstruct the late Pleistocene geological and evolution of the El Jable Basin pointing out which have been the different depositional changes through time. The basin is the remnant of a Miocene caldera which flanks are made of basalts. On these colluvial deposits, similar to the gravity driven present at the rim and floor of a Martian impact craters, are forming. Moreover, the ephemeral streams associated with the basin border form a suite of colluvial gravity driven fans eventually evolving in alluvial fans alternating with aeolian deposits. Dunes become the dominant sedimentary feature in the more distal part of the basin. This dune system can easily be correlated to those forming inside some Martian craters where the colluvial deposits lose their character.

Selected luminescence protocol has been the pIRIR200 applied to fine-grained polymineral k-feldspar. Derived ages span form 132±12.3 to 13.3±2.6; that is, from the late Marine Isotope Stage (MIS) 6 to the late MIS 2.

From a sedimentary perspective, this study successfully reconstructed the evolution of the El Jable basin. This reconstruction enabled the correlation of deposits with different climatic periods, distinguishing between dry and humid conditions. During dry conditions, dunes dominated the deposition, whereas during wet alluvial fan systems developed. However, it does not seem that deposition followed a simple trend wet-and dry, but that minor climatic oscillation influenced and occasionally changed the normal deposition in the basin.

The ability to discern climatic oscillations recorded in terrestrial analogue provides a framework for interpreting past Martian climates and deciphering the planet recent geological evolution. By focusing on active deposits such as dunes or gravity driven, we can overcome the limitations posed by the age of ancient Martian alluvial-fluvial deposits and expand our understanding of the planet dynamic surface processes.

Geochemical characteristics of a newly discovered Vigarano chondrite fragment (CV3) - Study of redox conditions with unconventional Mössbauer spectroscopy

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Keywords: Vigarano meteorite, carbonaceous chondrite, Mössbauer spectroscopy.

The Vigarano meteorite fell in 1910 in the province of Ferrara, Italy, and, after the impact, was divided into two blocks, "Cariani" and "Morandi", respectively, named after the owners of the farms where they were recovered (Trevisani, 2011 and reference therein). A new series of debris was found in a storehouse near the impact site at the beginning of the XXI century and was classified as part of the Cariani stone (Trevisani, 2011). This meteorite has been widely studied and represents the reference type of the reduced CV3 carbonaceous chondrite group (McSween, 1977). Notwithstanding it is worth noticing that the main contribution to the nature and origin of this meteorite is from fragments of the Morandi block, while knowledge on the other block is scarce.

This work aimed to characterize one of these newly discovered fragments to confirm its belonging to the Vigarano meteorite, with both bulk (XRF, and ICP-MS), in-situ (EMPA) major and trace element contents, and C-S elemental and isotopic (EA-IRMS) analyses. EMPA and petrographic thin section analyses did not identify phyllosilicates and carbonates, which were determined in the literature dealing with the Morandi block (McSween, 1977). Therefore, additional Mössbauer spectroscopy analyses were conducted to investigate iron speciation and possibly to determine the formation system's redox conditions and volatile elements circulation in the planetary body. Both XRF and ICP-MS analyses showed a composition in agreement with the literature data (McSween, 1977; Dauphas & Pourmand, 2015), confirming at first, that the recovered unnamed meteorite fragments belonged to the Vigarano meteorite, even though the fragment had no CAIs evidence, and, for major elements, a higher Mg/Si (1.43 versus 0.94) and Fe/Si (1.59 versus 1.46) and lower Ca/Al rate (0.71 versus 1.09). Slightly differences between the two blocks were also observed for trace element contents: the newly found fragment had a lower Eu (0.09 versus 0.11 ppm), Gd (0.29 versus 0.40 ppm), Dy (0.40 versus 0.53 ppm), Er (0.25 versus 0.30 ppm), Lu (0.04 versus 0.05 ppm) contents than what found in the well-studied Morandi block (Dauphas & Pourmand, 2015).

Due to a lack of carbonates and less sulfides presence, carbon and sulfur elemental contents (0.92±0.05, 1.38±0.05 wt.%) and isotopic ratios (δ^{13}CPDB: -17.8 PDB, δ^{34}SCDT: +0.3 CDT) were lower compared with literature CV3 values (e.g., McSween, 1977).

The iron speciation determined with Mössbauer analyses led to an Iron Oxidation Index (IOI), whose results increase with increasing oxidized iron to the total iron content, with a value of 2.13, consistent with the 2.12 shown in the classification of reduced CV3 group (Garenne et al., 2019). The sample contained 17% Fe^{3+}, attributable to incipient thermal metamorphism that tends to form magnetite and oxidize Fe in silicates and matrices. The fragment is more oxidized when comparing the IOI with the literature value (Garenne et al., 2019).

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Reflectance spectra of synthetic Nakhlitic rocks as lab-made analogues for Martian terrains: influence of mineralogy, glass content and acquisition geometry

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Keywords: analogs, laboratory, spectroscopy.

Silicates dominate volcanic terrains across the Solar System's terrestrial planets. Earth's volcanic landscapes consist of lava flows and pyroclasts with a predominantly glassy texture. Understanding how the glass/crystal ratio influences the spectral response of volcanic rocks is crucial for planetary interpreting remote sensing data from Mars and other rocky bodies. In the Petro Vulcanology Research Group (PVRG) labs, mafic volcanic materials were synthesized to mimic the composition of Nakhlite meteorites. A homogeneous silicate glass (Nglass) was created and then used to produce three samples by melting at 1500°C and gradually cooling to subliquidus temperatures of ~1200°C (N12), ~1100°C (N11), and ~1000°C (N10). Analysis revealed varying degrees of crystallinity, with N11 and N10 exhibiting similar mineralogical compositions, while N12 showed intermediate crystal content. X-ray powder diffraction (XRPD) coupled with Rietveld method for quantitative phase analysis, X-ray fluorescence (XRF) and scanning electron microscope (SEM) analyses were performed to assess type, degree of crystallinity and glass content. Reflectance spectra were collected at room temperature in the 1-4.2 μm range considering a set of 3 incidence (i = 0°; 30°; 60°) and emergence angles between -70° and 70° using the custom-made bidirectional reflectance spectro-goniometers SHINE (SpectropHotometer with variable INcidence and Emergence) at the Cold Surface Spectroscopy (CSS) facility laboratory at the Institut de Planétologie et d'Astrophysique (IPAG) (project number 21-EPN-FT1-025 Europlanet 2024). The spectral features of the single mineral phases are barely distinguishable for N10 and N11, due to the presence of magnetite that probably flattened the spectra, whereas the spectral signature of Fe in augite is distinguishable for N12 located at ~0.9 and ~1.15 μm. Spectral shifts from positive slopes for glasses to flat-negative slopes for crystalline materials were observed in the Visible and Near-Infrared range as crystallinity increased. Changing observation geometry, reflectance values and spectral slope show important variations while the bands position remains unchanged. We observe important dependence of band and slope in correspondence of low phase (< 30°) angle and high phase angle (> 100°). Principal component analysis (PCA) identified four distinct clusters corresponding to the four samples, particularly for glass-bearing materials. These findings offer additional insights into the spectral characteristics of synthesized rock samples, particularly those containing glass materials. Such information is valuable for accurately modelling the spectral signatures observed from rocky bodies within the Solar system.

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Geological map, depositional processes, environments, and evolution of the Eberswalde delta (Mars)

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Keywords: geological map, depositional environments, Mars.

Geological mapping of planetary surfaces has some intrinsic peculiarities when compared to Earth. Among the many (and body-specific) issues, the main ones are that the scales are instrument-dependent, and the remote sensing approach can be rarely tied with groundtruth. Still, while lithology has limited or no constraints, often landforms are preserved in the deep geological time, thus marking a considerable (and somewhat also philosophically significant) difference with Earth.

In this framework, the sedimentary deposits of Mars are particularly tricky because landforms are the result of a succession of depositional and erosional events which complicates a straightforward geomorphological interpretation. In order to address these issues, classical geological maps and associated stratigraphic reconstruction can be associated with a 3D geological model in order to strengthen and constrain the genetic interpretation of the landforms.

The Eberswalde contributing basin - delta - basin system (delta centered 23.8°S/-33.3°W) represents an ideal geological setting to test this approach and evaluate the good practices that might become the basis to standardize the detailed (i.e., CTX to HiRISE scale) geological and geomorphological mapping of Martian sedimentary deposits. This area is characterized in fact by pristine morphologies, exposed stratigraphy, data quantity, and quality, including compositional and topographic ones (e.g., Malin & Edgett, 2003; Pondrelli et al., 2008; Mangold et al., 2012; Hughes et al., 2023).

The contributing basin consists of about 6890 km^2, the delta of about 130 km^2, and the basin of roughly 950 km^2. Sedimentary deposits related to the fluvio-lacustrine phase consist of light-toned layered deposits (LTDs) placed unconformably on top of a Noachian substratum and disconformably covered by recent cover units. Within the delta LTDs occur in correspondence with a distinctive morphological assemblage, including delta plain, delta front, and prodelta morphofacies, found in different deltaic lobes. Depositional elements can be distinguished to further detail depositional processes. These deltaic lobes correspond to different water levels within the basin, suggesting an external control (possibly climatic) on sedimentary deposition, although intrinsic controls (e.g., erosion of the contributing basin/crater rim) are also present.

We attempted a source to sink-to-sink and time-related reconstruction by unraveling the depositional architecture of the depositional system.

Hughes C.M. et al. (2023) - Sources of Clay-Rich Sediment in Eberswalde Crater, Mars With Implications for Biopreservation Potential. J. Geophys. Res., 128, e2022JE007545, https://doi.org/10.1029/2022je007545.

Malin M.C. & Edgett K.S. (2003) - Evidence for Persistent Flow and Aqueous Sedimentation on Early Mars. Science, 302, 1931-1934, https://doi.org/10.1126/science.1090544.

Mangold N. et al. (2012) - The origin and timing of fluvial activity at Eberswalde crater, Mars. Icarus, 220, 530-551, https://doi.org/10.1016/j.icarus.2012.05.026.

Pondrelli M. et al. (2008) - Evolution and depositional environments of the Eberswalde fan delta, Mars. Icarus, 197, 429-451, https://doi.org/10.1016/j.icarus.2008.05.018.

EUROPLANET GMAP: the geology and planetary mapping winter school

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Keywords: planetary, school, GMAP.

The increase of complexity and number of planetary exploration missions, make geological maps a fundamental resource both concerning safety, planning of surface operations, scientific objective's location and prioritization, in situ resource identification and planetary protection. Any future planetary exploration framework which does not envisage production and use of geological maps is prone to failure. These require a careful planning that come in large part from geologic maps including hazard analysis. Currently, only the United State Geological Survey the only institute able to produce such maps on a regular basis while Europe have fostered the production of planetary maps firstly with the European PLANMAP project and then with the GMAP action within the EUROPLANET infrastructure. Both these activities are led by the Department of Geoscience of the University of Padua around which different institutions are gathered to form a European network of planetary mapping experts. A pivotal aim of the network is to prepare the next generation of planetary scientists to face the challenges of future planetary missions. As the missions increase in number and complexity, also the technical and scientific skills in geological mapping are evolving at a fast pace, so that the teaching strategy need to be continuously renewed and re-focused. The 4th Geology and Planetary Mapping Winter School 2024 took place from 22nd to 26th of January 2024 with more than 600 subscribers spanned all over the world in 75 countries in all time zones, continuing to the most recent outcomes and techniques on the production of planetary geological mapping, fostering a large international network and community of mappers with in mind the newly announced missions to Venus and the recently launched Missions to the Jupiter Icy satellites. The previous editions - held in February 2023, February 2021 and 2022 - share similar outstanding numbers (over 200 hundred participants in the first edition and over 300 in the second and 400 in the third with a similar number of instructors). The objectives of the 2024 were partly common to the previous ones, adding each time a relevant sub topic (i.e. from the first edition 3D geologic mapping, landing sites selection). The main topics covered are listed here:

- processing techniques for planetary data handling and basemaps creation;
- production geological maps of selected areas embedding traditional geological mapping with crater chronology;
- spectral and compositional data handling;
- insights on SAR data for Venus volcano-tectonic mapping;
- Vesta;
- Ganymede structural mapping;
- Irregular small bodies mapping (67P comet).

Due to the high number of online participants spread over diverse time zones, like in previous editions, we have provided live lectures, hands-on and seminars in a format that can be also followed asynchronously with the possibility to download lesson materials from Zenodo or alike, as well as, datasets for exercises and recorded lessons over a 5 days winter school duration. Al the 4 Winter School editions are still available in asynchronous format for long-term exploitation through the website planetarymapping.eu.

Mankind cannot stay in the cradle forever. The Space It Up project

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Keywords: PE15, Space It Up, planetary sciences.

This presentation serves as an introduction to the Space It Up project, with a specific focus on the geo-mineralogical activities that will be at the heart of our research.

Space It Up – The Italian Partnership for Space Science and Engineering was conceived within the Extended Partnership 15 (PE15) and subsequently developed as an autonomous project financed by the Italian Space Agency (ASI) and the Ministry of the University and Research (MUR) for 80 million euros.

The project will last 36 months and involves 33 partners (13 universities, 10 research centers, and 10 enterprises) representing the best available science in Italy regarding space exploration and research. Space It Up will hire hundreds of Ph.D. students and researchers to work on nine Spokes and some 45 work packages. Spokes 1 to 4 focus on models and technologies for Space science and engineering, including satellite systems, system engineering and digital twins, and remote imaging and non-imaging sensing. Spokes 5 to 7 focus on Earth observation, whereas Spokes 8 and 9 on extraterrestrial observation.

The main Space It Up goals are (i) extending the fundamental knowledge on exploration and exploitation of space, (ii) fostering sustainable technologies to preserve the Earth and space for future generations, and (iii) ensuring long-term human permanence in extraterrestrial environments. On this latter point, the contribution of geosciences will be of fundamental importance in advancing the body of knowledge regarding extraterrestrial exploration, resource exploitation, mining, in situ manufacturing, and circular solutions for life adaptation to the space environment.

Spoke 8 and Spoke 9 deal with the following activities requiring geo-mineralogical knowledge and expertise: experimental research for advanced space exploration; identification and characterization of potential extraterrestrial habitats; laboratory and in situ analyses of planetary resources; resource mapping.

In particular, geological, mineralogical, petrologic, geochemical and geotechnical studies will be performed on lunar, martian, and asteroidal meteorites to increase the knowledge of these bodies and to evaluate their potential as in-situ resource (ISRU) valuable for human settlements. Methods and instrumentations for surface and subsurface exploration will be also developed for exploitation and mining the volatiles. Moreover, terrestrial analogs will be investigated to test mission methodologies, protocols, and technologies/instrumentations useful to train astronauts and scientists. Finally,mineralogical, compositional and lithological mapping from global to local scales will be obtained by using available datasets and developing new portable instruments for in situ investigations.

In conclusion, the Space It Up project aims to develop innovative ideas and solutions that will strengthen Italy's role as a leading country in space science and exploration. The synergies between universities, research institutions, industries, and small and medium enterprises will be strategic for the scientific, economic, and cultural systems, thus promoting the establishment of a comprehensive Italian space ecosystem. In this framework, geosciences will have a key role in achieving these ambitious goals and creating new professional opportunities within and outside academia.

"Chirfa" meteorite: the largest specimen from Mars

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Keywords: Mars, meteorite, petrography.

The Martian meteorites (MMs) are peculiar igneous rocks distinguished from other achondrite meteorites based on their different petrography, mineralogy, mineral-chemistry, major and trace elements, and isotopic compositions. To date, MMs are classified into three main groups: Shergottites (basalts), Nakhlites (clinopyroxenites), and Chassignite (dunite). In addition, two unique types of meteorites have been found: ALH84001 (orthopyroxenite) and NWA 7034 (and the related pairs) regolith breccias. The basaltic shergottites, the most abundant MMs (about 90% of the total MMs), can be further subdivided into the following subgroups: basaltic (45%), olivine-phyric (30%), poikilitic (18%), gabbroic (5.5%), augite-rich (0.9%) and pigeonite-rich NWA 10414 (0.5%). In this work, we present the preliminary petrographic results of a new MM found on 18th November 2023 in the Sahara desert near Chirfa, Niger (coordinate: 21°05'12.72"N, 11°26'07.76"E). It represents the largest individual Martian sample hitherto described in the Meteorite Bulletin database - total weight of ~ 24.6 kg. A centimeter-size fragment has been embedded and polished for petrographic investigations. Backscattered images were acquired by scanning electron microscopy (SEM) at the Centro di Servizi di Microscopia Elettronica e Microanalisi (MEMA) of the Università degli Studi di Firenze, Italy. Quantitative analyses were obtained by electron microprobe (EMPA-WDS) at the same center. Backscattered images show a coarse-grained texture, with crystals ranging from tens to hundreds of microns, dominated by pyroxene, olivine, and plagioclase (possibly maskelinite). Large elongated prismatic pyroxene (up to 2.1 mm) and olivine (up to 2.5 mm) crystals may also occur. Oxides, phosphates, and sulfides are present as accessory phases. Pyroxenes are subhedral to euhedral with total abundance of about 66 total vol%. They also occurring with a lath-like and, generally, show low-Ca cores (average $En_{68}Fs_2Wo_5$) surrounded by more Ca-rich rims (average $En_{49}Fe_{38}Wo_{13}$), although complex zoning patterns are commonly observed However, a poikilitic texture containing olivine chadacrysts (~100 μm) enclosed by pyroxene oikocrysts (mm-size) is also present. Olivine grains are both subhedral and euhedral and generally show normal zoning from the Fo_{65} core to the Fo_{34} rim (about 16 total vol%). The Fe/Mn ratio ranges from 50.4 to 55.5 and from 27.8 to 36.3 for olivine and pyroxene grains, respectively. Maskelinite mainly occurs in both lath-like and interstitial textures (about 15 total vol%). The size ranges from ~100 μm up to 1mm, and the average composition is about $An_{50}Ab_{48}Or_2$. Tiny veins (~50 μm in thickness) mainly composed of granular calcite are present. Olivine gabbroic shergottite, proposed as a link between gabbroic and poikilitic shergottites (Benaroya et al., 2022), are coarse-grained igneous rocks predominantly composed of pyroxene, olivine and maskelinite. Likewise, the poikilitic shergottites contain poikilitic olivine set in a groundmass of smaller olivine, pyroxene, and maskelinite. The coarse grained and poikilitic texture, and the abundance of maskelinite (>10 vol%) found in the "Chirfa" meteorite, suggest more affinities to olivine gabbroic shergottite rather than poikilitic, or other shergottite subtypes. In conclusion, we propose that "Chirfa" meteorite, the largest martian specimen, is an olivine gabbroic shergottite. We believe this meteorite worthy, and further investigations such as petrographic, petrologic, and geochemical analyses will be carried out. The "Chirfa" meteorite could indeed improve our understanding of the Martian geological processes.

Benaroya S. et al. (2022) - Olivine-Gabbroic Shergottite Northwest Africa (NWA) 13227: A Link Between Gabbroic and Poikilitic Shergottites? 53rd LPSC, 2678, 1175.

Experimental alteration of volcanic bedrock: a terrestrial analogue for Mars

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Keywords: Mars, clay minerals, basaltic rock.

The study of the alteration of mineral assemblages, produced under a different range of conditions (i.e., pH, temperature, and time), can provide information on the reconstruction of the environmental conditions that occurred or may still occur on Mars. Specifically, Clay minerals have been detected on Mars to outcrop mainly as alteration of ancient bedrock, and secondarily, as deposition from aqueous environments or interlayered with evaporitic deposits on Mars. The main goal of this work is to better understand and constrain the conditions required for the formation of clay minerals as alteration of volcanic bedrocks on Mars, using laboratory experiments carried out on terrestrial analogues. We reproduced experimentally at lab scale the alteration of a fresh alkaline basaltic rock collected at Etna Mount. We selected Etna Mount as a Martian analogue for the following reasons: (i) the basalts are compositionally similar to those identified in differerent areas of the Martian; (ii) the volcanic morphologies such as basaltic channels, caves and lava tubes are widely exposed on the Etna active volcano and are very similar to those observed on Mars. Previous works considered only volcanic glass or single mineral, but this may not reflect the full environmental conditions. The novelty of this work is to experimentally simulate the alteration considering a powdered bulk composition of the fresh holocrystalline Etnean alkali-basalt as starting material and without acidic sulphates solution as catalyst. In particular, we simply mixing the basaltic fresh bulk powder with an acidic aqueous solution of HCl at pH 5.0 and 3.5, after exposure at low to moderate temperature, between 80°C and 250°C and investigate the alteration patina on single parent crystal for each stage. We observed that under acidic aqueous solution (pH ~ 3.5-5.0) and moderate temperature (~ 150-175°C), produced the formation of coatings with "honeycomb" morphology typical of smectite (as Fe-Mg saponite) on the surface of clinopyroxene and plagioclase crystals, just in a few days. The cations mobilization from the crystal to the patina indicates the development of coatings faster and more efficient on clinopyroxene than plagioclase where the formation of analcime (zeolite) occurs. Furthermore, temperature above 175°C seems to favor the formation of oxides rather than clays, regardless the pH. The results of our work suggest that on Mars, environmental conditions to produce clays can be reached in, a limited range of T and pH with acidic fluids (probably deriving from the volcanic activity in a warm and humid climate or by oxidation of the groundwater on the surface), and the alteration of the basaltic bedrock can occur at shallow depth if a source of heat (volcanic or impact) is close enough to reach the optimum temperature range. Finally, this work demonstrates that the basaltic rocks of Etna can be considered as a good Martian analogue to model the alteration processes.

Application of CHyM hydrological model on Mars surface: clues of drainage patterns on Jezero crater

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Keywords: Mars, hydrology, drainage.

In our Solar System, the diversity in surface topographic features is observed. On Earth, plate tectonics has extensively shaped its topography; instead, on other less tectonically active rocky bodies, as Mars, as well as, on the ice bodies, the history of the observed surface topography are different and, in some cases, unknown.

Inside inner Solar System, fluid runoff has shaped the surfaces of Earth and Mars in the form of liquid water. On Mars, large-scale topography was established more than 3.5 billion years ago (Ga) in the wake of the formation of Borealis Basin and the growth of the Tharsis volcanic rise. Most fluvial activity likely occurred early in the planet's history (Black et al., 2017 and references therein). Some clues of past drainage patterns could be "seen" on Mars surface; however, some of them could be masked from impacts occurred.

Surface liquid water may also imply that environmental conditions appropriate to sustain prebiotic chemistry were present on Mars. In this context, Jezero crater (coordinates 18.38° N - 77.58° E) is the chosen (among other candidates) target for the programme Mars Sample Return (Grant et al., 2018; NASA Science Mars 2020 mission, https://mars.nasa.gov/mars2020/mission/science/landing-site/) which will allow the scientific community to receive (in 2033) and study the martian samples, possibly having biosignatures.

In this work, the Cetemps Hydrological Model (CHyM), already tested in different domains of the Earth surface (Coppola et al., 2006), is used to characterize a possible drainage pattern on Mars. Analysis derived by using CHyM model have been carried out in several areas of Mars (Jezero, Eridania, Ismenius), and preliminary results show that it may plausible to speculate that some areas on Mars have been covered by water body similar to the lakes on Earth. Moreover, the boundaries between the drained and not-drained areas seem to be characterized by a high slope.

Black B. et al. (2017) - Global drainage patterns and the origins of topographic relief on Earth, Mars, and Titan. Science, 356, 727-731, https://doi.org/10.1126/science.aag0171.

Coppola E. et al. (2006) - Cellular automata algorithms for drainage network extraction and rainfall data assimilation. Hydrolog. Sci. J., 52, 579-592, https://doi.org/10.1623/hysj.52.3.579.

Grant J.A. et al. (2018) - The science process for selecting the landing site for the 2020 Mars rover. Planet. Space Sci., 164, 106-126, https://doi.org/10.1016/j.pss.2018.07.001.

S36.

Challenges in the characterization of active faults: the contribution from seismology, geodesy, and structural analysis

CONVENERS & CHAIRPERSONS

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Structural setting and tectonic evolution of the Central Matese Fault System, Southern Apennines: preliminary observations

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Keywords: Central Matese Fault System, faulted Pleistocene breccia, left-lateral shear zone.

The central part of the Matese Massif is crossed by a major fault system, the Central Matese Fault System (CMFS), which is associated to several intramontane basins developed through to the interaction of karst and tectonics processes. To date, the tectonic evolution of the CMFS is poorly constrained due to a lack of detailed structural and chronological data. Nevertheless, the fault system is often considered active (e.g. Valente et al., 2019) and included in the ITHACA database of capable faults (ITHACA Working Group, 2019).

A geological-structural field survey was conducted in order to constrain the geometry of the fault system and to map the associated Quaternary deposits. Additionally, a morphological analysis was performed using the 1-m resolution LIDAR DTM provided by the Ministero dell'Ambiente of Italy and the 5-m resolution Carte Tecniche Regionali provided by Regione Campania.

The survey revealed that the main basin-bounding faults have dominant ~ E-W and ~ NW-SE strikes and a dip ranging from ~ 60° to vertical. In few cases, kinematic indicators were collected on the fault planes to carry out a strain inversion. We mapped stratiform breccia deposits covering the Mesozoic carbonate bedrock, consisting of carbonate clasts sourced from the bedrock, embedded in a clayey reddish matrix and frequently exhibiting channel-like features. Noteworthy, the attitude and geometric pattern of the breccias are not consistent with the current mountain slope. Based on facies and mineral analysis, these breccia deposits can be referred to the "Brecce Mortadella", a well-known continental deposit that outcrop in several mountain localities of Central and locally Southern Italy and is thought to have a Lower Pleistocene age (D'Agostino et al.,1997).

Locally, NW-SE striking high-angle faults with a marked reverse component thrust the Mesozoic carbonates above the breccias, often tilting them up to 55° and creating fault damage zones with thickness of several meters in the carbonate bedrock. Moreover, the CMFS includes E-W striking normal faults, such as the Letino, the Gallo Matese and the Cusano Mutri faults, show few hundred meters of geological throw between the Mesozoic carbonate in the footwall and the Upper Miocene siliciclastic flysch in the hanging-wall.

The high-angle reverse faults can be interpreted as formed within restraining bends of the CMFS, which is thus interpreted as a major NW-SE striking shear zone with a dominant left-lateral displacement. Similarly, the E-W striking normal faults could have formed within releasing bends of the shear zone. Although no evidence of a recent extensional displacement on the NW-SE main faults was found, further investigations will explore whether these faults are active in the current tectonic setting of the region, which is dominated by NE-SW extension.

D'Agostino N. et al. (1997) - Le Brecce Mortadella dell'Appennino Centrale: primi risultati di stratigrafia magnetica. Il Quaternario, 10(2), 385-388.

ITHACA Working Group (2019) - ITHACA (ITaly HAzard from CApable faulting), A database of active capable faults of the Italian territory. Version December 2019. ISPRA Geological Survey of Italy. Web Portal http://sgi2.isprambiente.it/ithacaweb/Mappatura.aspx.

Valente, E. et al. (2019) - Constraining mountain front tectonic activity in extensional setting from geomorphology and Quaternary stratigraphy: A case study from the Matese ridge, southern Apennines. Quaternary Science Reviews 219, 47-67.

Addressing fault structural complexity and geometric interference in seismic hazard assessment for railways design

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Keywords: active and capable faults, seismic hazard, railways.

Active and Capable Faults (ACFs) represent a threat to crucial infrastructures, as they may generate substantial permanent deformation of the topographic surface. This geohazard is more relevant for railway lines that, unlike punctual infrastructures such as dams or nuclear installations, span hundreds of kilometers and potentially cross complex structural features belonging to distinct tectonic contexts. In this regard, the Italian territory shows several interference situations because of the intricate tangle of railway lines and ACFs.

ACFs are generally described by fault attributes, namely its geometry, kinematics, and temporal constraints on its activity. Unfortunately, the structural complexity commonly associated with internal architecture of fault zones does not readily translate to uniform hazard values, as it can lead to significant variability in fault parameters both along and across the fault. This could be related to the growth mechanisms of such tectonic structures and to the modes of deformation localization and partitioning, potentially resulting in the development of a specific fault aspect rather than others.

We propose a new structural geology-based methodological approach to assess seismic hazard related to ACFs specifically for railway planning purposes, identifying four key geometric interference cases between faults and railway line: fault-crossing, fault-parallel, near-fault tip, and transfer zone-crossing railways. For each case, we determined: a) the key fault parameters to be estimated, and b) the most suitable investigations to obtain deterministic structural input data respecting the main fault element to be detected with higher priority specifically for planning purposes. Also, the incidence angle is an essential factor to consider as the impacted zone tends to grow if the railways cross the ACF with lower angles. Hence, we suggest that the potential impact of seismic fault-related effects can be distinguished based on the way ACFs geometrically interact and physically interfere with the railway infrastructure.

Our proposed workflow and the results thereof provide novel insights into the full parametrization of a fault zone to be used to support probabilistic fault displacement hazard analysis scenarios and finally lead to the development of mitigation strategies to minimize infrastructure vulnerability.

First comparison of instrumental European Ground Motion Service by Copernicus Data with short and long-term geological vertical movements for the Italian Coasts

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Keywords: InSAR data, coastal tectonics, vertical deformation.

A deep comprehension of ground motion is essential for assessing seismic and volcanic hazards, geological interpretations, and geotechnical applications. This study addresses the imperative of conducting a thorough first comparison between vertical ground motion (InSAR) data from the European Ground Motion Service (EGMS) released by Copernicus (https://egms.land.copernicus.eu/) and geological vertical movements along the Italian coasts across various time scales, including the MIS 5e (Late Pleistocene), the Holocene, and the very short term (2015-2022) data. Anchored to the European Terrestrial Reference Frame 2014 (ETRF2014), EGMS level 3 data, covering both horizontal and vertical ground deformation (Costantini et al., 2021, 2022), facilitates a precise geodetic comparison. With a focus on discerning areas affected by tectonic, volcanism, and sediment compaction crucial for geological risk assessment, our research evaluates the reliability of EGMS data. This review study provides valuable insights for seismic hazard assessments, environmental applications, and an enhanced understanding of geological processes. Our findings disclose a promising alignment between EGMS data and geological observations in stable areas like Sardinia, affirming the efficacy of EGMS for monitoring ground stability. In areas with fault-related activities, such as the Pontina Plain and Volsci Range, EGMS data reveal differential subsidence, underscoring its capability to detect localized ground motion phenomena, possibly related to a combination of compaction and tectonic activity. In volcanic regions, particularly in Campi Flegrei and Mt. Etna, observed short-term data are the most sensitive for EGMS applications, as long-term observations are unrelated to them. The study also illustrates that the smaller disparities between EGMS and GPS data in active tectonic zones emphasize the intricate nature of short-term and long-term deformation interactions, highlighting the significance of local-scale geo-structural analysis. These insights contribute to a nuanced understanding of ground motion dynamics, crucial for informed hazard assessments and environmental planning.

Costantini M. et al. (2022). EGMS: Europe-wide ground motion monitoring based on full resolution InSAR processing of all Sentinel-1 acquisitions. In: IGARSS 2022-2022 IEEE International Geoscience and Remote Sensing Symposium, 5093-5096.

Costantini M. et al. (2021) - European ground motion service (EGMS). In 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 3293-3296.

Fault activation energy

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Keywords: earthquake energy, graviquake, elastoquake.

Faults are passive features mobilized by the dissipation of the energy and shear stress accumulated in the crustal volume surrounding them. However, the energy in the volume differs from the tectonic setting, i.e., it is gravitational in extensional tectonic settings, whereas it is elastic in strike-slip and contractional tectonic environments. In extensional settings, below 1 km the horizontal tensile stress is overwhelmed by the confining pressure of the lithostatic load. Therefore, the motion pro-gravity of the crustal volume is provided by the lithostatic load that is the vertical maximum principal stress. The elastic energy is rather accumulated by the maximum horizontal principal stresses, i.e., iso-gravity in transcurrent settings and counter-gravity in contractional tectonic settings. The different relation with the gravitational force in the different tectonic settings generates several relevant differences in the three main tectonic environments. The pro-gravity movements, or graviquakes, determine i) lower energy and lower differential stress to activate faults with respect to the other tectonic settings; ii) lower maximum earthquake magnitude than the other tectonic environments; iii) a larger number of low magnitude earthquakes in extensional settings because the crust moves downward as soon as it can move, whereas contractional settings require larger accumulation of energy to move counter-gravity; iv) therefore, the b-value of the Gutenberg-Richter is higher than 1 and the aftershocks are more numerous and last longer in extensional settings; v) the downward motion of the hangingwall determines more diffuse cataclastic deformation with respect to the other tectonic settings because the lithostatic load works everywhere, whereas in the other tectonic settings is concentrated where the elastic energy accumulates; vi) in extensional settings the volume dimension is determined by thickness of the brittle layer, and its length is about three times the seismogenic thickness, whereas in the strike-slip and contractional settings, where the elastic energy dominates (elastoquakes) the volume may be ten to thirty times longer, being its size proportional both to the brittle thickness and the relative speed of plates. These differences characterize the seismic cycle of graviquakes with respect to the elastoquakes. The bigger the volume, the wider the seismogenic fault in all tectonic settings. The interplay between the horizontal tectonic forces and the lithostatic load, which is ubiquitous, varies in the three main tectonic settings, generating different seismotectonic styles and an increase of seismic energy as the effect of the vertical gravitational force becomes minority.

The continuous GNSS network of Salina Island in the framework of CAVEAT project

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Keywords: GEodesy, Aeolian Islands.

CAVEAT (Central-southern Aeolian islands: Volcanism and tEAring in the Tyrrhenian subduction system) aims to study the active dynamics of the Central-Southern Aeolian Islands (CSAI) in the framework of the ring-volcanism and the subduction of the Ionian plate under the Calabrian Arc. CSAI, formed by Salina, Lipari and Vulcano islands, is considered as a volcanic ridge located at the intersection of the WNW-ESE Sisifo-Alicudi fault system to the west, and the NNW-SSE Aeolian-Tindari-Letojanni fault system to southeast. To properly detect the geodetic transients over CSAI area, recently we established a new GNSS network on Salina Island. The new local GNSS network, SalinaNet, consists of five stations that monitor by June 2023 and equipped with STONEX SC600+ GNSS receiver and antenna SA1200 GNSS. All raw GNSS observations acquired during first year are processed by using the GAMIT/GLOBK 10.71 software (Herring et al., 2018). The installation of these stations will significant improve the resolution of regional velocity field and the associated strain rate map. We present time-series and the preliminary results.

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Geodetic velocity constraints on fault strain accumulation in southern Italy

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Keywords: geodetic strain accumulation, active faults, Southern Italy.

We provide updated rates of geodetic strain accumulation on faults and deformation zones in southern Italy (from Molise to northern Calabria) by using a dense geodetic network derived from a combination of continuous (2001–2024) and episodic (1995–2013) GNSS observations. The continuous GNSS sites are part of several networks; the episodic sites belong to the PTGA network (Ferranti et al., 2008). For this analysis, the estimated GNSS velocities were aligned to a fixed Central Eurasia reference frame and successively to a local reference frame, whose Euler pole was estimated by using GNSS sites located in southern Apulia and eastern Lucania regions.

We refine previous estimations presented in Ferranti et al. (2014) using a new fault model derived by combining seismogenic sources of the INGV-DISS catalogue, faults inferred to be active in literature from the ITHACA database, and newly defined sources. The faults were modelled using a rectangular hull embedded in an elastic half-space. Computed geodetic rates for each modelled fault were compared with geological displacement estimates using Pleistocene or Holocene offset markers, where available.

Our analysis supports previous inferences that active deformation in southern Italy is accommodated by faults with low–moderate slip rates distributed in two distinct domains. A western domain of extension along the axis of the Apennines include faults with mainly extensional geodetic strain. Conversely, mostly blind, geodetically active strike-slip faults are found in an eastern domain encompassing the frontal Apennines, the Apulia foreland and eastern Calabria.

A longitudinal gradient in extension rate is observed for the axial fault array, with two sectors of higher strain accumulation (~0.8–1.7 mm/yr for individual faults). The modelled extensional faults do not form a continuous array, rather they show recurrent en-echelon patterns and strike changes that closely follows structural highs in the Apulian belt underneath the Apennines outlined in the map by Nicolai & Gambini (2007). This result is consistent with geological observations and supports the notion that extension occurs in discrete patches and is controlled by the inherited orogenic structure buried beneath the mountain belt.

Faults of the eastern domain have lower (few 0.1 to ~1.2 mm/yr) strike–slip rates and locally both extensional and contractional components. Noteworthy, significant geodetic displacement is detected in areas of the eastern domain lacking clear geological evidence of activity.

The pattern of strain accumulation in southern Italy appears strongly influenced by a combination of processes including mantle upwelling, and exploitation of intra-plate crustal anisotropy, which are not immediately related to plate boundary forces.

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Ferranti L. et al. (2014) - Rates of geodetic deformation across active faults in southern Italy. Tectonophysics, 621, 101-122, https://doi.org/10.1016/j.tecto.2014.02.007.

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ML vs. semi-automatic seismic catalogs: a new catalog for the L'Aquila 2009 earthquake sequence

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Keywords: L'Aquila 2009 seismic sequence, machine-learning seismic catalog.

Nowadays the use of neural networks and artificial intelligence in seismology provides high-resolution seismic catalogs including very small magnitude events that remained undetected by human analysts and standard monitoring procedures. Here, we test the performance of two new machine-learning (ML) modules that provide P- and S- wave arrival times (i.e. PhaseNet from Zhu & Beroza, 2019) and seismic waves association (i.e. GaMMA from Zhu et al., 2022) for their reliability in the high-seismic hazard area of the Central Apennines, Italy. In this work, we build a new earthquake catalog for the Mw6.1 L'Aquila 2009 seismic sequence using all the permanent and temporary seismic stations that operated in the epicentral area for a period of one year. After applying the combination of PhaseNet and GaMMA to the entire 2009, we obtained a new ML-based earthquake catalog composed of 407,229 seismic events with at least 3 P- and S- arrival times per event. The availability of a large-scale high-resolution catalog (about 63,000 earthquakes) for the L'Aquila seismic sequence (Valoroso et al., 2013), computed using semi-automatic picking and detection methods (Aldersons et al., 2009), permits testing the performance of the ML technique. In our new ML-based catalog, we found 62,492 common seismic events (about 99%) with the existing high-resolution catalog, demonstrating how powerful the ML techniques are to deliver a huge seismic catalog. The deep neural network PhaseNet recognizes more P- and S-wave arrival times than the semi-automatic algorithm, providing a decrease in the hypocentral horizontal and vertical error in the locations of the earthquakes. As a final step, we test the use of the newly developed ML earthquake catalog to compute 3D Vp and Vp/Vs velocity models that we compare with those obtained by using the MannekenPix procedure. Our final goal is to use this application to the L'Aquila 2009 seismic sequence as a test-case to validate whether this new ML- approach could be used for real-time monitoring during a future seismic sequence in Italy.

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Interseismic coupling degree along the Serre and Cittanova faults in Southern Calabria, (Italy): new constraints from geodetic data observations

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Keywords: block modelling, Calabria, active faults.

Extensional faults in Southern Calabria (Italy) have been widely studied for their capability to generate high magnitude earthquakes (Mw 7-7.2). An example is the historical seismic sequence of the 1783 (Jacques et al., 2001), which caused numerous fatalities near the villages located along the largest fault structures of this region, the Cittanova the Serre faults. In this area, the low strain rates and the high seismic moment release observed over time represent an open problem and raise a continuous interest of the scientific community.

In this work, we estimate the seismic potential of the Serre and Cittanova faults by a kinematic block modelling approach (McAffrey, 2002). We used the BLOCKS MATLAB code (Meade & Loveless, 2009) to divide the study area into rigid blocks bounded by faults and GNSS data of both campaign and permanent stations. Our results indicate that both faults are accommodating the extensional velocity gradient (~ 1 mm/yr), with long-term slip rates (~ 2 mm/yr).

Then, we estimate the spatial variability of the back-slip on fault planes (Savage, 1983) generating a 3D mesh with triangular dislocation elements (TDEs). We also compute the corresponding interseismic coupling degree for the studied faults and investigate the resolution capability related to GPS network geometry. This approach allowed us to distinguish the fault areas where elastic seismic rupture is more likely to happen from those affected by aseismic creeping behaviour. The obtained interseismic coupling distribution shows a good agreement with the relocated microseismicity of the area, concentrated mainly in the fault portions of low coupling degree. Moreover, the highest values of coupling are concentrated near the shallow portion of the fault planes and near the southern tip of the Cittanova fault.

The obtained results allowed us to propose a possible sets of rupture scenarios in southern Calabria by estimating the coupled area of the faults for each coupling increment, the related moment magnitude (Mw) and recurrence intervals. Moreover, geodetically constrained slip deficit rates, allowed us to estimate an overall interseismic moment accumulation rate of 4.05´1015 Nm/yr, larger than the average rate of the moment release (~1.19´1015 Nm/yr,) for the studied area.

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Detailed geological and geophysical investigation of a segment of a major active normal fault: the Northern Matese Fault System

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Keywords: active faults, geophysical investigation, structural geology.

Understanding the architecture of active faults is crucial to assess their seismic hazard, in both terms of ground motion and coseismic fault displacement. This is important especially when active faults are located in geologically complex areas, characterized by the overprinting of preexisting and newly formed fault splays. An example of this is provided by the NW-SE striking, NE dipping Northern Matese Fault System, Southern Apennines (Italy), a main normal fault formed by numerous fault strands with both along- and across strike arrangements. The fault is thought to be responsible of destructive historical earthquakes (e.g. Galli et al., 2017) and it is included in the Italian catalogues of seismogenic sources and capable faults. Although the general fault geometry, segmentation pattern and kinematics are relatively well understood (e.g. Ferrarini et al., 2017), accurate definition of fault arrangements, detailed measurements of slip-rates, and high-resolution subsurface images are lacking.

We combined remote sensing analysis through high resolution Digital Terrain Model (DTM), structural mapping and high-resolution geophysical investigations to reconstruct the complex architecture of the northern sector of the Northern Matese Fault System. Our study provides (1) new evidence of a WNW-SSE fault strand characterized by an overall large (up to ~25 m high) fault scarp of likely Late Pleistocene-Holocene age along the NE flank of the Mt. Patalecchia, and (2) a detailed mapping of the fault strand bounding the "Il Lago" plain, where the only paleoseismological trench to date was carried along the fault system (Blumetti et al., 2002). The linkage between these two main strands occurs through a relay ramp affected by a series of newly mapped antithetic and synthetic faults that accommodate the transfer of the deformation along the fault system.

In addition, we investigated the subsurface structure of the "Il Lago" plain by acquiring two high-resolution seismic reflection profiles. The strong reflection at the interface between the carbonate bedrock and the sedimentary fill shows an overall deepening of the bedrock towards SW, and a maximum thickness of the infilling of about 100 m. Although the profiles did not reach the main fault at the border of the basin, we imaged multiple synthetic and antithetic fault strands that affect the buried bedrock underneath the plain. Future investigations will allow us to verify whether the buried faults cut the sedimentary infilling and to determine a possible age of the infilling.

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New geodetic 3D velocity field of Iberia and adjacent mountain ranges

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Keywords: active tectonics, GNSS geodesy, Iberian Peninsula.

Geodetic measurements from GNSS networks are vital for quantifying active tectonic processes. Their combination with seismological and structural studies of active faults allows for the characterization of fault parameters (e.g. long-term and short-term slip-rate, seismic release, dimension), leading to an improved picture of seismic hazard of the study region. Iberia was the westernmost microplate situated between the Eurasian and Nubian plates, affected by the Alpine-Himalayan orogeny. In the north, the Iberian margin was mainly deformed during the Oligocene-Eocene collision with Eurasia. At present, geodetic deformations are not very high. The largest, N-S extension of up to 2 mm/yr, is concentrated in the western Pyrenean Cordillera. In turn, seismicity in the Pyrenees is mainly associated with extensional contexts (Rigo et al., 2015). Currently, the 4-6 mm/yr convergence between Nubia and Eurasia mainly affects the southern and southeastern margins of Iberia, resulting in the development of the Betic Cordillera, which, along with the Rif and the Alboran Sea basin, composes the Gibraltar Arc. Moreover, the southern Iberian and Nubian margins are deformed due to the 3-5 mm/yr westward migration of the Gibraltar Arc (González-Castillo et al., 2015). These frameworks make it the region with the highest deformation and affected by the most seismicity in Iberia (www.ign.es). The interior of the Iberian microplate was deformed, inverting all previously rifted regions, and producing intraplate mountain ranges. Nowadays, the intraplate region is affected by recurrent low-magnitude seismicity in the Iberian Cordillera and the Galician-North Portugal region where no main relative velocity changes are registered. In this work, we present a new 3D velocity model obtained from nearly 500 public continuous stations throughout the Iberian Peninsula and adjacent mountain belts. The data cover a time span of almost 25 years from 1999.00 to 2024.00. Overall, they improve previous models of Iberia (Palano et al., 2015) with new 100 stations and 9 years of measurements. These data have been processed using GAMIT/GLOBK (www-gpsg.mit.edu) following the process described in Palano et al. (2020). Achieved results are referred to the ITRF2014 reference frame. To improve the detail of the geodetic velocity field over the studied area, we perform a rigorous integration of our solutions with those reported in recent literature. The final velocity field has been used as input to compute a novel strain-rate field at the scale of the whole Iberia. The new velocity and strain fields will improve the knowledge of active deformation around Iberia and surrounding mountain belts and combined with seismology and active faults databases would be an important tool for hazard assessment.

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The new website of the Italian Seismic Bulletin (BSI): architecture and content

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Keywords: Italian seismicity, seismic bulletin, Open Access Data.

The activity of the Italian Seismic Bulletin (BSI) is addressed to the scientific community and the public with the objective of publishing a seismic bulletin and accurate information on Italian seismicity. The analysts of the BSI routinely review data recorded by the Italian National Seismic Network managed by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), and other permanent networks operated by Italian and European institutions (Margheriti et al., 2021). Arrival time readings of local and regional P and S waves, as well as polarities and ground motion amplitudes, are manually revised to compute earthquake hypocenter locations, magnitude and focal mechanisms. BSI datasets are released every 4 months and integrated into the International Seismological Center (ISC) bulletin. Since 2015, the BSI working group rapidly revises events of magnitude ML ≥ 3.5 releasing parameters and focal mechanisms of earthquakes in 24 to 72 hours (BSI Working Group, 2015).

Recently, the BSI activity is focused on developing a new website where data and other products including reports, publications and conference presentations, will be accessible to the public and the scientific community. The website presents an intuitive navigation. The homepage displays an interactive map where users can explore earthquakes of magnitude ML ≥ 3.5 that occurred in the last 12 months. For each event, users can view hypocenter parameters and, if available, the beachball representing the double-couple focal mechanism calculated with first-arrival polarities. The "History" section is dedicated to the historical observatories and their seismic bulletins that led to the formation and evolution of the BSI Working Group. The "Data Archive" section currently allows users to download data that was previously available on the websites terremoti.ingv.it/bsi (2015 to present) and bollettinosismico.rm.ingv.it(2002 to 2012). In the future, a data access point will be created for the whole BSI catalog, from 1985 to the present. Data of four-month bulletins from 2015 are available both in QuakeML and in text file formats commonly used by the scientific community. The "Seismicity in Italy" section displays the list of earthquakes with ML ≥ 3.5 recorded in the past 12 months and rapidly reviewed. For each earthquake, the first-polarity focal mechanisms are released if available (Ciaccio et al., 2021). In the near future, we plan to enhance the website by incorporating in-depth studies of the main Italian seismic sequences analyzed by the BSI working group.

BSI working group (Arcoraci L., Bagh S., Battelli A., Berardi M., Cantucci B., Castellano C., Cheloni D., Cirella A., Colini L., De Caro M., Frepoli A., Improta L., Lisi A., Lombardi A.M., Malagnini A., Margheriti L., Mariucci M.T., Melorio C., Michele M., Miconi L., Misiti V., Modica G., Monna S., Montuori C., Pagliuca N., Pastori M., Pinzi S., Pizzino L., Rossi A., Sciarra A., Sgroi T., Smedile A., Spadoni S., Tardini R., Thermes C., Bono A., Fares M., Franceschi D., Mandiello A.,, Moretti M., Pintore S., Quintiliani M. & Scognamiglio L.).

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Integrating geophysical, structural and tectonic data in a probabilistic seismic hazard assessment (PSHA) for the South-East of France

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Keywords: PSHA, active faults, tectonics, seismology, geodesy, structural geology.

Identifying and studying active faults is crucial for assessing seismic hazards and implementing measures to mitigate earthquake risks in areas prone to seismic activity. The region of South-East France is found in an tectonic domain where seismic activity is low to moderate and crustal deformation is slow, nevertheless about one magnitude 6 earthquake is recorded per century (Bertrand et al., 2007). Social vulnerability to seismic hazard in South-East France is noticeble, specifically due to the presence of urban agglomerations, chemical industries and most importantly, nuclear facilities.

Today's seismic activity in this region is of transtensional behaviour and is dominated by the ongoing tectonics of the post-alpine orogen and gravitational isostatic adjustments (Sue et al., 2007). However, the near future location and magnitude of this activity is not well constrained due to the relatively small time windows of seismic records and GPS data aquisition in respect to the seismic cycle of a slow deformation domain. The available knowledge on potentially active structures which determine the location of events is low, affirmed after the unexpected 4.9 Mw Teil earthquake in 2019 (Cornou et al., 2021). The geomorphic evidence of faults is weak as the seismic cycle is slower than erosional processes, difficulting the identification of recent fault activity. Moreover, the possible activity of faults with no neotectonic activity evidence under today's tectonic stress fields is ignored.

My work aims to analyse all major tectonic structures in the South-East of France and re-evaluate their near future rupture probability in accordance to the instrumental and historical seismicity and the stress field. The characterisation of potentially active faults in a slow deformation domain is a complex task which requires the determination of uncertainty levels for the defined data. For this, a methodology of estimation of fault activity and information reliability is proposed. The resulting fault dataset from this study will then be applied for the construction of a multidisciplinary and complex source model which considers all possible ruptures for a PSHA study of the area.

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Sue C. et al. (2007) - Extensional neotectonics around the bend of the Western/Central Alps: an overview. Int. J. Earth Sci., 96, 1101-1129.
Cornou C. et al. (2021) - Rapid response to the Mw 4.9 earthquake of November 11, 2019 in Le Teil, Lower Rhône Valley, France.

Time-dependent rift connection between the Red Sea and Gulf of Aden rifts in central Afar

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Keywords: Afar, rift linkage, numerical modeling.

Detailed understanding on how propagating rifts connect is crucial to fully capture the dynamics of continental break-up and the onset of seafloor spreading. The Afar rift is a classic natural laboratory where we can directly observe tectonic processes related to the ongoing deformation between the Red Sea and Gulf of Aden rifts. While there have been several geophysical studies conducted in the region, we know surprisingly little about the mechanism of connection between the two rifts. Earlier studies suggest that the two rifts form an overlap zone within which crustal blocks rotate in a clockwise sense. In contrast, geodetic data indicate a direct linkage via a zone of extension with dextral shearing at the lateral tips of the zone of extension and minimal vertical axis block rotation. Here we combine high-resolution 3D lithospheric scale geodynamic models and strain rate derived from geodesy to fully capture the evolution of deformation between the Red Sea and Gulf of Aden rifts as they evolve. The results demonstrate that the two rifts initially overlap and crustal blocks within the overlap rotate in a clockwise sense before direct linkage forms. We argue that the discrepancy between the proposed models for the Red Sea and Gulf of Aden rift connection can be reconciled when considering the spatial and temporal evolution of the rifts.

DInSAR coseismic surface deformation of the 2023 Mw 6.8 Al Haouz earthquake (High Atlas Mountains, Morocco)

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Keywords: earthquake, DInSAR, tectonics.

On 8th September 2023, the Al Haouz province in Morocco was struck by a strong earthquake of 6.8 Mw. The mainshock was generated by a reverse fault with an ENE-WSW orientation, as suggested by the derived focal mechanism. To obtain preliminary information of a seismic event, and to characterize the associated seismotectonic framework, in the last decades, the combination of field geology with satellite observations is becoming gradually more frequent. In particular, the DInSAR technique can be a powerful method of analysis to have an initial detailed information on the deformation field produced by the earthquake. In the present study, to understand the deformation field induced by the event and the structures involved, the DInSAR technique has been applied to obtain displacement maps in LOS, vertical, and horizontal (E-W) directions. On these maps, the geological meaning of both the vertical and horizontal displacement components is interpreted in the framework of the known tectonic structures of the Western High Atlas Belt. The inferred coseismic deformation along its vertical component shows a wide antiform characterized by an overall E-W trend and a slight southward vergence. On the other side, the horizontal (E-W) component of the deformation seems to be affected by the flexuring of the antiform flanks. Integrating the retrieved DInSAR maps with published geological observations and preliminary seismological data, it is possible to demonstrate how the coseismic deformation pattern may be affected not only by a possible activity of the main Tizi n'test fault but also by the far western High Atlas frontal thrust and by possible blind faults, better oriented to the vertical deformation field.

Geodetic and seismological constraints for the intra-orogenic normal Lakes Fault (Sila, Calabria, southern Italy)

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Keywords: geodesy, seismic data, modelling.

The Calabrian Orogenic Arc is affected by active extensional and strike-slip tectonics as largely documented by the presence of N-S and NE-SW trending intra-montane basins bordered by faults, whose slip has caused many destructive earthquakes during the last millennium. Here we collected a new set of geodetic and seismological observation related to the central sector of the Calabrian Orogenic Arc, i.e. the Sila Massif. By analyzing these novel datasets, we observed some relevant differences (e.g. seismic activity and hypocentral depths, faulting style, geodetic strain, vertical rates) between the western and eastern sectors of the Sila Massif. The transition between the two sectors occurs in the area of the Lakes Fault, a NW-SE striking and west-dipping fault indicated as the causative source of the 8 June 1638 M 6.8 earthquake. By modelling of the available geodetic data, we inferred a dislocation plane whose geometry and kinematics (a prevalent dip-slip component coupled with minor left-lateral strike-slip) is compatible with the real fault reported in literature. This fault only accounts for a small amount of the deformation across northern Calabrian Orogenic Arc and divides the seismically more active western sector from its eastern counterpart with appreciable geodetic strain and moderate seismicity. Achieved results (Palano et al., 2023) are encouraging and suggests that a similar approach can help in other regions where surface evidences of active faults are rare or non-existing and field geological investigations are hence difficult.

Palano M. et al. (2023) - The intra-orogenic normal Lakes Fault (Sila, Calabria, southern Italy): new insights from geodetic and seismological data. Ital. J. Geosci., 142(3), 384-397, https://doi.org/10.3301/IJG.2023.18.

Crustal deformation along the Dead Sea fault system

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Keywords: GNSS velocity, geodetic strain, natural strain markers.

The Dead Sea fault system (DSFS) represents the ~1000-km-long left-lateral transform boundary between the Arabian plate and the Sinai sub-plate, stretching from the Red Sea in the south, to the Hatay triple junction in the north, where it joins with the East Anatolian fault and the Bitlis-Zagros continental collision zone. The DSFS is characterized by a significant natural hazard due to its substantial seismic activity documented by historical records (Ambraseys, 2009). Although most seismic events along this fault are of small magnitude, typically less than Mw 4, there have been two significant earthquakes during the instrumental period. The first, theroughly Mw 6.3 Jericho earthquake in 1927 and the second event, the Mw 7.3, 1995 Nuweiba earthquake, a nearly pure strike-slip mechanism with approximately 1.6 m of left-lateral slip along an 80 km fault segment oriented about N20E (e.g. Klinger et al., 2000 and references therein). Such a persistent seismic activity can cause extensive damage to infrastructure and homes and pose significant safety risks to populations. Consequently, understanding and monitoring this fault is essential for earthquake preparedness and risk management in the affected regions. Both continuous and episodic GNSS networks, established in the last 2 decades along the DSFS, have allowed to infer the main slip-rates of the major fault segments (Li et al., 2024). Here we propose a new GNSS-based horizontal velocity field for DSFS by taking into account novel observations as well as literature solutions. By using as input this unified velocity field we computed both the strain-rate field and the slip-rate distribution along the entire DSFS. Furthermore, we have identified areas within the DSFS where river basins exhibit more significant rotations by utilizing them as natural strain markers for tectonically active regions (e.g., Goren et al., 2015), aiming to understand the spatial variations of long-term tectonic deformation across the fault system. Finally, achieved results have been framed into the general seismotectonic setting of the study area.

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A method for the determination of the orientation of fault plane from the analysis of seismograms in the time domain

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Keywords: focal mechanism, directivity, rise time.

During the last decades, many studies (i.e., Sato & Hirasawa in 1973; de Lorenzo & Zollo in 2003) have tried to solve the problem of the ambiguity of the solution of the focal mechanisms of earthquakes by modeling the directivity source effect.

The directivity effect is the changing in shape and amplitude of the body wave pulses, varying the position between the source and the stations. Directivity effect is linked to the shape of the source (unilateral, circular or complex), so, in order to create a model of directivity, it's important to define *a priori* a source model.

Starting from the limits of the work by Filippucci et al. (2006), a method has been developed to better costrain the fault plane solution.

In this work a circular-crack source model with constant rupture velocity and a fixed 0.9 ratio between ν (rupture velocity) and β (S-wave velocity) has been used (Model by Sato & Hirasawa, 1973).

In this study the measurement of the rise times at a regional scale has been carried out for 21 earthquakes of the Amatrice-Visso-Norcia Seismic Sequence (2016). This dataset is composed of ML 3 to 4 earthquakes, with depths varying between 8 and 13 km, which focal mechanisms have been determined by previous studies.

The proposed method explaines the differences between observed and theoretical source rise times as due to local attenuation site effect or to an additional station Q. In this way the limiting assumption (constant Q for all the seismic stations) of the previous method is now overcome.

Data analysis and data plotting have been carried out through csh procedures, Fortran based softwares and Matlab scripts.

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Paleoseismological evidence of multiple, large magnitude earthquake surface ruptures on the active Mt. Morrone normal fault, central Apennines, Italy

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Keywords: paleoseismology, seismic hazard, Central Apennines.

The Mt. Morrone active normal Fault (MMF) and the related Sulmona intermountain hanging wall basin constitute one of the most characteristic examples of the extensional tectonic landscape carving the central Apennines of Italy. Above the SW-dipping MMF, extending for more than 22 km in a mean NW-SE direction, concentrates a population of several tens thousands of inhabitants with a thriving industrial and commercial reality, as well as a historical and cultural heritage of great significance documented by archaeological and architectural elements. According to the current knowledge, the last activation event of the whole MMF occurred approximately 2000 years ago (Ceccaroni et al., 2009) and the maximum expected magnitude from fault activation is approximately M 6.6-7 (Gori et al., 2009). Thus, the MMF today constitutes one of the most problematic structures in the central Apennine seismotectonic setting in terms of large magnitude earthquake probability. However, despite this, information on the activity of the MMF rare presently relatively few, both as for associated historical seismicity and paleoseismological data. To strengthen these knowledge weaknesses, we performed new extensive paleoseismological analyses (by means of four trenches dug across the MMF) in the central sector of the fault, specifically in the Roccacasale village area. Our goal was to supplement the limited existing dataset, primarily comprised of a single paleoseismological study (Galli et al., 2015) on evidence of coseismic faulting (situated close to the northwestern tip of the fault). Additionally, we aimed to incorporate findings from a pair of studies focused on archaeoseismological and speleoseismological secondary evidence (Di Domenica & Pizzi, 2017). Through these analyses, we unveiled three significant surface rupture events of the MMF occurred over the past 6000 years Before the Present (BP). Specifically, as for the youngest displacement event (Eq1) that we identified, it occurred after 3.6-3.5 kyr BP, being thus chronologically consistent with the previous paleoseismological and archaeosesismological information that dated the event at 2nd century CE; a penultimate event (Eq2) occurred after 4.4 kyrs BP; a previous event (Eq3) occurred after 5.4-5.3 kyr BP, presumably between 4.8 kyr and 4.6 kyr BP; and the oldest event (Eq4) took place after 9-8.9 kyr and (presumably) before 5.8-5.7 kyr BP. Considering that the cumulative minimum vertical displacement (minimum because we lacked correlative stratigraphic markers in the fault footwall as to define the actual cumulative offset), estimated encompassing the last three events, is approximately 140 cm, that metre-scale large ground chasms opened during these events, and based on the length of the fault at the surface, we can confirm that earthquakes with M 6.6-7.0 may be expected from the activation of the MMF with an inferred average recurrence interval not longer than 1800 years over the last ca. 5500 years.

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Integration of active and passive seismic data to investigate the relationships between seismicity and geological structures at the hanging-wall of the alto Tiberina fault (Northern Apennines of Italy)

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Keywords: seismo-tectonics, active faults, seismic sequences.

One of the most seismically active areas in Central Italy is located within the Pre-Apennine Umbria region, between the Tiber Valley, the town of Gubbio and the northern sector of the Umbria-Marche Apennine Mountain chain. The main geological structure of the area is the Alto-Tiberina fault (ATF), a 60 km long low angle normal fault active since the Late Pliocene-Early Pleistocene and characterized by a high rate of micro-seismicity (Ml < 3.0) nucleating along the fault plane. A considerable number of synthetic and antithetic faults are located within the ATF hanging wall; among them, the 20 km long Gubbio normal fault produced historical and more recent earthquakes of moderate magnitude (e.g., MW 5.1 1984 Gubbio earthquake). Our study focuses on 5 major seismic sequences occurred from 2010 to 2023 at the hanging-wall of the ATF, located and published in the Database of the Central Eastern Italy Seismometric Network (ReSIICO) (Cattaneo et al., 2019). They are characterized by mainshocks of moderate magnitude up to 4.5 and not associated to any previous mapped fault on the field (Mw= 3.6 - Pietralunga 2010, Mw= 3.6 - Città di Castello 2013, Mw = 3.9 - Gubbio 2021, Mw = 4.5 - Umbertide 2023). We aim to investigate the concept of "on-fault" vs "distributed" seismicity (Collettini et al., 2022) in areas where earthquakes of moderate magnitude occurred without rupturing any major fault at the surface. In this case, we don't know if the seismic clusters trace the rupture along a single segment of a larger fault or if the seismicity is distributed within a "seismic volume" characterized by smaller sub-parallel faults. Our research questions, relevant for seismic hazard definition at a local scale, are the following: first, whether the mechanical stratigraphy of the crust controls the seismicity distribution and second, whether these seismic sequences can be associated to minor faults with a seismic expression. To investigate the first aspect, we performed statistical analysis on seismicity distribution with respect to the four main geological units of the area (starting from the bottom: the acoustic basement, the evaporitic, carbonatic and turbiditic layers). To explore the presence of other minor faults we developed a revised detailed interpretation of a set of 2D-sesimic reflection profiles, acquired in the 80s for hydrocarbon exploration purposes and used in previous works to study the subsurface geology at a regional scale (Mirabella et al., 2011). To improve the correlation between seismicity and geological structures atepth, we relocated the 2010-2023 seismic catalogue using a 3D velocity model derived from geological data (Latorre et al., 2016), integrated with the innovative Markov chain Monte Carlo location algorithm. By combining interpretation of active seismic data with innovative strategies of earthquake re-location and statistical analysis, our study proposes as a significant experience for seismo-tectonic interpretation of low-magnitude seismic sequences.

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The role of structural complexity in seismicity distribution: L'Aquila 2009 seismic sequence (Central Apennines, Italy)

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Keywords: L'Aquila seismic sequence, fault zone structure, seismicity distribution.

The integration of structural geology with high-resolution earthquake location is a fundamental approach to build a comprehensive reconstruction of fault zone structure that is a prerequisite for understanding the time-space evolution of a seismic sequence. As faults accumulate displacement, their length and degree of maturity increase (Cowie & Scholz, 1992) influencing earthquake rupture dynamics and crustal scale fluid flow. Our study focuses on the 2009 seismic sequence, when a mainshock of Mw 6.1 struck the city of L'Aquila in the central region of Italy, activating the Paganica-San Demetrio fault system (PSDFS). This fault system involves multiple sub-parallel N133°E-trending active faults forming a complex structure with an overall length of 20 km. We constructed a series of geological cross-sections that we used to characterize the long-term fault throw and the degree of fault segment interaction. The fault throw profile highlights two main fault segments that merge in a zone characterized by relatively low throw that is partitioned along different small fault segments, resulting in a zone of soft linkage (e. g. Walsh et al., 2003). The PSDFS has also been studied via 2 km-spaced seismological cross-sections normal to the fault system. In each section, aftershock distribution illuminates the earthquake fault represented by <1 km wide zone of earthquake alignment along a SW-dipping structure together with antithetic faults. Furthermore, at shallow depth (1-4 km) the seismicity distribution highlights a sub-horizontal cluster of aftershocks. Within the cluster, the seismicity rate is characterized by a bimodal distribution, with a typical Omori decay followed by a further increase of the seismicity rate at about 15 days after the mainshock. This second pulse of seismicity is associated with a temporal increase of Vp/Vs ratio occurring in the same time window (Chiarabba et al., 2022). Because this cluster is located in correspondence with the fault soft linkage detected by our structural geology analysis, we interpret that this zone of structural complexities represents a preferential path for fluid flow promoting post mainshock fluid migration and favoring the observed clustered seismicity at shallow crustal depth.

Our results suggest that fault zone structure and associated structural complexities can play a primary role in seismicity distribution and crustal scale fluid flow.

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Analysis of the Seismic Coupling Coefficient for Italy: first results

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Keywords: GNSS geodesy, seismology, hazard.

Over the past three decades, the worldwide growth of continuous and episodic GNSS stations as well as more dense seismic networks allowed the acquisition of extensive geodetic and seismological datasets. This resulted in more reliable applications for comparing geodetic and seismic strain-rates at the scale of regional fault systems. Studies focusing on this topic have provided new insights on the partitioning between fault slip and bulk lithosphere permanent strain. The fundamental notion underlying these studies is that, for a given region, the moment released by earthquakes mirrors the rate of tectonic deformation. Achieved results have allowed us to identify regions in Italy where the crustal deformation budget appears entirely released by seismicity but also regions where the excess deformation could be potentially released either as aseismic slip or through large future earthquakes.In this study we present an analysis of the Seismic Coupling Coefficient (SCC) for Italy by adopting the same structure and input data of the current seismic hazard map MPS04, on which seismic building code provisions are based. The computation of SCC is based on the seismic source zone model ZS9 (Meletti et al., 2008), the earthquake catalogue CPTI04 (Gruppo di lavoro CPTI, 2004) and the related Gutenberg-Richter parameters, expected maximum magnitude and seismogenic thickness, that are used to estimate the seismic moment-rates. Finally, the geodetic moment-rates are calculated from the GNSS velocity field (1995-2022 time interval) available for the Italian territory (EUREF, https://www.epncb.oma.be/; ASI, https://www.asi.it/; RING, http://ring.gm.ingv.it/; and other networks). The SCC analysis has been performed following the Kostrov (1974) approach.

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Unraveling the dynamics of the active frontal sector of the Northern Apennine thrust belt: a multidisciplinary investigation following the 2022 Mw 5.5 Adriatic earthquake

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Keywords: Adriatic Sea, seismogenic buried faults, rupture model.

On 9 November 2022, a Mw 5.5 earthquake struck approximately 30 km offshore the city of Pesaro in the Adriatic Sea (Italy), followed by several M4+ earthquakes and numerous minor aftershocks. The tectonic activity in the region is poorly constrained. The area falls in the NE-verging composite seismogenic source ITCS106 (DISS Working Group, 2021), but its seismic activity has been debated due to the absence of historical earthquakes (before 2022) and the lack of evidence of active tectonics in high-resolution bathymetric and seismic data.

Given the proximity of the seismic sequence to the densely populated coastline of the area, accurately characterizing the activated fault and the associated rupture history assumes great importance for a comprehensive seismic risk assessment and for a proper evaluation of the related tsunamigenic hazards.

Exploring seismogenic faults in offshore regions presents various challenges, particularly in delineating their geometry and kinematics. Geological data from deep-sea exploration and geophysical surveys are commonly used to characterize offshore active faults and earthquake hypocentral locations. Nevertheless, limitations in data availability and quality may affect the creation of precise 3D models. Furthermore, the relocation of offshore seismic events, especially in the depth domain, is challenging due to the limited azimuthal coverage and the minimum station-event distance. For these reasons, an interdisciplinary approach that combines geological, seismological, and geodetic methodologies represents an essential workflow for defining seismogenic sources and constructing a comprehensive rupture model in offshore areas.

In this study, we defined the structural setting of the area involved in the Pesaro offshore seismic sequence through the interpretation of 38 seismic reflection profiles and well data acquired over the past decades, provided by oil companies, which integrate several publicly available seismic and geological data.

The interpretation of the seismic profiles enabled an accurate delineation of the principal stratigraphic markers and the thrusts geometry focusing on their relationship with inherited structures. Starting from the reconstructed geometry of the activated fault, strong motion data and continuous GNSS stations, located both onshore (within storage centers) and offshore (on seabed-anchored hydrocarbon platforms), were jointly inverted to reconstruct the coseismic rupture history of the Mw 5.5 event and to precisely delineate the activated portion of the fault plane.

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S37.

Carbonate platform systems: records of palaeoenvironmental change

CONVENERS & CHAIRPERSONS

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Open questions on the Likva locality K-Pg boundary bed on the Adriatic carbonate platform

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Keywords: K/Pg boundary, event bed, stratigraphy.

While the K-Pg boundary hiatus is common across much of the Adriatic carbonate platform, exceptions exist, particularly in the southwestern part (present-day Dalmatian archipelago). Here, continuous K-Pg successions and unique deposits at the boundary suggest a possibility of a major event-bed (tsunamite?) related to the Chicxulub asteroid impact. Simulations suggest the impact cratering may have triggered a near-global tsunami, potentially underestimated due to seismic shock-induced collapses along the Yucatan and Cuban carbonate platforms. Submarine landslides along the southeastern North American margin could have further propagated a trans-Atlantic mega tsunami, influencing the K-Pg boundary neritic sedimentation in Europe and Africa (Korbar, 2019).

While Hvar and Brač island yield the evidence of the K-Pg event (Korbar, 2019), additional evidence from a site over 300 km northwest (Karso/Kras) corroborates the existence of a widespread Adriatic carbonate platform tsunami, although precise correlation with the K-Pg boundary and the Chicxulub impact awaits further evidence. Strontium isotope stratigraphy could provide better resolution of Maastrichtian deposits, while the foraminifera could ascertain the supposed Paleocene age of the overlaying deposits.

Likva section (Brač island) provide the strongest evidence of the K-Pg event on the platform), although some researcher argued for firmground (Cvetko Tešović et al., 2020) or even hardground (Font et al., 2017) within the event-bed, suggesting a hiatus in the deposition around the K-Pg boundary. However, as pointed out by Korbar (2019), sedimentological evidence strongly supports the event-bed deposition. With the aim to found further evidence on the origin of the debated K-Pg boundary bed, we analysed the deposit in details and found further evidence on its specific origin.

Cvetko Tešović B. et al. (2020) - Lithostratigraphy and biostratigraphy of the uppermost Cretaceous to lowermost Palaeogene shallow-marine succession: top of the Adriatic Carbonate Platform at the Likva Cove section (island of Brač, Croatia). Cretaceous Research, 114, 104507, https://doi.org/10.1016/j.cretres.2020.104507.

Font E. et al. (2017) - Comment on "Postimpact event bed (tsunamite) at the Cretaceous-Palaeogene boundary deposited on a distal carbonate platform interior". Terra Nova, 29, 329-331, https://doi.org/10.1111/ter.12282.

Korbar T. (2019) - Cretaceous-Paleogene boundary tsunamite on the Adriatic carbonate platform and possible source of a hypothetical Atlantic-to-western-Tethys megatsunami. In Koeberl C. & Bice D.M. (Eds), 250 Million Years of Earth History in Central Italy: Celebrating 25 Years of the Geological Observatory of Coldigioco. Geological Society of America Special Paper 542, 319-332, https://doi.org/10.1130/2019.2542(16).

Diversity of Early Cretaceous carbonate facies around the OAE1a on Adriatic carbonate platform

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Keywords: carbonate platform, Aptian, OAE 1a.

The Early Cretaceous was a period of relatively high temperatures, marked by the occurrence of several Oceanic Anoxic Events (OAEs). Significant is the early Aptian OAE-1a, one of the extreme occurrences triggered by the initiation of volcanic activity within large igneous provinces, leading to a substantial release of CO_2 into the atmosphere, either directly or indirectly. The resultant greenhouse gas emissions set off a series of environmental repercussions. This case study is an example how a tropical carbonate platform responded to the disruptions associated with the OAE1a.

During the Lower Cretaceous, the Adriatic carbonate platform was a subtropical isolated carbonate platform, which existed for most of the Mesozoic. At the beginning of the mid-Cretaceous environmental perturbations, the Adriatic carbonate platform was characterized by subtidal, more open environments characterized by *Lithocodium-Bacinella* (L-B) oncoliths or rudists rich facies, as described from Istria and Dalmatian islands (Husinec & Sokač, 2006; Huck et al., 2010), recognized as the Kanfanar formation. On the island of Vis (central Adriatic, Croatia), deposits underlying and overlaying the supposed OAE1a succession are characterized by monotonous peritidal cycles, while the relatively thick Lower Aptian succession is characterized by significant facies diversifications, recognized as the Barjaška formation.

The base is a thick-bedded dolomite with L-B oncoliths, resembling Kanfanar formation. They are followed by the distinct sub-units stacked one atop another: a) thinly bedded marly limestones - skeletal-peloidal W-P with orbitolinids; b) laterally variously thick sedimentary bodies rich in various rudist and chondrodont shells topped by chondrodont and orbitolinid tempestites; c) bioturbated limestones containing chert nodules with the last occurrence of *Palorbitolina lenticularis* (Blumenbach, 1805); d) *Salpingoporella* unit, representing the shallowing of the depositional environment, characterized in its lower part by layers of M-P rich in oriented *dinaricas* – indicating a shallow, restrictive environment with increased freshwater influence, followed by skeletal W-P with small miliolids and textularids – indicating a re-establishment of marine conditions, and skeletal-peloidal M-W with shell fragments and L-B oncoliths at the topmost part.

Formation ends with layers of marls interpreted as a regional Aptian-Albian emergence. Above succession contains micritic limestones with subaerial exposure evidence and increases fresh water influence alternating with layers of peloid-skeletal P-G with benthic foraminifera, *Mesorbitolina* sp.

Integrated bio- and chemostratigraphy indicate the Early Aptian age of the investigated deposits. Significant facies diversification is observed, partly related to sea level changes partly to changing environmental conditions, but for deposition of about 60 meters of deposits the influence of synsedimentary tectonics is also needed.

Huck S. et. al. (2010) - Latitudinally different responses of Tethyan shoal-water carbonate systems to the Early Aptian oceanic anoxic event (OAE 1a). Sedimentology, 57(7), 1585-1614, https://doi.org/10.1111/j.1365-3091.2010.01157.x.

Husinec A. & Sokač B. (2006) - Early Cretaceous benthic associations (foraminifera and calcareous algae) of a shallow tropical-water platform environment (Mljet Island, southern Croatia). Cretaceous Research, 27(3), 418-441, https://doi.org/10.1016/j.cretres.2005.07.008.

The record of the Early Cretaceous Oceanic Anoxic Events (OAE) in the Apennine carbonate platform: insight from the geological mapping of the Sheet 390 - Frosinone (CARG project)

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Keywords: oceanic anossic events, Ernici mountains, shallow-water carbonate platform.

The ongoing CARG project gives us the opportunity to investigate with renewed perspectives and different approaches the multiple geological facets of the central Apennines. Here we present the preliminary results of a study related to the geological mapping of the sheet 390 – Frosinone, aimed at the identification and description of the perturbation induced in the Latium-Abruzzi Carbonate Platform by the well-known Early Cretaceous Oceanic Anoxic Events (OAEs).

In the examined area, located in the Ernici Mts., a shallow-water carbonate platform succession, ranging from Late Triassic/Early Jurassic to Late Cretaceous, crops out (Cosentino et al., 2010; Fabbi et al., 2023). This study is focused on the "calcari ciclotemici a gasteropodi" (CCG - Berriasian *p.p.* - lower Aptian *p.p.*) and the "calcari e marne a *Salpingoporella dinarica* e carophyta" (CMS - lower Aptian *p.p.*). A layer of black dolostones, about ten centimeters thick, was observed at the same stratigraphic position in several outcrops of the dolomitic lithofacies (CCGa) of the CCG unit. Moreover, black shales, a few centimeters thick, were observed within the thin CMS unit.

Chemical composition variations on whitish and blackish dolostones (CCGa) were investigated in *situ* using the laser ablation inductively coupled plasma mass spectrometry (LA-IC-MS) facility at Roma Tre University. Results show significant increase of elemental concentration of P, Fe, Zn, As, Ba, Pb, and U, as well as in the Fe/Al ratio in the blackish layers, which are generally considered as redox sensitive proxies associated with anoxic paleoenvironments (Bodin et al., 2007; Craigie, 2018).

Biostratigraphic calibration performed on the samples has shown an Hauterivian *p.p.* age for the CCGa levels and lower Aptian *p.p.* age for the CMS calcareous beds. A preliminary attempt was carried out for U-Pb dating of the CCGa dolomite through the LA-ICP-MS technique. In the Tera-Wasserburg diagram the measured, uncorrected, compositions of CCGa dolomite yielded a lower intercept age of 123.8 ± 3.2 Ma (MSWD=1.6; N=19;). These promising results allow us to hypothesize a correlation between the black dolostones levels in CCGa with the Faraoni event. For the black shales within the CMS, a correlation with the Selli event is likely. Future investigations will aim to consolidate this hypothesis by taking advantage of a multidisciplinary approach between field work, bio-lithostratigraphic correlations and chemostratigraphical analyses.

Bodin S. et al. (2007) - Enrichment of redox-sensitive trace metals (U, V, Mo, As) associated with the late Hauterivian Faraoni oceanic anoxic event. Int. J. Earth Sci., 96, 327-341, https://doi.org./10.1007/s00531-006-0091-9.

Cosentino D. et al. (2010) - Geology of the central Apennines: a regional review. J. Virtual Explorer, 36(11), 1-37.

Craigie N. (2018) - Principles of Elemental Chemostratigraphy: A practical user guide. In: "Advances in Oil and Gas Exploration & Production". Springer International Publishing. ISBN 978-3-319-71216-1,177 pp, https://doi.org/10.1007/978-3-319-71216-1.

Fabbi S. et al. (2023) - Stratigraphy and tectonic evolution of a portion of the Simbruini-Ernici Mountains (Central Apennines-Italy). Review and new data from detailed geological mapping. Geol. F. Trips Maps, 15(2.3), 1-40, https://doi.org/10.3301/GFT.2023.08.

Soft-sediment deformation structures and Neptunian dykes across a carbonate system: Evidence for an earthquake-related origin (Norian, Dolomia Principale, Southern Alps, Italy)

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Keywords: soft-sediment deformation structures, carbonate platform, Triassic.

Identification of the processes producing soft–sediment deformation structures, common in siliciclastic deposits and less abundant in carbonate successions, is complex, because different processes may produce similar structures. Thus, interpreting the origin of these structures may be challenging: it requires both a detailed sedimentological study and the knowledge of the depositional environment and stratigraphic evolution, in order to provide hints to identify the processes affecting sediments after deposition. Among the potential causes of the formation of soft–sediment deformation structures, seismic shock is one of the possibilities, but their origin could be also related to other triggering mechanisms, such as volcanic activity, sediment loading, salt tectonics, fluid expulsion, meteorite impacts and mass movements. Although it is a plausible option, the interpretation of these structures as 'seismites' is not obvious: it must be supported by different lines of evidence, considering that the correct interpretation of soft–sediment deformation structures as a consequence of seismic shocks acquires important implications in palaeoseismology studies The possibility to study and interpret the origin of soft-sediment deformation structures in carbonate successions is favoured when diverse structures are preserved in different subenvironments of the same depositional system. A favourable situation is represented by the Norian carbonate system in the Southern Alps of Italy, where different soft-sediment deformation structures occur in different carbonate facies. Sedimentological analyses provide the chance to characterize different types of soft–sediment deformation structures along a platform–to–basin depositional profile. Presence of pseudonodules in basinal resedimented limestone, sedimentary dykes and clinostratified breccias with unlithified clasts in slope settings and liquefaction of inner platform facies at the platform top testify to an origin compatible with multiple seismic shocks, repetitively affecting the same stratigraphic intervals. This interpretation fits with the evidence of extensional syndepositional tectonics documented for this succession by rapid thickness changes and by the development of strongly-subsiding intraplatform basins within the inner platform domain. The diverse types of soft–sediment deformation structures in the studied carbonate system provide a rich catalogue of structures related to seismic shocks, representing a possible reference for other similar settings, especially for carbonate succession where the preservation and identification of diverse and associated soft-sediment deformation structures is less common with respect to siliciclastic successions.

The drowning of the Trento Platform: facies characterization and depositional changes across the San Vigilio Oolite - Rosso Ammonitico Veronese transition (Lower-Middle Jurassic, Venetian Southern Alps, N Italy)

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Keywords: Trento platform, drowning, Southern Alps.

The drowning of Jurassic shallow-water carbonate platforms is a widespread phenomenon across the Tethys realm in a context of extensional tectonics manifested with the deposition of red colour, hemi-pelagic nodular limestone, rich in ammonites. The study of the facies deposited during the stages preceding and following platform drowning contributes to the understanding of the causes, modes and timing of carbonate platform demise. The Lower-Middle Jurassic carbonate succession of the Trento Platform (Venetian Southern Alps, N Italy) is a field laboratory for studying the sedimentary record of the onset of platform drowning and demise of a carbonate platform consisting of peritidal facies (Monte Zugna Formation, 120 m thick; Hettangian-Sinemurian), high-energy ooidal grainstone (Loppio Oolitic Limestone, 40 m thick; Sinemurian) and low-energy subtidal lagoon (Rotzo Formation, 200 m thick; Sinemurian-Pliensbachian). The San Vigilio Oolite (10 m thick; Toarcian-lower Aalenian) represents the last shallow and high-energy deposit before drowning and consists of oolitic grainstone with intraclasts and peloids deposited above fair-weather wave base. The upper portion of the San Vigilio lithostratigraphic unit is devoid of ooidal grainstone (20 m thick) and consists, from base to top, of: 1) bioclastic packstone with lithistid sponges, oncoids and coated grains, 2) oncoidal packstone-rudstone with coated grains and bioclasts, 3) coated grain skeletal packstone-grainstone. The abundance of siliceous sponges and crinoids, the lack of ooids and the reddish colour of the upper San Vigilio unit are indicative of a gradual deepening of the depositional environment, compatible with the onset of carbonate platform drowning. A regional drowning unconformity marked by an erosional surface and a hardground composed of mm to cm thick Fe-Mn nodules separates the San Vigilio Oolite from the overlying hemi-pelagic Rosso Ammonitico Veronese (upper Bajocian-Tithonian). The hardground consists of mm to cm thick Fe-Mn polymetallic nodules favoured by low sedimentation rates, enhanced by the sweeping action of bottom currents, removing fine sediment and oxygenating the seafloor. The lower Rosso Ammonitico Veronese (5-11 m thick) overlying the hardground consists of superimposed: 1) skeletal packstone with protoglobigerinids and peloids, 2) bioclastic packstone with *Bositra* thin-shelled bivalves and peloids, 3) intraclastic packstone with bioclasts. This facies superposition demonstrates a gradual deepening of depositional environments from above (San Vigilio Oolite) to below fair-weather wave base (sponges and echinoderms rich deposits; upper San Vigilio) followed by the abrupt reduction in sedimentation rate (hardground polymetallic nodules) and by the establishment of a hemi-pelagic sedimentation (drowning succession; Rosso Ammonitico Veronese) on bioturbated oxygenated seafloors below the photic zone, as confirmed by a drop in the benthic faunal diversity.

Unveiling the architecture and geological significance of mesophotic oyster reefs on the Apulian Continental Shelf: a multiscale approach

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Keywords: marine bioconstructions, mesophotic reef, Apulia shelf.

The Apulian continental shelf in the Southern Adriatic Sea is a unique geological region characterized by the formation of various biogenic facies at depths ranging from 20 to 80 meters. These facies result in persistent structures that provide habitats for diverse marine communities and contribute to the complexity of the seafloor topography.

Three distinct biogenic facies have been identified in this region: coralligenous, mesophotic coral reef, and mesophotic oyster reef. The mesophotic oyster reefs of Monopoli have been the subject of several studies in recent years. These studies have documented the distribution, structure, and composition of the reefs, as well as their ecological importance.

The present study provides a detailed analysis of the mesophotic oyster reefs of Monopoli, focusing on their structure, composition, and relationship with the underlying substrate. A multiscale approach was employed, combining field observations, bathymetric data, and laboratory analyses of rock samples. The mesophotic oyster reefs of Monopoli are characterized by a peculiar pinnacular morphology, with oysters - *Neopycnodonte cochlear* (Poli, 1795) - encrusting rocky outcrops and creating complex three-dimensional structures and oysters are typically arranged in "*bouquets*".

The present study provides, using thin sections and image analysis, new insights into the structure, composition, and relationship of the mesophotic oyster reefs of Monopoli with the substrate. The findings of this study have important implications for the conservation and management of these reefs.

The lateral-vertical relationships in facies distribution have been studied to document sea-level rise during the Holocene, providing a framework for understanding past dynamics and predicting future trends in the evolution of shelf communities. The current distribution of these temperate biogenic facies on the shelf contributes to the complexity of the seafloor topography, promoting diverse communities that enhance biodiversity. This work highlights the importance of the Apulian continental shelf as a unique geological region with significant ecological value.

Carbonate platforms: what can still be learned from outcrops?

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Keywords: carbonate platforms, outcrops, carbonate factories.

Outcrop studies are the foundation of sedimentary geology notwithstanding the advanced laboratory and digital techniques necessary for the in-depth analyses of collected field data. Exceptionally exposed carbonate platform outcrops of different geological ages and settings (Wright & Della Porta, 2021) provide a unique record of the secular changes and evolution of carbonate systems and the compelling evidence that the present-day carbonate deposits are not necessarily a key to the past for the geological record of carbonate platforms and carbonate-producing factories.

Carbonate sediments and rocks are inherently varied, especially because their constituents are mainly the remains of calcareous animals and algae, as well as the product of physico-chemical and microbially mediated carbonate precipitation. As a result, the distribution, abundance (productivity) and composition (biological, mineralogical and textural) of carbonates reflect ecologic controls, not simply physical processes. Add to that the fact that biological evolution, large scale global climatic, palaeoceanographic and environmental changes, and extinction events have altered the biological make up of seas and oceans over geologic time. Hence, it is little wonder that the resulting nature of carbonate sediments has changed so much. The sedimentary record of carbonate successions, through their composition, geometry and stratigraphic architecture, is an irreplaceable archive of past biological, environmental, accommodation, oceanographic, tectonic and climate changes.

A major theme in understanding carbonate deposition has been that of the carbonate factory and its interaction with accommodation changes and physical processes. Carbonate factories are the sites of formation of biogenic (skeletal, microbial, biologically induced and influenced) and abiogenic (inorganic, chemogenic or physico-chemical) carbonates; and mixtures of these components are found in most carbonate successions. In the Phanerozoic geological record, the microbial carbonate factory represents an opportunistic mode of carbonate production taking over when substrates become available following biotic crises. Carbonate sediments, rocks and platforms have varied through time as their originators and carbonate factories have responded to intrinsic and extrinsic factors linked to global climate change, geodynamics and macroevolutionary changes.

This review comprises carbonate platform systems well-exposed in continuous outcrops from the platform top interior to slope and adjacent basin from the late Paleozoic to the Cenozoic cropping out in Northern to Southern Italy, France, Spain, Morocco, Oman, China and USA. This compilation is intended to provide a means to facilitate other researchers to access outcrops which, while limited in number, illustrate key aspects of carbonate facies character, architecture and controlling factors through time and space.

Wright V.P. & Della Porta G. (2021) - Field Guides to Exceptionally Exposed Carbonate Outcrops. International Association of Sedimentologists (IAS). Field Guides, 3, 822 pp., https://doi.org/10.54780/IASFG003.

An unusual rhodolith bed as a record of human activities in Mar Piccolo (Taranto)

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Keywords: rhodolith bed, Mar Piccolo, anthropic impact.

Rhodoliths are free-living rocks living on seafloor at various depths. The aggregation of several single rhodoliths forms a unique habitat called Rhodolith Bed (RB). RBs are typically found at depths ranging between 30 and 100 meters; only a small percentage of these habitats are located 25 meters below sea level. Due to their complex structural characteristics, RBs represent a perfect environment for housing various fish species and are crucial marine ecosystems associated with a rich variety of flora and fauna. In the Mar Piccolo basin, a part of marine sector of Taranto city, a RB with an extension of 1.5 km was recently discovered at a depth range from 0.5 m to 2 m (Pierri et al., 2024).

Mar Piccolo is a unique environment due to its exclusive morphology, which defines its temperature, salinity and hydrodynamics features. All these parameters influence RB development and the characteristics of individual nodules.

Rhodoliths were studied describing the outer and inner features of each nodule. Our study characterized rhodoliths development environment and nodules morphological parameters as a product of environment peculiarity. The nuclei discovered in the rhodolith nodules are classified into three main categories: bioclastic nucleus, lithic nucleus and anthropic nucleus. Chemical analyses were performed on anthropogenic nuclei to determine their origin and nature.

In Taranto city, numerous industries and factories are responsible for the high level of pollution in air, water and soils. In this context, marine environments are the final sinks of various human materials and chemical pollutants.

Mar Piccolo rhodoliths are very interesting because: 1. they develop in a very shallow depth range. In the Mediterranean Sea, only two others have been discovered with these features, one in Îles Kuriat in Tunisia (CAR/ASP-PNUE/PAM, 2011) and the second one in Stagnone di Marsala, Trapani, Italy (Mazzola & Vizzini, 2005); 2. Red algae have the ability to isolate and separate any type of material from the surrounding environment. This ability allows them to reduce the dispersion of pollutants from anthropogenic materials and to promote an increase of biodiversity.

CAR/ASP—PNUE/PAM. (2011) - In: Langar, H.P., Bouafif C., Charfeddine A., El Asmi S., Limam A., Ouerghiet A., & Sghaier Y.R. (Eds.) Habitats marins et principales espèces des îles Kuriat (Tunisie) - etude complémentaire: formations naturelles d'intérêt pour la conservation. Tunis: CAR/ASP—Projet MedMPAnet 36 pages + annexes.

Mazzola A. & Vizzini S. (2005) - Caratteristiche ecologiche, fattori di pressione antropica e sviluppo sostenibile di un ambiente costiero mediterraneo (Stagnone di Marsala, Sicilia occidentale). Naturalista Siciliano, S.IV, XXIX(5), 37-65.

Pierri C. et al. (2024) - Invertebrate diversity associated with a shallow rhodolith bed in the Mediterranean Sea (Mar piccolo of Taranto, south–east Italy). Aquatic Conservation: Marine and Freshwater Ecosystems, 34(1), https://doi.org/10.1002/aqc.4054.

The Cassian Dolomite demise: basinal insights on the carbonate platforms' agony (Dolomites, Late Triassic)

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Keywords: carbonate platform demise, Carnian Pluvial Episode, paleoclimate.

In the Early Carnian a perturbation of the carbon cycle marked a worldwide biological and climate crisis known as Carnian Pluvial Episode (CPE) (234-232 Ma).The large injection of light CO_2 in the atmosphere-ocean system caused several environmental changes: a general global warming, a transition to more humid climatic conditions, demonstrated by weathering indexes, and a consequent intensification of the hydrological cycle with the arrival of large quantities of siliciclastic material in the basins. One of the major consequences of this climatic perturbation is the global crisis of the Early Carnian carbonate systems. A well known example in the Western Tethys is the demise of the Cassian high-relief, rimmed carbonate platforms and their gradual transition from a microbial dominated carbonate factory to a skeletal dominated one. To clarify the complex dynamics and the interweaving factors that ultimately led to these platforms demise a basinal perspective may be helpful. The basinal deposits of the lower Carnian are represented by the S. Cassiano Fm, coeval with the Cassian platforms, and the Heiligkreuz Fm, which lies above. The crisis of the platforms, synchronous with the first NCIE (upper T. aonoides zone/A. austriacum ammonite zones boundary) of the CPE, is lithologically testified by the gradual disappearance of bio-calcarenite intercalations which also marks the transition between the two formations. The basal part of the Heiligkreuz Fm, represented by the Alpe di Specie mb, reflects the evolution of the platform demise, during which the microbial production was not totally wiped out but mainly moved towards the slopes, where numerous small mounds nucleated. After this critical period a transition from the microbial component of the high-relief carbonate systems to a skeletal component of homoclinal ramp is testified by the platform debris shed in the basin. Following upwards, a relatively thick interval of hybrid arenites and sandstones attests to a strong terrigenous input (A. austriacum zone, Borca Mb). The sharp transition is strictly linked to a significant relative sea-level fall, occurred in a short time span, which also exposed the Cassian platform top, developing karst surfaces.

The performed high resolution stratigraphic study on the available Carnian basinal sections of the Dolomite's region allowed us to better discriminate the stages of these platform-basin systems complex evolution.

Facies analysis of a Cretaceous peritidal carbonate succession cropping out at Cava Porcili (Minervino Murge, southern Italy)

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Keywords: Cretaceous, carbonate platform, cyclic sedimentation.

Cava Porcili is a limestone quarry located south of the town of Minervino Murge in the western Murge area (Apulian foreland, southern Italy). It is one of the most important quarry in Puglia, due to the discovery of six well-preserved karst caves. Despite its relevant geological importance, it remains quite underexplored for stratigraphic and sedimentological topics. In order to fill this gap, the preliminary results of the stratigraphic and sedimentological study are shown.

The succession cropping out along the quarry wall formed in the inner sector of the Apulia Carbonate Platform that, during the Cretaceous, was situated at a palaeolatitude of 20 to 25° N, along the southern margin of the Tethys Ocean, and was part of the continental Adria Plate. It is about 90 m, consists of well-bedded peritidal and shallow subtidal carbonate lithofacies associations, and belongs to the Calcare di Bari Fm. Although facies analysis testifies that this succession formed in protected shallow-water environments, the occurrence of continental silty clays, interbedded with carbonates, suggests that carbonate sedimentation suffered periods of temporary interruption due to subaerial exposure. Moreover, the vertical organization of lithofacies in beds and bedsets shows a clear cyclic recurrence of both depositional and early diagenetic features. This stratigraphic architecture suggests that relative sea-level changes were probably the main controlling factor of carbonate sedimentation.

This succession is preliminary referred to the upper Albian-lower Cenomanian based on the existing literature (Iannone et al., 1979).

Iannone et al. (1979) - Considerazioni stratigrafiche, sedimentologiche e micropaleontologiche su una successione cenomaniana del "Calcare di Bari" (Murge occidentali). Studi Geol. e Morf. sulla Reg. Pugliese, Ist. Geol. Paleont. Univ. Bari, 9, 28 pp.

The Eocene carbonate deposits of the Gargano Promontory and Tremiti Islands (southern Italy)

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Keywords: Eocene, Gargano Promontory, Tremiti Islands.

The stratigraphic framework of the Eocene deposits of the Gargano Promontory and Tremiti Islands, belonging to the Apulia Carbonate Platform (ACP), has been previously described in literature in numerous works since the late18th century (e.g. Tellini, 1890). These deposits are located in three clearly distinct sectors respectively in the south-eastern Gargano, south of Mattinata (Monte Saraceno), in the north-eastern Gargano, along the coast between Peschici and Vieste, in the Tremiti and Pianosa Islands (Morsilli et al., 2021 and references therein). In particular, previous stratigraphic studies, combined with recent findings on the carbonate factory change occurred during the middle to late Eocene epoch, highlight that this area represents an important stratigraphic archive comparable to worldwide coeval systems (Morabito et al., 2024).

The northern sector, characterised by the Peschici Formation, has been interpreted as a more distal setting. It consists predominantly of alternations, often affected by slumping, of pelagic mudstones with planktonic foraminifera and resedimented deposits, such as calciturbidites and breccia bodies with abundant Larger Benthic Foraminifera (LBF) and clasts with corals and rudists, resulting from the dismantling of Cretaceous and Eocene units.

In the southern sector, on the other hand, the shallow-water to basinal deposits belonged to the Monte Saraceno Sequence are spectacularly exposed and well documented. In particular, the upper intervals of the succession, which are characterised by a sharp transition from nummulitic clinoforms to coral facies, have recently been studied in order to explain their palaeoecological and palaeoclimatic significance (Morabito et al., 2024).

Furthermore, the Tremiti Islands, situated 20 km north of the Gargano Promontory, are mostly characterized by shallow-water settings with abundant larger benthic foraminifera covered by coral-rich facies. Unlike the upper intervals of the Monte Saraceno Sequence, corals in this area exhibit high variability in species and morphology (Morsilli, 2004).

Hence, the exposed Eocene formations on the Gargano Promontory and the Tremiti-Pianosa Islands offer insights into a range of depositional environments, spanning from shallow-water to slope-basin settings, constituting a valuable stratigraphic archive. The objective of this study is to reassess the interpretations of these diverse deposits and to explore their geological significance.

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Unraveling the evolution of the Apulia Carbonate Platform and its sedimentary dynamics

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Keywords: Apulia Carbonate Platform, carbonate systems, sedimentology, stratigraphy.

The Apulia Carbonate Platform (ACP) stands out as one of the enduring carbonate platforms within the Tethys realm, persisting over an extensive period from the Triassic to the Miocene, punctuated by some hiatuses. Its outcropping succession, spanning from the Upper Jurassic to the Miocene, observable across the transect from Maiella to Salento, along with its submerged portion in the Adriatic offshore, offers a window into the platform's evolutionary history (Bosellini et al., 1999; Bernoulli, 2001).

This platform underwent varied growth dynamics, including progradation, aggradation, and retrogradation, alongside significant shifts in profile driven by evolving biota, environmental changes such as Oceanic Anoxic Events (OAEs), and regional or local factors. These transformations led to notable fluctuations in sediment deposition patterns, bypassing, and erosion along the slope, resulting in a diverse array of inner-platform, margin, and deep-water resedimented carbonate facies, each reflecting unique stratal architectures (Eberli et al., 1993; Morsilli et al., 2021).

The ACP was only partially affected by the orogenic phases that have characterized the broader region, allowing for the direct observation of original geometric relationships and various facies from the inner platform to contemporaneous basin deposits. Furthermore, the eastern margin visible only in Maiella and Gargano, along with the seismic profiles available along the Adriatic offshore, facilitates the reconstruction of the platform's physiography and its spatio-temporal evolution.

In contrast, the western margin of the platform is currently buried beneath the allochthonous elements of the Apennine chain, and limited knowledge stems from intense petroleum exploration leading to the discovery of the Val D'Agri fields. The western extent of the platform and its relationships with the Lagonegro-Molisan basin and the adjacent Apennine Carbonate Platform are not entirely understood.

The main goal of this study is to provide a comprehensive review of the development and evolution of the Apulia Carbonate Platform, focusing on its stratigraphic and sedimentological attributes from outcrops to seismic profiles along the Adriatic offshore. The intricate interplay of factors influencing its development, ranging from biotic evolution to environmental changes, emphasizes the necessity for further investigation to fully understand the complexities of this long-lasting carbonate system.

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Lower Messinian *Halimeda* bioherms from the Mediterranean area: new insights on the controlling factors

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Keywords: Halimeda bioherms, Messinian, Mediterranean.

Halimeda bioherms are gaining increasing attention in the scientific community due to their significance as carbonate producers and as a stratigraphic and paleoecological archive. Currently, the genus *Halimeda* thrives in both tropical and temperate environments, significantly contributing to carbonate sediment production due to its rapid calcification processes. *Halimeda* can form localized or extensive multi-kilometric bioherms, exemplified by those observed in the northwestern part of the Australian Great Barrier Reef and other tropical areas in the Caribbean and Indian Ocean.

Despite their prevalence in today's oceans, the documentation about *Halimeda* bioherms is scarce during the Cenozoic, showing a discontinuous stratigraphic distribution. Specifically, these bioherms are primarily described in carbonate Messinian pre-evaporitic successions in a few locations around the Mediterranean Sea, even though their first occurrence as reef builders dates back to the Oligocene period (Fournier et al., 2024).

Here we present a comparison of data carried out from stratigraphic and sedimentological analysis conducted on *Halimeda*-rich deposits from three significant sites within the Mediterranean region during the pre-evaporitic Messinian period: the Salento Peninsula (southeastern Italy), the Sorbas and Nijár Basins (southeastern Spain), the Heraklion Basin (Crete Island, Greece).

From field observations, it emerged that the *Halimeda*-rich deposits occurring in the Neogenic basins of southeastern Spain (Braga et al., 1996) and in the Heraklion Basin on Crete Island (Brachert et al., 2007) have developed in a similar mixed carbonate-siliciclastic depositional context. They are found in many locations both as large, isolated mound-shaped bodies and as extensive resedimented layers. The two *Halimeda* deposits of the Salento Peninsula (Bosellini et al., 2002), on the other hand, besides being smaller in size, have developed in a semi-enclosed environment with prevalent carbonate deposition and are located on the reef slope.

The integration of extensive field work, thin section analysis and taphonomic assessment on algal thalli allowed the identification of the main facies. The *Halimeda* deposits occurring in the three key areas exhibit more or less the same facies, predominantly represented by *Halimeda rudstones-floatstones*, along with abundant encrusting organisms like crustose red algae, vermetids/serpulids and acervulinids.

As the remarkable presence of *Halimeda* in the lower Messinian successions of the Mediterranean area is more significant than previously documented, the aim of this study is to shed light on the controlling factors responsible for the growth and development of this algae in the Mediterranean region during this specific stratigraphic interval, and to compare this fossil depositional systems with modern and extensive ones currently thriving in the tropical belt, specifically in the Great Barrier Reef, in order to obtain paleoenvironmental and paleoclimatic information.

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Marlstone pseudo-desiccation cracks: an enigmatic sedimentary structure in the Early Triassic Feixianguan Formation in South China

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Keywords: pseudo-desiccation cracks, network structure, Feixianguan Formation.

Thin-bedded marlstones in the second member of the Feixianguan Formation, Early Triassic, in the upper Yangtze region, northwestern South China, display pseudo-desiccation cracks of uncertain origin. Field survey show that pseudo-desiccation cracks developed both in the Yangtze carbonate platform margin and platform interior, frequently occurring in laminated or channel-shaped beds 2-10 cm in thickness. At the macroscopic observation, cracks can display quadrangular to pentagonal shape and give origin to reticulate pattern. In vertical cut sections, pseudo-desiccation cracks cut through the marlstone with high angle, and do not display "V" or "U" shape that is instead typical of structures like mud-cracks. Observation in thin section, scanning electron microscope and energy dispersive spectrum analysis show that sparry calcite veins with occasionally forked ends cut through mud clasts and bioclasts in the positions where pseudo-desiccation cracks developed. Carbon and oxygen stable isotopic analyses display δ13C and δ13O values of calcite veins from -14.40 ~ -15.98‰ and -9.99 ~ -10.54‰ respectively, which are lower than those of the marlstone matrix (δ13C and δ13O values of -0.02 ~ 0.61‰ and -9.28 ~ -5.89‰). This indicates that calcite veins should be formed during the diagenetic stage and suggest that pseudo-desiccation cracks are not syn-depositional structures. Therefore, a model is proposed that pseudo-desiccation cracks were formed under diagenetic compaction and the influence of difference hardness and thickness of rock-layers combination, then pressure solution lead calcium carbonate fluid into the cracks and formed calcite veins. In conclusion, the identification of pseudo-desiccation cracks as diagenetic product could be of reference significance for the interpretation of the origin of reticulated limestones.

The record of paleoenvironmental change in Mesozoic carbonate platforms of Western Tethys: some half-baked ideas

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Keywords: carbonate platform, Mesozoic, reefs.

The circum-Mediterranean region features a complete, substantially continuous and areally widespread record of Mesozoic carbonate platforms, which recorded profound changes in carbonate production, skeletal and non-skeletal associations and depositional geometries. This region was located about the intertropical belt throughout the Mesozoic, hence, palaeolatitudinal changes were unlikely to cause such modifications, leaving climate, palaeoceanography and seawater chemistry as potential main drivers.

The Mesozoic began with the end-Permian mass extinction, that reset Paleozoic communities of carbonate producers. This episode of mass extinction was associated with a disruption of the carbon cycle that continued for most of the Early Triassic. This time of prolonged perturbation is represented in the Southern Alps by carbonate ramp and clastic coastal deposits with common ooids. Afterwards, Middle Triassic microbial carbonate platforms developed significant relief and became increasingly large.

At least three major perturbations of the carbon cycle impacted on carbonate platform systems after the P/T mass extinction; in the Carnian, between the Rhaetian and the Triassic-Jurassic boundary and at the Pliensbachian-Toarcian boundary. Each of these major events coincided with changes of the shallow water carbonate factories, interrupting the growth of high-relief carbonate platforms. Carbonate production, however, never really ceased and, at times, accumulations of oolites are observed at these events. The response of carbonate platforms to Cretaceous carbon cycle perturbations and related OAEs seem instead less dramatic.

Along with this stepwise evolution, some long-term trends seem to emerge in the carbonate record: a progressive change from mainly microbial carbonates during the Triassic and Early Jurassic, to mainly skeletal by the end of the Cretaceous, and from relatively abundant marine cements and oolitic limestones in the Triassic and Jurassic, to Late Cretaceous deposits virtually devoid of these components. Such patterns occurred along with the steady rise in the abundance of calcareous plankton in Mesozoic oceans, and secular changes in seawater chemistry that led to a switch from the Triassic aragonite-sea to the Cretaceous calcite-sea.

With a few notable exceptions, studies on Mesozoic carbonate platforms of the circum-Mediterranean region focused on specific intervals. We suggest that a more comprehensive view at the time scale of the whole Mesozoic Era may offer insights on processes that impacted greatly on carbonate depositional systems, and that could not be captured by detailed studies on shorter time scales.

Diagenetic and tectonic history of the Upper Triassic, Dachstein-type margin of the Panormide Carbonate Platform (Sicily, Southern Italy)

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Keywords: carbonates, diagenesis, Triassic.

Dachstein-type carbonate platforms bordered the Neotethys Ocean in the Late Triassic, typically developing high-energy reef complexes dominated by corals and calcisponges seaward and inner platform facies landward, where Dolomia Principale-Hauptdolomit inner platform facies were deposited. Boundstone and framestone are characterized by widespread reef cavities filled by multiple generations of calcite cements, as observed in the Upper Triassic margin of the Panormide Carbonate Platform, well exposed in the Palermo Mountains (Sicily, Southern Italy). This platform preserves a sponge-dominated reef complex grading to upper slope massive carbonate breccia, known as *Pietra di Billiemi*. This breccia exhibits not only a complex network of primary porosity but also different sets of fractures (secondary porosity) filled by multiple generations of calcite cements and polychrome carbonate silts (black, white, red, yellow, and less often blue). Transmitted light, cathodoluminescence (CL), fluorescence (FL), and stable isotope analyses (C and O) have been performed on these fills in order to reconstruct the diagenetic history of the *Pietra di Billiemi*. This integrated approach allowed to define and characterize a succession of diagenetic events. Different generations of cements, occurring both in reef cavities and fractures, were identified in FL, while most of them were non-luminescent in CL. First generation of calcite cement (P1) consists of isopachous cloudy radiaxial calcite, dark green in FL, showing the same features both in reef voids and early fractures, thus suggesting an early (syndepositional) origin of primary fracture set (F1). The following P2, bright green in FL, shows clean/cloudy scalenohedral morphology and is related to a second set of subtle fractures (F2) that crosscut P1 and precipitate in persisting voids both within F1 and growth framework (GF), when not completely occluded by P1. P3 shows clean scalenohedral morphology and dark green fluorescence. It is related to a third set of fractures (F3) crosscutting P1 and P2 and filling remaining voids of GF and F1 fractures. P4, clean scalenoedral, is observed only in youngest fractures (F4) showing minor displacement and is bright green in FL. After P4 precipitation, reef voids and fractures can be completely occluded or, when still open, filled by clean blocky calcite, bright green in FL (P5). Polychrome silts (P6; bright to dull luminescent in CL and showing variable tones of green in FL) may follow; clean blocky calcite (P7, black green in FL) eventually fills remaining voids. Data from all calcite cement generations are consistent with Late Triassic marine values both for δ18O and δ13C (-0.5‰ - 1.5‰ and 2.0‰ - 3.5‰). Minor cement dissolution is associated with yellow silt and observed δ18O and δ13C values (P6; 4.7‰ - -4.6‰ and -4.0‰ - -1.2‰) may suggest influx of meteoric water.

Exploring shallow-water carbonate precipitation rates through geological time

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Keywords: carbonate precipitation rates, carbonate platform, ocean saturation state.

Carbonate precipitation is a key part of the global carbon cycle and the rate at which this process takes place plays a pivotal role at many levels, from the production of shells and mineralized parts in calcifying organisms to determining the formation and evolution of carbonate platforms. To which extent and how biology and seawater chemistry steer carbonate precipitation, however, is still a matter of debate. We tried to explore the link between carbonate production rates on shallow water platforms in the geological past and some of the main parameters of the carbonate system in seawater, focusing in particular on carbonate saturation state (Ω). We examined 12 stratigraphic intervals of different tropical carbonate platforms, ranging from Devonian to Miocene in age, and estimated for each the carbonate production rate (G) as a mass of carbonate precipitated on a unit area in the unit time. As such, our Gs differ from the usually calculated accumulation rates which are instead computed as thicknesses on unit time and that, being influenced by accommodation, can be considered as crude estimates of actual carbonate production rate. Computing G in the fossil record poses challenges that range from the degree of preservation of the examined carbonate platform to the selection of the stratigraphic interval. Having such estimates and referring to modeled Ω in the geological past (Ridgwell, 2005) allows comparison to laboratory (Burton & Walter, 1987; Zhong & Mucci, 1989) and fields studies (e.g. Langdon et al., 2000) that investigate the influence of Ω on carbonate precipitation rates in abiotic and modern natural systems. In such comparison we also considered the influence of temperature – a parameter that strongly influences carbonate precipitation rates – and the issue represented by the fact that the impact of hiatuses in the completeness of the sedimentary record increases with the length of the time interval that is considered. A Generalized Linear Modeling approach (GLM) was applied on a dataset comprising fossil, modern and laboratory data (250 observations) in order to assess the importance and the mutual interaction of the proposed predictors on the carbonate precipitation rates. Results suggest that Ω is the most influential factor in determining the carbonate precipitation rates and a Ω/G relationship of fossil examples – which are characterized by the dominance of different carbonate precipitation modes – can be modeled by a relationship which is close to that that can model Ω/G of shallow water tropical carbonate systems and that both these latter share commonalities and differences with the empirical kinetic law that links carbonate precipitation rate and saturation state in abiotic systems. These results may help shedding light on the role of biotic influence and Ω in driving carbonate precipitation in the oceans through geological time and may offer insights for predicting future responses of marine carbonate ecosystems under changing environmental conditions.

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Cretaceous cyclic peritidal carbonates of the Apulia Carbonate Platform (Apulia, southern Italy) in a hierarchical sequence-stratigraphic perspective: a case study from the Murge area (the Giovinazzo sea-cliff section)

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Keywords: peritidal facies, relative sea-level change, unconformity zone.

Cretaceous cyclic peritidal carbonates form the bulk of the Apulia Region in southern Italy and represent the vestiges of the Apulia Carbonate Platform (Ricchetti et al., 1988). In order to show, from a sequence stratigraphic perspective, the stratigraphic architecture of peritidal carbonates, the 17 m thick Albian Giovinazzo sea-cliff section was studied at a cm detail, aiming to: i) describe cyclic facies organization in beds and bedsets; ii) reconstruct the relative sea-level curve and its evolution over time; iii) interpret the long-term evolution of the accommodation space in terms of sequence stratigraphy. The hierarchical stacking pattern of facies in beds and bedsets reveals Milankovitch cyclicity (Spalluto, 2012). As a working hypothesis, elementary sequences are assumed to represent the precession cycle (~20 kyr), and small- and medium-scale sequences the short (~100 kyr) and long (~400 kyr) eccentricity cycles, respectively. Four different types of elementary sequences (condensed, catch-down, catch-up and give-up) are recognized and interpreted in terms of relative sea-level changes to reconstruct the relative sea-level curve of the entire succession. The envelope of the reconstructed relative sea-level curve is used to represent the long-term accommodation change on the platform, that covers a time span of approximately 1.8 Myr. Most of this time was spent in subaerial exposure, as approximately 1.2 Myr was predicted to be condensed in a stratigraphic interval encompassing both the sequence-boundary zone/falling stage deposits and the lowstand deposits. Moreover, it was interpreted that about 2/3 of the total thickness of the studied succession was formed in only 280 kyr and consist of both transgressive and maximum-flooding deposits. The main implication of this study is that peritidal succession unconformities do not necessarily correspond to single surfaces but, rather, to very amalgamated intervals or unconformity zones. Moreover, based on biostratigraphic constraints, there is a correlation between the unconformity zone of the studied succession and the third-order KAl4 sequence boundary of the Cretaceous eustatic cycle chart (Haq, 2014).

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The recovery of carbonate platforms after the End Triassic Mass Extinction: new data of a Lower Jurassic succession from south-western Sicily

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Keywords: shallow water limestone, carbonate productivity, Lower Jurassic.

The End Triassic Mass extinction (ETE) event was one of the big five mass extinctions that caused the disappearance of more than 70% of marine and terrestrial species. Due to the strict connection with biological activity, the shallow water carbonate environments were mainly involved, suffering the marine acidification and the warming trend recorded at the end of Triassic. After the extinction event, the carbonate sedimentation continued in the shallow water realm, however, the biostratigraphy of Lower Jurassic strata is poorly represented. The microfacies analyses of a Lower Jurassic succession outcropping in southwestern Sicily allow to describe the progressive recovery of the benthic foraminifera community in a sector of the Western Tethys.

The succession consists of peritidal cycles characterized by an alternation of three main lithofacies. The low frequency of the intertidal stromatolitic and supratidal marly horizons allows to belong these lithofacies to an open lagoon bordered by oolitic/bioclastic sandy margins. The microfacies analyses allow to describe a benthic foraminiferal association covering Hettangian-early Pliensbachian interval. In detail, the benthic foraminifera association allows to divide the Lower Jurassic strata into two subunits. The lowermost unit is characterized by the exclusive occurrence of *Thaumatoporella parvovesiculifera* and *Aeolisaccus* sp. The second unit is characterized by an association of *Thaumatoporella parvovesiculifera*, *Aeolisaccus* sp., calcareous algae (*Paleodasycladus mediterraneus*), *Siphovalvulina* sp. and larger benthic foraminifera as *Mayncina termieri* suggesting an increase of taxonomic diversification. The fossil association belonging to the survival unit is characterized by r-strategist taxa capable of living in eutrophic conditions representing the survival phase after the ETE. The occurrence of the larger benthic foraminifera indicates more stable oligotrophic conditions suggesting the recovery phase of the carbonate productivity.

Response of a carbonate platform to the Cenomanian-Turonian Boundary Event: the Akrabou Formation of Southern Morocco

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Keywords: Cenomanian-Turonian Boundary (CTB), OAE2, Moroccan North Saharian Platform.

The Late Cretaceous was one of the warmest periods in Earth history, with the acme reached near the Cenomanian/Turonian Boundary (CTB), corresponding with the highest sea-level stand of the Phanerozoic and one of the most important Oceanic Anoxic Events in the geological record (OAE2). This major eustatic sea-level rise led to the flooding of huge portions of continental margins, recorded all along North Africa, from Egypt to Morocco, by the emplacement of a neritic epicontinental carbonate platform known as North Saharian Platform.

Within this context, our research has been focused on Southern Morocco between the Central High Atlas and the Anti-Atlas mountain ranges, where continental sedimentation is interrupted near the CTB by a marine ingression, as witnessed by the development of an open-marine carbonate platform represented by the Akrabou Formation (Ettachfini & Andreu, 2004).

This succession, up to 100 m thick in the more subsiding areas, is characterized by an alternation of bioclastic floatstone and rudstone and laminated mudstones and marls. In the lower portion of the unit, oyster-rich beds are frequent, constituting part of the first bioclastic interval. Upward, the presence of laminated beds, chert lens and carbonate nodules with ammonites underlines a deepening of the system. Above it, a new shallowing upward trend is observed, with the return to more bioclastic levels interbedded with abundant chert plagues and ferruginous surfaces. On top, the re-establishment of continental conditions is recorded by post-Turonian sandstones and siltstones.

Stable isotope geochemistry (d13C and d18O) was performed on bulk carbonates and oyster shells of the Akrabou Fm. Cements were analyzed as well, to rule out the diagenetic signal. A net d13C positive shift of about +3 ‰ VPDB was identified in the sections analyzed, aligned with the values reported in literature for OAE2 (Jarvis et al., 2006). The d13C positive shift take place in the lower portion of the unit, just after the marine ingression, in correspondence with the first bioclastic interval and below the laminated interval. Further up in the succession, the d13C isotopic values decrease to around -2 ‰ VPDB, concurrently with the beginning of the laminated facies, interpreted as the maximum flooding interval. The isotopic signal allowed the correlation between sections at different subsidence rates.

The OAE2 represented a significant stress factor for the epicontinental platform, as evidenced by the temporary shift to deeper environments. However, the crisis of the platform was just transient, and did not determine the shutdown of the benthic carbonate community, as shallow-water bioclastic facies quickly restored after the shorth deepening episode.

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S38.

Frontiers in the regional geology of the Apennines: a multidisciplinary perspective

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A new proposal for the stratigraphy of the "Tolfa unit" (CARG project, 364-Bracciano)

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Keywords: External Ligurian Domain, sedimentary mélange, Tolfa Unit.

The Tolfa Unit belongs to the eastern succession of the External Ligurian Domain. In northern Latium, the allochthonous succession of the Tolfa Unit tectonically overlays the Meso-Cenozoic Tuscan and Umbria successions. Recent fieldwork conducted as a part of the geological survey for the CARG Project 364-Bracciano provided important insights into the stratigraphic setting of the Tolfa Unit. A comprehensive approach, based on the use of high-resolution imagery, FieldMove software and biostratigraphic analyses, significantly changed the previously known geological and stratigraphic framework of the sedimentary successions outcropping in the western part of the 364-Bracciano sheet. In the study area, stratigraphical and geometrical evidence reveal the presence of an extensive mega sedimentary mélange (OMF) ("il Casone-Monte delle Fate" Olistostrome; Cipollari et al. 2024), lying on top of the Mignone clays (AGM). These latter, in turn, stratigraphically overlies the Flysch della Tolfa (FYT). The calcareous nannofossils biostratigraphic analyses constrain the sedimentary mélange of "il Casone-Monte delle Fate" to the upper part of the middle Bartonian (middle Eocene) and the Mignone clays to the lower part of the middle Bartonian.

Based on these results, we propose a new stratigraphic framework for the Tolfa Unit. Specifically, we suggest the Mignone clays to be formally assigned to the rank of formation. These clays overlie the top of the Flysch della Tolfa (FYT), which has been distinguished in two members: the lower Eocene marly-limestones and yellowish marls of Fosso Anitrella member (FYT2), and the Paleocene - Upper Cretaceous p.p. calcareous argillaceous succession of Poggio Vivo member (FYT1). Finally, the Pietraforte Fm. (Upper Cretaceous p.p.), stratigraphically located beneath FYT1, represents the lowermost stratigraphic unit of the allochthonous succession of the Tolfa Unit.

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The geochemical domains map of the Volturno river basin (South Italy): usefulness and comparison with the geological map

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Keywords: geochemical domains, stream sediments, machine learning.

To deepen our understanding of the phenomena that drive the chemistry of environmental compartments (such as soil, water, and stream sediments), it is crucial to identify the unique geochemical fingerprints of both natural and anthropogenic sources of potentially toxic elements. Historically, geological maps have been used to understand the geochemistry of these environments better, even though geological units are not classified chemically. This study employs a combination of Compositional Data Analysis (CoDA) and machine learning techniques, along with geolithological information, to minimize uncertainty in defining geochemical domains and their reference values for 16 chemical elements. We use, as a case study, geochemical data from 887 stream sediment samples collected across the Volturno River catchment basin in Southern Italy, an area of significant lithological heterogeneity. Thus, we have identified five geochemical domains, or predominant components influencing stream sediments geochemistry: a) carbonatic, b) siliciclastic, c) pyroclastic, d) volcanic, and e) mixed. The predominantly carbonate domain is characterized by sediments rich in Ca, Mg, and Sr and poor in Th, La, Ba, Ga, K, Na, and Al. The predominantly siliciclastic domain shows a relative enrichment in Co, Ni, Fe, and Mn. Both the siliciclastic domain and the volcanic domain include sediments generally rich in Th, La, Ba, Ga, K, Na, and Al. Pyroclastic deposits are enriched in high-mobility elements (K, Na, Mg, Ca), while older volcanic rocks are enriched in low-mobility elements (Th, La, Ti, Ga, Mn). Mixed sediments, derived from a combination of volcanic and sedimentary material, do not show any particular enrichments. The area of each geochemical domain was defined by joining together the basin areas in which the samples belonging to that specific domain fall. Reference values for the geochemical background are calculated and assigned to samples based on their geochemical domains. The results of this study highlight the need to supplement the geological map with a map of geochemical domains, especially in areas with pyroclastic cover and sedimentary successions that show significant lithological variations.

The paleontological heritage and innovative communication modalities for the territorial development

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Keywords: paleontological heritage, territorial development, mixed reality.

We present the preliminary results from the research project (INSITE) - PRIN 2022 founded by MUR – Ministero dell'Università e della Ricerca. This study focuses on the consideration that geoheritage can act as a driver factor for territorial sustainable development also for cultural and slow tourism, particularly in inner areas. Two sites in Campania region have been considered as case studies because of their paleontology, paleoanthropology, geology, and geophysics significance The site of Pietraroja (PTJ), located in Benevento's province, is the place where a baby dinosaur, *Scypionix samniticus*, was found, drowned in a tropical lagoon about 110 Ma ago, known in the world for its perfect fossilization (Dal Sasso & Maganuco, 2011). The site known as "Le Ciampate del Diavolo" (LCD)" is in Caserta's province and preserves animal and human footprints, very likely referable to *Homo heidelbergensis* or archaic *Homo neanderthalensis*, which are among the oldest and rarest in the world (Mietto et al., 2022). Considering these two paleontological sites as part of the whole system of the cultural heritage supply in Campania, the project INSITE considers two primary levels for their promotion. On one hand, it tries to define a global design to help residents and social parts of the territorial context in which the sites are located realize the uniqueness in which they live.

On the other hand, based on the potentialities of the innovative technologies, the project proposes to develop new models of knowledge by using immersive technologies for virtual, augmented, and mixed reality models and communication modalities supported by widely used devices. Referring to the knowledge model, the use of GIS-based informative technologies allows for the systematization of information in the shared database and the construction of a knowledge model applied to cultural contexts and paleontological sites as a cultural part of the heritage. Referring to the elaboration of digital models, the two pilot sites could be elaborated in mixed reality environments (AR/VR) and, thus, propose additional methods of use than the on-site fruition.

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Multi-proxy analyses to reconstruct the environmental evolution through the composite section cropping out at San Giuliano Lake area (Matera, Southern Italy)

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Keywords: multi-proxy analyses, enviromental recostruction, San Giuliano Lake (Matera).

A geological field mapping in the area near Lago San Giuliano (Matera-Italy), and sedimentological, micropaleontological, paleoecological and palynological analyses of a composite section (Meo et al., 2024). These analyses were performed to reconstruct the depositional environment of a fossil cetacean was discovered. The sedimentological analyses, carried out on samples taken from a borehole (Giuli 1) and from a stratigraphic section (Assiolo) identified in the Giuli 1, silt and silty clay that in the upper part of the succession, show the presence of silty-sandy sediments with bioclastic fragments. The Assiolo section, showed silt and clayey silt sediments. The depositional units have been identified and interpreted by means of the sequence stratigraphy (Catuneanu et al., 2011) that provides the context within which to interpret the evolution of depositional systems through space and time. In this framework the SGL stratigraphic succession has been inserted in a in stratal stacking patterns to the responses to varying accommodation and sediment supply through its time span of deposition. The succession is Early Pleistocene in age for the presence, from the bottom, of the nannoplankton species *Reticulofenestra asanoi* CN 13b Biozone. The LO of *Helicosphaera selli*, dated 1.2/1.1 Ma (Raffi & Rio, 1979; Di Stefano et al., 2023) occur in the middle part of the succession at 101, 8 msl and the LCO of *R. asanoi*, at ≈ 0.91 Ma, in the upper part were also detected. The integrated study conducted on the benthonic foraminifera and ostracods assemblages of San Giuliano Lake composite section documented the occurrence, along all the section, of the opportunistic species group, together with episodes of the hypoxic group prevalence, indicating phases of oxygen depletion at the bottom, which are interrupted by sporadic events of bottom re-oxygenation, as evidenced by the increase in abundance of superficial microhabitat oxic taxa, typical of relatively high oxygen and oligotrophic bottom conditions. These patterns allow to define the depositional environment characterized by repeated events relatively high organic matter and low oxygen contents of the bottom water masses and which varies in depth from 600 m to 1000 m from the base of the section up to 1020 ky (≈ 3.5 meters in the Giuli1); from 1020 upwards the depths show a shallowing trend from epibathyal to circalittoral environments. The regionally extinct tree taxa *Tsuga, Cedrus, Pterocarya,* and *Zelkova,* with sporadic appearances of *Cathaya*, *Picea, Carya*, *Liquidambar*, and *Taxodium* type, suggest a late Calabrian age, consistent with nannoplankton data.

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Oblique plate collision remnants of the Southern Apennines-Calabrian Arc boundary revealed in the offshore Bradano Basin (Ionian Sea - Central Mediterranean)

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Keywords: oblique convergence, orogen translation, Southern Apennines, Calabrian Arc.

The Bradano Basin is a foreland basin lying along the Africa-Apulia/Eurasia plate boundary. It serves as a natural recorder of Plio-Pleistocene tectonic processes because of its physiography and location between the Southern Apennines (SA) and the Calabrian Arc (CA).

Integrated analysis of seismic reflection profiles, exploration well logs, and seafloor bathymetry allowed us to unravel the basin architecture and the interplay between tectonics and sedimentation, providing stratigraphic and structural evidence on deep and shallow morpho-structural processes (Basso et al., 2021). Since Pliocene, two major tectonic events affected the area and controlled the development of three interregional unconformities (MPCU – Middle Pliocene Unconformity; EPSU – Early Pleistocene Unconformity; MPSU – Middle Pleistocene Unconformity) which bound four sedimentary sequences (P1, P2, P3, P4 of Zecchin et al., 2015).

During Pliocene times, an obliquely convergent margin led to collision between SA and CA along a regional deformation zone which is estimated to be ~10 km wide and ~100 km long and is associated with shelf-to-deep marine turbiditic deposits. Around the Pliocene-Pleistocene boundary (~2.58 Ma or EPSU), a sudden and widespread rearrangement took place. The SA front, along with portions of the earlier obliquely collisional margin, started to move toward the NE along progressively deeper detachments involving the lower Apulia plate. During this second phase, the orogenic wedge initially translated for a distance of ~50 km and, since ~0.78 Ma (or MPSU), started to uplift, shorten and fold the seafloor. This second phase is marked by deep marine deposits in the central part of the basin, clinoforms in the shallower western and northern sectors, and mass transport complexes which still shape the seafloor. On a larger regional scale, our data suggest that the deformation zone developed during the oblique convergence affects the upper plate and is the remnant of a Pliocene transfer zone that accommodates differential retreat of the lower subducting Apulia plate. This remnant and reshaped transfer zone, which is now part of the SA-CA accretionary wedge, had to prosecute in the Tyrrhenian Sea (Jolivet et al., 2021; Vitale & Ciarcia, 2013) where it should be reshaped by back-arc extension.

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The redefinition of the Ligurian Units at the Alps-Apennines junction (NW Italy) and their role in the evolution of the Ligurian accretionary wedge

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Keywords: Northern Apennines, External Ligurian Units, ocean-continent transition zone.

In the sector of the Alps – Apennines junction (i.e., the Monferrato and Torino Hill) in NW Italy, the Ligurian Units are unconformably overlain by a middle-upper Eocene – upper Miocene episutural succession, represented by the Tertiary Piedmont Basin. In contrast to the Northern Apennines, these units have always been described as an upper Cretaceous–Paleogene(?) undifferentiated chaotic complex or mélange, complicating the reconstruction of the Late Cretaceous - Early Eocene tectono-stratigraphic architecture of this sector.

We document that the undifferentiated chaotic Ligurian Units of the Monferrato and Torino Hill consist of three different units that are well-comparable with the Cassio, Caio and Sporno Units of the External Ligurian Units of Northern Apennines. Their internal stratigraphy reflects the character of units deposited in an ocean-continent transition zone between the northwestern termination of the Ligurian-Piedmont oceanic basin and the thinned passive margin of Adria microcontinent. The inherited wedge-shaped architecture of this ocean continent transition zone, which gradually closed toward north in the present-day Canavese Zone, controlled the Late Cretaceous – early Eocene flysch deposition at the trench of the External Ligurian accretionary wedge during the oblique subduction. This favoured the formation of an accretionary wedge increasing in thickness and elevation toward the southeast, from the Monferrato and Torino Hill to the Emilia Northern Apennines. Our results, therefore, provide significant information on both the paleogeographic reconstruction of the northwestern termination of the Ligurian-Piedmont oceanic basin and the role played by inherited along-strike variations (stratigraphy, structural architecture and morphology) of the ocean continent transition zones in controlling subduction-accretionary processes.

Linking the exposed belt to the buried one: preliminary data and results in the framework of the project CARG 160 Pavia

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Keywords: Northern Apennines, Po Plain, transition zone.

The study of complex transition zone between the outcropping front and the buried one of collisional belts usually faces some challenges due to the difficulty in homogenization and correlation of field and subsurface data. An attempt to unravel this complicated relationship, aiming to understand the spatial and evolutionary connection of outcropping units and buried structures, is being pursued in a sector of the Northern Apennines (namely in the central part of the Emilian arc), within the activities for the implementation of the "Foglio 160 – Pavia", as part of the CARG Project. The study area is specifically located at the southeastern portion of the Pavia Sheet, between Casteggio and Stradella (Oltrepo Pavese), where the units exposed in the Northern Apennines outcropping chain slopes rapidly below to the Po alluvial plain. The hill sector includes a Paleocene to Pleistocene sedimentary succession, involved in the SW-NE oriented thrusts and folds of the Apennines front, which can be traced along the western flank of the Emilian arc, currently buried below the Quaternary deposits of the Po Plain where it controlled the syntectonic sedimentation of the Plio-Quaternary sequence (Amadori & al., 2019; Maesano et al., 2024).

In the hill sector, the 1:10.000-scale geological survey activity for the CARG project allowed the collection of a dataset regarding the outcropping units, implemented by the integration with shallow well data provided by local public administrations (Provincia di Pavia, Regione Lombardia), due to the scattered distribution of outcrops and the extensive development of alteration profiles and soils. By contrast, the spatial arrangement of folds and thrusts forming the buried front of this sector of the Northern Apennines below the Po Plain deposits was obtained by a comprehensive 3D reconstruction of the regional scale structures and Plio-Pleistocene unconformities, derived from the integration of well logs and available seismic data (ongoing PHD project by Daniel Barrera Acosta, University of Pavia). Based on this integrated data set, it is possible to carry out several geological cross sections, showing the geometry and mutual relationship of structures and geological units moving from the exposed belt to the buried one.

This work presents a preliminary attempt to correlate and homogenize field and subsurface data, in order to set up a conceptual model of the transition zone between topographic front of the Apennines with its tectonic front and, in perspective, to evaluate the flexural response of the foredeep to the emplacement of the Northern Apennines buried fronts. The obtained conceptual geological model is expected to provide a more complete knowledge of the structural and stratigraphical evolution of the Apennine border, as well as the understanding of the dynamics of frontal chain uplift and foreland basin subsidence and their time/space correlations.

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Late Pliocene-Pleistocene stratigraphic evolution of the Menfi wedge-top basin (South-western Sicily - Italy)

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Keywords: Sicilian foreland basin system, syntectonic sedimentation, CARG Project.

The Menfi basin represents one of south-western Sicily's largest wedge-top basins (WTBs), identified by a broad depression mainly oriented NW-SE belonging to a larger Plio-Pleistocene foreland basin system. This basin lies in the outer sector of the Sicilian Fold and Thrust Belt, which consists of Meso-Cenozoic S-verging tectonic units (Saccense Domain) unconformably overlain by Late Miocene-Early Pliocene and Late Pliocene-Pleistocene WTB deposits (Vitale & Sulli, 1997; Catalano et al., 1998; Gasparo Morticelli et al., 2015; Pucci et al., 2023). The field data and samples used for this work were collected during the geological surveys carried out within the Italian National Cartography Project at 1:50.000 scale-CARG Project (sheets n.628 - "Sciacca" and n.618 - "Castelvetrano"), also supported by the analysis and interpretation of different previous data. Sedimentological and stratigraphic analyses were carried out on different outcrops, integrated by detailed calcareous plankton biostratigraphy (planktonic foraminifera and nannofossils), which allowed the reconstruction of a complete chronostratigraphic framework of the Plio-Pleistocene succession. In detail, the stratigraphic succession of the Menfi WTB is constituted at the bottom by hemipelagic marly clays and sandy-silts, laterally and vertically passing to shallow water biocalcarenites (Marnoso-Arenacea del Belice Fm.), Piacenzian-Gelasian in age. This unit is overlain by hemipelagic clayey marls, alternated with inner shelf bio-calcarenites and sands, of the Agrigento Fm. (Calabrian). Conformably overlying the Agrigento Fm., hemipelagic clays and marls with local intercalation of sands and calcarenites, late Calabrian-Chibanian in age, are present. Lastly, marine terrace deposits and continental deposits (late Chibanian to recent in age) unconformably overlie different terms of the Menfi WTB succession. The stratigraphic succession shows an average S-SW dip direction thickening towards the coast and reaching values greater than 1 km. The depositional geometries highlight the interplay between tectonic and sea-level changes characterised by syntectonic sedimentation during the Late Pliocene-Early Pleistocene. In this period main unconformities were generated followed by the deposition of a continuous Calabrian-Chibanian succession, containing only minor hiatuses.

In conclusion, progressive variations of the accommodation space during the growth phases of the Menfi WTB were observed. Notably, in the central-western part, hemipelagic and neritic conditions persisted until the Chibanian, while towards south-east they ended in the late Calabrian.

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The Oligo-Miocene Carbonate ramp succession of Maiella Mountain, the record of changing oceanographic conditions in the Central Mediterranean

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Keywords: paleoceanography, facies analysis, carbonate ramp.

This study provides a detailed stratigraphic reconstruction of the Oligo-Upper Miocene ramp carbonate sequence exposed in Majella, which is the northern extension of the large Apulian Platform within the Mediterranean region. The performed stratigraphic analysis included a detailed facies analysis integrated by biostratigraphic analysis based on calcareous nannofossils. Six new stratigraphic sections were measured and sampled in the southern and eastern regions of Majella, and correlated with nine previously published sections. This analysis not only facilitates the reconstruction of the stratigraphic architecture but also enables insights into the evolution of oceanographic conditions.

Between the Rupelian and Chattian interval, a carbonate ramp was established, characterized by extensive dune fields in the middle ramp environment, indicating vigorous currents transporting sediment from southeast to northwest. Subsequently, during the Chattian to Aquitanian transition, a shift towards more siliceous facies occurred, marked by deposits rich in planktonic and spicule, suggesting a transition to deeper depositional environments and a reduction in carbonate production, followed by further deepening.

During the Burdigalian, a resurgence of north-directed currents led to the formation of a new dune field in the mid-ramp. Subsequently, from the end of the Burdigalian to the middle Serravallian, a renewed phase of deepening occurred, characterized by the deposition of outer ramp facies with a notable increase in the terrigenous component. Successively a significant drop in sea level resulted in an erosive surface demarcating the lower boundary of the subsequent lower Tortonian to upper Messinian carbonate deposits.

These deposited on an extensive ramp where carbonate production was dominated by red algae in the middle ramp and by the epiphytic component in the inner ramp. Upwards a new drowning is recorded and it is linked to the progressive deterioration of environmental conditions due to the closure of the Mediterranean.

Bioclastic intercalations in the Tortonian hemipelagic marls of the Latium-Abruzzi carbonate platform domain (Central Apennines): the link between oceanography and climate

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Keywords: Tortonian, Internal wave, paleoclimate.

The sedimentary record of a foreland basin provides insights into the interplay between shallow-water carbonate production and subsiding basins. This work aims to identify the source and the triggering mechanism behind the deposition of Tortonian bioclastic intercalations found within hemipelagic deposits of the Latium Abruzzi Domain (Central Apennines). These deposits are represented by the *Orbulina* marls that lies on the Burdigalian to Serravallian Miocene carbonate ramp, the *Lithothamnion* and Bryozoan Limestones. The hemipelagic deposits are overlain by turbiditic, siliciclastic succession deposited in the foredeep system. The calcareous nannofossil assemblages at the base of the intercalation indicate a Tortonian age, attributable to Biozone MNN9.

Two distinct types of intercalations were distinguished. The first exhibits a diverse skeletal assemblage comprising oligophotic and aphotic organisms, while the second consists solely of planktonic biota. The presence of these intercalations indicates the existence of an active carbonate ramp during the Tortonian, while the sedimentary structures of carbonate intercalation indicate deposition through gravity flows (turbidity currents). The triggering mechanism for the sedimentation of these deposits has been attributed to the influence of internal waves. These waves emerged as a result of the development of a robust pycnocline, fueled by global and regional climate changes that led to pronounced stratification in the water column due to heightened thermal and density gradients.

Neogene evolution of the inner northern Apennines and the related geothermal systems: insights from the Elba Island

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Keywords: Northern Apennines, extensional tectonics, exhumed geothermal systems.

The Neogene evolution of the Northern Apennines was the result of the Cretaceous-Early Miocene continental collision, the subsequent Miocene dismantling of the stacked units and the development of the Tyrrhenian basin. Due to its geographical position, the Elba Island is a crucial sector for the study of this evolution. Indeed the Elba island is part of the inner Northern Apennines and represents an exhumed crustal sector that has undergone: (i) HP metamorphism > 1. 6 Gpa at about 20 Ma; (ii) Miocene extensional tectonics; (iii) Miocene magmatism and associated HT metamorphism, resulting in the emplacement of two intrusive magmatic systems between 8.5 and 5.9 Ma. The Elba island thus represents a natural laboratory for studying the processes related to the the relationships among crustal structures, emplacement of anatectic magmas at shallow crustal levels and the circulation of geothermal fluids leading to the development of ore deposits. This presentation illustrates the up-date knowledge on the geological setting of Elba Island and the implications for the Neogene-Quaternary evolution of the inner Northern Apennines. At the same time, the key role of Elba island in representing an exhumed geothermal system is highlighted, providing key elements for a better comprehension of the Tuscan geothermal systems.

Chronostratigraphy of Palaeozoic formations by means of palynological studies: the case of the Filladi e Quarziti di Buti Formation (Northwestern Tuscany)

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Keywords: Palaeozoic, Northern Apennine, chronostratigraphy.

The inner Northern Apennines represent a key area for analyses of Palaeozoic succession and the overlying units. Unfortunately, Palaeozoic outcrops are often patchily exposed in some areas (Tuscan and Latium) and most of them suffer of precise chronostratigraphic attribution, due to metamorphism and the general absence of fossils. One of these formations is the Filladi e Quarziti di Buti Fm (Rau & Tongiorigi, 1974), cropping out in the northwestern sector of Tuscany, in the area between Monte Pisano and Punta Bianca. It consists of intensively deformed and foliated grey-white quartzite and grey phyllite with relics of an older foliation of Variscan age, transposed from Alpine foliation. The base of the unit is never exposed, while at the top it shows erosional relationship (angular unconformity type) with the overlying deposits of the Middle Triassic cycle. Radiometric data on the whole rock give a lower Permian age of 285 ± 12 Ma (Rb/Sr; Borsi et al., 1967) that is interpreted as the closure age of Variscan metamorphism. As regards to the age of deposition, it was attributed to the Silurian (Bagnoli et al., 1979) for petrological analogy with the Ordovician Porphyroids, or to lower Palaeozoic (Cambrian? - upper Ordovician?) for correlation with different metamorphic units exposed in the Apuan Alps (alternatively Filladi inferiori Fm and Filladi superiori Fm by different authors). Generally, no fossils are reported from the formation, even if Bagnoli et alii (1978) reports conodonts (*Pseudooneotodus beckmanni* and *Panderodus* sp.) from a controversial limestone outcrop (and no longer identifiable) internal to the formation and referred to the Middle Ordovician-Lower Devonian. Similarly to other Palaeozoic successions from the Northern Apennines, palynological studies have been here applied to the Filladi e Quarziti di Buti Fm as a possible tool for age attribution and to obtain biostratigraphic data.First preliminary results performed on a number of 10 samples of dark grey phyllites collected in different areas of Punta Bianca and Monte Pisano evidence the presence of a quite diversified microfloristic assemblage of Cryptospores (*Tetrahedraletes medinensis, Dyadospora murusdensa, Dyadospora murusattenuata, Gneudnaspora divellomedia, Pseudodyadospora laevigata)* and Trilete spores (*Emphanisporites rotates, Chelinospora poecilomorpha, Retusotriletes maculatus, Retusotriletes triangulates, Retusotriletes abundo, Concentricosisporites Sagittarius, Ambitisporites avitus, Retusotriletes warringtonii)*. Such a microfloristic assemblage allows us to attribute Filladi e Quarziti di Buti Fm to the Ludlow (middle Silurian).

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Tectono-stratigraphic evolution of the Apulia plate and the role of the advancing Southern Apennine/Calabrian Arc wedge on its present-day structural and stratigraphic architecture

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Keywords: Northern Ionian Sea, Apulia Plate, transpressive tectonics.

In the Northern Ionian Sea, the Apulia plate, a sliver of continental crust covered by about 8 km of Mesozoic carbonates (Maesano et al., 2020), serves as the foreland of two opposed and verging chains. One is the SE-verging Southern Apennine, to the SW, which merges with the Calabrian Arc wedge in the Taranto Gulf (Basso et al., 2021), and the other is the SW-verging External Hellenides, to the NE (Chizzini et al., 2022). With the primary goal of precisely identifying the major tectonic processes that have controlled the onset of the existing structural architecture of this region, we use deep seismic reflection profiles to define the tectonic structures and stratigraphic relationships between the frontal part of the Southern Apennine/Calabrian Arc wedge and the adjacent Apulia plate. Based on seismo-stratigraphic analysis, three main regional unconformities are identified: i) the Jurassic/Cretaceous unconformity is characterized by Cretaceous reflectors that clearly onlap the Jurassic carbonate platform; ii) the Messinian unconformity is connected to a regional erosive event linked to the Messinian dissecation of the Mediterranean basin; and iii) the middle Pliocene unconformity, an erosive and angular unconformity that truncates the Lower Pliocene reflectors. Although the Apulia plate is generally considered a stable region given its foreland setting, our analysis indicates that it underwent significant tectonic activities, with deformative style controlled by its interaction with the nearby Southern Apennine/Calabrian Arc wedge. In fact, an active NW-SE-striking extensional fault system generated due to the Apulia plate bending under the load of the two opposite orogens, is superposed and locally coeval to: 1) smooth and open folds close to the Calabrian Arc wedge-Apulia plate contact zone; 2) several active NE-SW-striking positive flower structures, likely enucleated from inherited Mesozoic normal faults which have been reactivated since the middle Pliocene; 3) mobilized and squeezed Upper Triassic evaporites which form teardrop diapirs (Chizzini et al., 2023). All the above deformations migrate in space since the late Miocene till present days and they are interpreted to be the result of compressive and transpressive regimes related to shortening processes and oblique plate convergence along the Eastern and Western boundaries of the Apulia plate. These observations make both the regional geological context and the pre-collisional grain of the Apulia plate pivotal features controlling the location and geometry of future tectonic structures in the Northern Ionian Sea posing the bases for a more accurate analysis of the natural hazards threatening the populated coastal area.

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Orogenic evolution of the northern Calabria-southern Apennines System: stratigraphy

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Keywords: southern Apennines, stratigraphy, tectonics.

We present a review of the orogenic evolution of northern Calabria and the southern Apennines (Vitale & Ciarcia, 2013, 2018, 2022) in terms of stratigraphy (poster 1) and tectonics (poster 2). Three main tectonic complexes characterize this orogenic chain: (1) remnants of the overriding plate, including Variscan Paleozoic basement (Calabria-Peloritani Terrane; CPT) that tectonically cover (2) an Alpine metamorphic belt, corresponding to an exhumed subduction channel, formed by slices of CPT, metaophiolites (metamorphic Ligurian units), and some successions of the continental Adria plate (downgoing plate); in turn superposed to (3) a fold-and-thrust belt made of remnants of an oceanic accretionary prism (non-metamorphic Ligurian units) on the top, and an imbricate orogenic pile consisting in shallow-water to pelagic continental Adria successions, also including the buried shallow-water carbonates of the Apulian Platform. The exposed Apulian Platform domain (Puglia region) and the Adriatic Sea represent the current foreland. The orogenic chain results from the subduction of the Ligurian Ocean lithosphere beneath the European Plate/CPT starting during the Paleocene-Eocene.

The synorogenic sedimentation was ruled by the migration of the forebulge-foreland basin system, with the flexure of the continental part of the Adria plate since the Oligocene with the erosion of a large part of the Apennine and Apulian carbonates that fed the foredeep basins with calciclastic supply. Siliciclastic input, which originated both by the overriding plate and orogenic wedge, joined with orogenic volcaniclastics, marked the sedimentation in the foreland basin system, including the mature stage of the foredeep troughs and the wedge-top basins located on the top of the chain, the latter also recording a calciclastic sedimentation originated by the erosion of the piled-up Adria carbonate successions.

Vitale S. & Ciarcia S. (2013) - Tectono-stratigraphic and kinematic evolution of the southern Apennines/Calabria-Peloritani Terrane system (Italy). Tectonophysics, 583, 164-182, https://doi.org/10.1016/j.tecto.2012.11.004.

Vitale S. & Ciarcia S. (2018) - Tectono-stratigraphic setting of the Campania region (Southern Italy). Journal of Maps, 14, 9-21, https://doi.org/10.1080/17445647.2018.1424655.

Vitale S. & Ciarcia S. (2022) - The dismembering of the Adria platforms following the Late Cretaceous-Eocene abortive rift: A review of the tectono-stratigraphic record in the southern Apennines. International Geology Review, 64(20), 2866-2889, https://doi.org/10.1080/00206814.2021.2004559.

Sedimentary evolution of the Pliocene wedge-top basins in the southern Apennines: a review

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Keywords: southern Apennines, stratigraphy, paleogeographic evolution.

We present a review of the Pliocene wedge-top depocenters belonging to the hundreds of kilometres long Foreland Basin System (FBS) in the southern Apennines (Ascione et al., 2012; Ciarcia & Vitale, 2013). As a whole, the stratigraphic successions are made of clastic deposits, including conglomerates, sandstones, siltites, and clays, organized into several members, reaching hundreds of meters and a maximum thickness of about two kilometres. The oldest Pliocene deposits are of late Zanclean in age and are mainly exposed in the northern portion of FBS. The occurrence of scattered specimens of *Globorotalia margaritae* constrains the lower terms to the upper MPl3 zone; in contrast, the remaining successions fall in the MPl4a zone based on the occurrence of *Globorotalia puncticulata*. A subsequent Pliocene clastic succession, constrained by *Globorotalia bononiensis* and the absence of *Bulimina marginata*, unconformably covers previous deposits.

The filling of the basins started in the northern part of the FBS (Ariano and Ofanto depocenters), characterized by relatively deeper water. In contrast, the southern basins (Calvello, Potenza and Vietri depocenters) were much shallower. The facies associations assemblage indicates alluvial, coastal-marine, and shelf environments. An alluvial progradational system and a gradual transition from neritic to low-gradient nearshore facies occur in the northern sector. Locally, the deposits in the pelitic facies yielded mixed assemblages, containing very shallow (upper infralittoral) and open shelf (circalittoral) benthic foraminiferal and ostracod species. A SE-ward migration of depocenters age, followed by basin filling and uplift, is observed along the southern Apennine FBS in late Zanclean to Early Pleistocene times, associated with the SE migration of the downgoing slab breakoff (Ascione et al., 2012).

Ascione A. et al. (2012) - The Pliocene–Quaternary wedge-top basins of southern Italy: An expression of propagating lateral slab tear beneath the Apennines. Basin Research, 24, 456-474.

Ciarcia S. & Vitale S. (2013) - Sedimentology, stratigraphy and tectonics of evolving wedge-top depozone: Ariano Basin, southern Apennines, Italy. Sedimentary Geology, 290, 27-46.

The impact of an integrated stratigraphic and structural analysis on the updating of the regional tectonic scheme: an example from the Hyblean Plateau (SE Sicily)

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Keywords: regional tectonics, Hyblean Plateau, sedimentation.

The local geometry of geological units is the signature of the interaction between the sedimentary regime and the tectonic dynamics of a region over time. The integration of stratigraphic and structural analyses is therefore crucial in geological investigation, since the reconstruction of a geological setting, regardless of the objectives pursued, needs validation for consistency with the tectono-stratigraphic history of the area. This goal is difficult to achieve if stratigraphic and structural investigations are conducted separately and at different periods.

We here would illustrate how an integrated stratigraphic-structural study, focused on mapping of the Geological 1:50.000 sheet “Ragusa” in the frame of the CARG Project, produced a significant updating of the tectonic history of the entire Hyblean Plateau, in SE Sicily. The area is an uplifted portion of the African continental shelf, forming the peripheral bulge in front of the Sicilian orogenic belt. The plateau consists of a culmination of an Oligo-Miocene carbonate succession, now dissected by distinct fault systems, controlling the main features of the landscape inside the plateau and plio-pleistocene depocenters along its borders.

The new integrated studies have resulted, differently from the past interpretation, in some new relevant insights, summarized as follows:

1. The Hyblean Oligo-Miocene succession consists of shallow-water sediments that are very sensitive to bathymetric variations due to syn-sedimentary deformation;
2. A main unconformity, marked by an obvious stratigraphic gap, separates the nearly homogeneous Late Oligocene-Aquitanian interval (Leonardo Fm.) from the early Burdigalian and Early Langhian horizons (Irminio Fm.), which are instead characterized by impressive lateral variability of lithofacies;
3. Heteropies within the Irminio Fm. occur mainly across major fault segments, as a direct response to differential syn-sedimentary movement between hangingwall and footwall structures;
4. An intraformational Burdigalian unconformity within the Irminio Fm. represents a new horizon-key useful for discriminating, among the set of faults active during Early Miocene sedimentation, the segments that reactivated during later deformation phases;
5. The new stratigraphic scheme implies a reassessment of stratigraphic separation across faults, which generally results in a drastic reduction of the cumulative offset;
6. Comparison of tectonic scarps with the geologically recorded offset is the tool for discriminating between fault-line scarps, along synsedimentary faults, and actual fault scarps along segments that reactivated after the area emerged.

We can conclude that most of the tectonic features of the Hyblean region actually formed during the Early Miocene tectonic deformation and conditioned the distribution of structures that reactivated during the successive stage of bulging and intraplate deformation, that dominate the tectonic picture of the region, since the Late Miocene.

New biostratigraphic data on the hemipelagic succession at the western escarpment of the Apennine Carbonate Platform: insights from the Volsci Range

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Keywords: biostratigraphy, foraminifera, calcareous nannofossils.

The Late Cretaceous-Eocene demise and drowning of the Apennine Carbonate Platform (ACP) stands out as a captivating phenomenon, with its structural inheritance profoundly influencing both the evolution of the platform to basin carbonate systems and the later development of the Late Miocene Apennine fold-and-thrust belt. This is locally recognized by the occurrence of heterogeneous base-of-slope and epiescarpment hemipelagic successions that cap the edges of carbonate platforms facing the adjacent basins. While these successions have been extensively studied elsewhere in the Apennines, the Volsci Range (VR) remained relatively unexplored, leaving its geological evolution only partially constrained. Building upon initial reports from the Velletri CARG sheet 388 (Servizio Geologico d'Italia, 2021), this study offers a comprehensive characterization at the western ACP margin. We examine stratigraphic contacts, facies composition, microfauna content, and discuss the regional significance of this hemipelagic succession. Exposed along the northernmost VR, the studied outcrops feature a few meters thin and discontinuous succession of Scaglia-type limestone, resting on a shallow-water carbonate succession of Cenomanian-Turonian age. Facies analysis reveals a spectrum of lithotypes including i) Bioclastic glauconitic wackestone-packstone containing coarse echinoderm, gastropod, and green algae fragments, along with planktonic and benthic (sometimes larger) foraminifera; ii) Reddish oxidized wackestone with coral fragments and planktonic and benthic foraminifera; iii) Packstone with a dense occurrence of planktonic foraminifera; iv) Dark hemipelagic wackestone.

The presence of planktonic foraminifera, such as *Acarinina bullbrooki*, *Acarinina topilensis*, *Subbotina senni*, *Globanomalina australiformis*, *Morozovelloides* cf. *crassatus,* which occurrence spans through the E7-E12 Zones (Wade et al., 2011), alongside calcareous nannoplankton species like *Sphenolitus spiniger*, *Furcatolithus obtusus*, *Coccolithus pelagicus* and *Reticulofenestra bisecta* of CNE 15 zone (Agnini et al., 2014) or NP17 Zone (Martini, 1971), indicates a depositional age ranging from late Lutetian to early Bartonian. Based on the patchy distribution of the succession, stratigraphic contacts and facies features, the environment can be interpreted as an escarpment characterized by an articulated topography, which received intermittent bioclastic inputs from an active, no longer exposed, Eocene photic carbonate factory. Notably, the occurrence of reworked Campanian-Maastrichtian calcareous nannofossils suggests winnowing of preexisting Upper Cretaceous deposits. Ongoing research on these hemipelagic successions, dubbed "Scaglia detritica" in the CARG database, holds promise for paleogeographic and regional tectonic reconstructions connected with the evolution of Cretaceous-Eocene platform margins.

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New morphotectonic and stratigraphic data on the Quaternary evolution of the Vallo di Diano basin, southern Italy

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Keywords: morphotectonics, intermontane basins, fault kinematics.

The Vallo di Diano basin is a flat-bottomed NW-SE-trending fault-bounded intermontane basin of the axial zone of the southern Italian Apennines. This elongated tectonic depression is bordered to the east by an impressive N140-150°-striking master fault whereas the western flank is articulated by an array of pre-existing N120°-trending left-lateral strike-slip faults. The infill is made of a thick succession (i.e. at least 200 m in the depocentral zone) of lower to middle Pleistocene fluvio-lacustrine deposits and coeval slope to alluvial fan deposits. Their deposition is associated to the higher slip rates of the master fault and such sediments pass upward to middle Pleistocene to Holocene palustrine and slope successions located along the valley flanks. We investigated the evolution of the basin by a multidisciplinary approach based on the integration of geomorphological observations, subsurface geological datasets, and geophysical surveys. Data were interpreted with the aim of building a detailed stratigraphic and tectonic model for the Pliocene-Quaternary deposits and the buried morphology of the Mesozoic-Cenozoic bedrock. Morphotectonic data consist of topographic analysis, drainage network morphometry, river profile analysis, and spatial distribution of alluvial fans and lacustrine depositional tops. The geometry and thickness of the basin infill were constrained by a campaign of seismic surveys integrated with stratigraphic data coming from deep and shallow boreholes. ESAC method and HVSR curves were tested as effective tools to reconstruct the architecture of the subsurface deposits and the Quaternary offsets of the basin-border faults. Finally, data interpretation allowed us to chronologically constrain the activity of several faults and to reconstruct the Quaternary evolution of this intermontane basin, where relevant anthropic activities persist.

Constraining the early stage of the post-orogenic extensional tectonics in central Italy: new evidence from a long sediment core from the tectonically active L'Aquila basin (Central Italy)

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Keywords: central Apennines, intermontane basins, post-orogenic tectonics.

The central Apennines is among the most seismically active sector of the central Mediterranean region, as testified by the recent sequence of earthquakes with Mw >6 (L'Aquila Mw 6.3, 06/04/2009; Amatrice Mw 6.2, 24/08/2016), which recently struck it. Although many recent studies focus on the recent history of the active and seismogenic faults, due to the poor understanding on the age of the tectonically bounded intermontane basins and on the early stage of their continental deposition, less is known on their long-term behavior.To try to fill this gap of knowledge, in this work an integrated multiple-dating approach, including 40Ar/39Ar dating, magnetostratigraphy, multiproxy paleoclimatic data (palynological analyses, Pollen Temperature Index and clumped isotopes), and astrocyclostratigraphy, was applied on a long sediment core (230 m depth, Castelnuovo 1 borehole; CN-1) recovered from the infill of the Plio-Pleistocene tectonically active L'Aquila Basin (Paganica-S. Demetrio-Castelnuovo Sub-basin -PSC).

Combining the results from the CN-1 pollen record, the 40Ar/39Ar dating of a tephra (1.77 ±0.15 Ma), and the magnetostratigraphy of the CN-1 sediment core, we can refer the longest normal polarity interval (N3) to the Olduvai subchron, which we use for constraining the CN-1 age model. Moreover, spectral analysis of the CN-1 calcimetry data series shows the presence of 13 obliquity-modulated cycles, resulting in an age of ca. 1490 ka, for the top of the core, and an age of ca. 2027 ka, for its base. This time span encompasses the Marine Isotopic Stages (MIS) 75 to 50. The occurrence of lacustrine ostracod fauna since the lowermost portion of the CN-1 core points to the presence in the PSC Sub-basin, already at 2 Ma, of a well-developed intermontane lake. Both pollen record and clumped isotopes show warm-to-cold climate changes along the CN-1 sediment core, with temperatures of 15.4 ±1.6 °C (MIS 53) and 11.5 ±1.3 °C (MIS 52), whereas temperatures of 21 ±1.7 °C and 15.6 ±1.7 °C correspond to MIS 67 and MIS 64, respectively.

The PSC Sub-basin shows a complex subsurface architecture, with thresholds and depocenters showing maximum thickness of the lacustrine deposits up to 450 m. Since the CN-1 age model points to a sedimentation rate of 0.3 mm/yr for the deep lacustrine deposits, the onset of the continental sedimentation in the L'Aquila intermontane basin started at ca. 3 Ma. This age for the post-orogenic formation of the tectonically active L'Aquila Basin is well in agreement with the kinematic evolution of the central Apennines, where the last documented compressional tectonic phase occurred at ca. 3.5 Ma. This post-orogenic extensional domain, which is still active, represents an archive of ca. 3 Myr of continued crustal extension and one of the most seismically active sectors of the central Mediterranean region.

Microfloristic evidence in metamorphosed rocks of Elba Island: new constraints and correlation of the early Palaeozoic

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Keywords: palynomorphs, Elba island, Central Mediterranean.

Elba Island, located in the Northern Tyrrhenian Sea, is part of the inner Northern Apennines, an alpine chain deriving from the convergence and collision (Cretaceous–Early Miocene) between the Adria microplate and the Sardinia-Corsica Massif. The age of the Palaeozoic protolith of the metamorphic rocks has always been uncertain due to the HT-metamorphism caused by the emplacement of a Messinian monzogranite.

The Palaeozoic rocks of Elba Island are part of three tectonic Units (Bianco et al., 2015). The succession occurring in the deepest tectonic Unit is attributed to ?Precambrian and Palaeozoic and is mostly composed of micaschist, quartzite and phyllite, covered by continental metaconglomerate and metapelite -to-littoral dolostone, metalimestone and phyllite. The second tectonic Unit consists of micaschist overlaid by felsic metavolcanics with local typical augen texture (porphyroids) to which porphyritic schists are interlayered, particularly in the upper part of the succession. Porphyroids and porphyritic schists were dated through geochronological methods and referred to Middle Ordovician (Sirevaag et al., 2016). These are covered by phyllites and quartzitic phyllites dated at the Middle Ordovician and Silurian and Carboniferous-Permian. The third tectonic Unit consists of low-grade metamorphic rocks formed by phyllite, metasandstone and metaconglomerate (Rio Marina Fm), attributed to the late Carboniferous-Permian. In the present study, we report palynological data from the succession exposed in the lower part of the first tectonic Unit cropping out in the Ortano and eastern side of the Monte Calamita areas. The succession consists of brown to grey-greenish cornubianitic quartz-muscovite-biotite micaschist with levels of quartzite, metasandstone and blackish phyllite. Microflora yielded mainly consists of permanent tetrad as *Tetrahedraletes medinensis*, dyad as *Dyadospora murusattenuata* and *D. murusdensa* and monad as *Gneudnaspora divellomedia* in assemblage with smooth and ornamented trilete spore as *Chelinospora poecilomorpha*, *Concentricosisporites sagittarius*, *Emphanisporites rotatus*, *Retusotriletes triangulatus* and others. Based on comparison with similar microflora recorded in Laurussia (UK, Ardenne-Rhenish region, Canada and Nova Scotia) and in the Western Gondwana (Tunisia, Algeria, Spain, Britanny, Libya, Turkey and Saudi Arabia), the present assemblage is here attributed to the Wenlock (Homerian)-Ludlow time interval. This is the first findings of a Silurian microflora in the Northern Apennines: the palynological study has proven to be an excellent tool helping to resolve stratigraphic and geodynamic problems even in rocks affected by pervasive dynamic HT-metamorphism.

Bianco C. et al. (2015) - HP-LT metamorphism in Elba Island: Implications for the geodynamic evolution of the inner Northern Apennines (Italy). Journal of Geodynamics, 91, 13-25.

Sirevaag H. et al. (2016) - From Gondwana to Europe: The journey of Elba Island (Italy) as recorded by U–Pb detrital zircon ages of Paleozoic metasedimentary rocks. Gondwana Research, 38, 273-288.

pH soil measurements of the Sant'Antuono CO_2 gas vent in the Sannio area (southern Apennines, Italy): insights on the active Southern Matese Fault system

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Keywords: pH soil surveys, non-volcanic CO_2 vents, southern Apennines.

pH is one of the most frequently measured parameters in standard soil analyses and probably the most valuable single indicator, especially in cultivation, for soil functioning and processes (Borggaard, 2000). Measured soil pH values offer insight into the chemical-physical reactions occurring in the soil. This work presents a study of the area around Sant'Antuono spring, located in the Solopaca hills (SE sector of the Matese Massif). This area is characterized by small scattered vents including the Sant'Antuono spring that represents the main non-volcanic CO_2 gas vent. Furthermore, in the whole area, acid fouling and alteration spots occur. This results from the soil pH survey carried out in the area around the CO_2 gas emissions. The pH soil measurements range from 2 to 8, indicating the coexistence of soil portions characterized by pH from highly acidic to weakly basic. The spots characterised by pH=2 are well-defined, localized, and relatively small (a few metres), suggesting that the phenomenon contributing to soil acidity follows specific pathways. Consistent with soil exhibiting such acidity levels, a whitish patina forms on the ground surface, associated with an absence of vegetation, indicating unfavourable conditions for biological activity. This important data fits in well with the findings of the study published by Vitale et al. (2023) and other geophysical investigations conducted in this area, adding a further piece to the characteristics of the ongoing phenomenon.

Borggaard O.K. (2000) Soil Chemistry in a Pedological Context. DSR Forlag, Copenhagen.

Vitale S. et al. (2023) - Insights on the active Southern Matese Fault system through geological, geochemical, and geophysical investigations of the CO_2 gas vent in the Solopaca area (southern Apennines, Italy)". Tectonophysics, 846, 1-12, 229657, https://doi.org/10.1016/j.tecto.2022.229657.

New data about Irpinian mud volcanoes: a multidisciplinary approach to understanding the relationship between fluid leakage and faults

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Keywords: mud volcanoes, southern Apennines, multidisciplinary surveys.

In this study, we present the results of an integrated multi-methodological approach to illuminate the relationships between the mud emission, which characterizes the "*Bolle della Malvizza*" mud volcanoes, and fault. Our aim was to investigate the mud and gas leakage process and source. The mud volcanoes of *"Bolle della Malvizza"* are situated in the Irpinia sector of the southern Apennines (southern Italy), in the Upper Cretaceous-Upper Miocene Fortore succession (Lagonegro-Molise Basin). Specifically, they are hosted in Upper Cretaceous-Burdigalian varicoloured clays with intercalations of calcareous turbiditic beds covered by upper Tortonian-lower Messinian unconformably clastic deposits of Castelvetere Group. These volcanoes emit mud, salt water and gases (CH_4 and CO_2). They are concentrated in a narrow area of ca. 5000 m2 in nine main groups, which vary in size (from a few centimetres to 13 meters) and height (from ca. 3 to 15 cm). These sedimentary structures are aligned along the directions ENE-WSW and N-S in correspondence with two main normal faults. Our research was approached with a multidisciplinary study, including stratigraphic and structural surveys, topographic evaluations using drone photogrammetry and a Virtual Outcrop Model, geophysical investigations using Electrical Resistivity Tomography (ERT), Induced Polarization (IP) and Self Potential (SP), and geochemical exploration through CO_2 and radioactivity soil flux, and pH soil measurements.

3D Structural architecture of the front of the Sicilian Apennine (Southern Italy) as derived from well-calibrated seismic reflection profiles interpretation

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Keywords: chain front, 3D model, seismic profile, well-log data.

The front of the Sicilian Apennine in southern Italy is a roughly E-W regional structural feature which extends for several km both on-land (Gela-Catania) and offshore (Sicily Channel), separating the Sicilian fold-and-thrust-belt to the North from the under-thrusted foreland domain to the south. While mapped in several regional maps and structural sketches, the tectonic architecture of the Front along with its space/time evolution are still poorly constrained. To reconstruct its 3D geometry and retrieve tighter constraints about its kinematics (e.g., cylindrical and/or oblique), propagation time, and deformation rates, commercial multichannel seismic reflection profiles and well-log data (available from the VI.DE.PI. national repository, www.videpi.com) were analysed within a 3D digital environment in the offshore sector between Gela and Sciacca. The seismic dataset includes about 100 km-spaced T.W.T seismic lines oriented parallel to the coast (WNW-ESE) and transversally (N-S). About 20 wells, drilled in the offshore during 60's-80's, have been also considered to i) gain additional information on the age of the offshore sedimentary units, ii) to calibrate the main reflectors along seismic lines, and iii) to build a velocity model for a reliable time-depth conversion of the seismic dataset. Seismic lines (released as PDF format) were initially checked and managed to reduce geometric distortion, which is common with most of the scanned copies of available geophysical profiles. Wells-log data were revised and the drilled units renamed to be in line with the modern stratigraphic nomenclature available from literature. All input data have been then converted as digital 3D features within the Move software package (Petex ltd), and seismic lines were interpreted on screen following age constraints coming from wells-logs data projected to seismic sections. Once all the horizons were picked, line-to-surface interpolation allowed modelling the 3D structural architecture of the Front whereas internal reflectors pattern of most of the illuminated seismic units provides insights on its latest tectonic advancement. Preliminary interpretation confirm that the front emplaced during the Plio-Pleistocene, propagating on an irregular paleo-surface corresponding with the top of the underthrusted Hyblean carbonates (mostly Hybla and Amerillo Formations). Basement buttressing and tectonic elision have locally controlled differential advancement of the front and hence its final shaping. Frontal thrusting is generally accompanied by the development of roughly coaxial splays that show evidence of over-step propagation. Further 3D elaborations will allow a better understanding about thrusts architecture and their deformation timing. In addition, numerical simulations such as back/forward modelling will be performed to retrieve information about the long-term tectonic shortening of the front.

Groundwater-rock interaction and mixing in fault-controlled karstic aquifers: a structural, hydrogeochemical and multi-isotopic review of the Pontina Plain (Central Italy)

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Keywords: hydrogeology, normal fault, Apennines.

Regional karstic aquifers represent indispensable water resources, the effective management of which relies on well-defined tectonic and hydrogeochemical models. This study investigates the complex groundwater-rock interaction and mixing processes within a fault-controlled karstic aquifer adjacent to the Pontina Plain at the piedmont of the northern Volsci Range in the Central Apennines. We conducted field-based structural, hydrogeochemical, and multi-isotopic screening of ten selected springs with different mineralization degrees, ranging from Ca-HCO3 to Na-Cl hydrofacies. Our analysis incorporated novel assessment and modeling for δ 34S(SO4), δ 18O(SO 4), 87Sr/86Sr, and δ 11B. Additionally, a seismic stratigraphic section extending to a depth of about 5-7 km provides a detailed geological framework, identifying the geometry of normal faults serving as pathways for upwelling fluids. Our findings unveil complex hydrogeochemical compositions resulting from multiple interactions across shallow to deep systems, with mixing increasing towards the southeast. Employing geothermometers, alongside geochemical modeling and trace elements

analysis, enabled the estimation of water temperature equilibrium with Triassic evaporites at 95.5 ± 3.5 °C, likely corresponding to a depth of about 3 km. Further equilibrium temperatures, potentially associated with ultrapotassic volcanic rocks at 35.5 ± 6°C, possibly indicating interactions with a diatreme of the tectonically-controlled Volsci Volcanic Field at approximately 1 km depth. This multidisciplinary approach enhances the understanding of groundwater behavior in fault-controlled karstic aquifers, potentially involving deeper crystalline basement or magmatic-derived fluid components. From a regional perspective, this work lays the groundwork for further studies on the regional mixing processes affecting fault-controlled aquifers. Beyond regional interest, this research bears implications for water resource management and environmental protection strategies in similar geological settings worldwide.

Seismo-stratigraphy architecture of the transgressive and highstand systems tracts during the Last Glacial-Holocene and the NYT reflector in the Gulf of Gaeta (Eastern Tyrrhenian margin, Italy)

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Keywords: seismic stratigraphy, transgressive system tracts, Neapolitan Yellow Tuff.

The Neapolitan Yellow Tuff (NYT) caldera-forming eruption (ca. 15 ky, Deino et al., 2004) is a large event that occurred at Phlegrean Fields during the Late Glacial – Holocene. The eruptive products represent a widespread isochronous marker that links the marine and terrestrial archives of the central Mediterranean area and Northern Europe. In this work, we describe the stratigraphic signature of the NYT deposits in the Late Glacial - Holocene shelf sequence of the Gulf of Gaeta (northern Campania region, southern Tyrrhenian Sea) throughout the seismo-stratigraphic interpretation of a grid of high-resolution Chirp seismic profiles. The Late Pleistocene - Holocene stratigraphic architecture of the continental shelf is characterized by an offlap prograding succession followed by a very thick transgressive onlapping unit and by the upper highstand unit, mainly characterized by undulations probably linked to gas-prone sediment. The NYT reflector observed is parallel and displays a high amplitude. It has been continuously detected from the shelf to the slope within the transgressive deposits. On the inner shelf, its continuity is interrupted by shallow gas pockets. The NYT depths ranges from 2 ms bsf on the slope to 38 ms bsf on the continental shelf, reaching maximum thickness at the Volturno River mouth. The NYT event appears to have played a key role in controlling the stratigraphic architecture of the studied area during the last transgression, acting as a trigger for the formation of the aggradational sedimentary successions fed by pyroclastic and volcaniclastic deposits.

Deino A.L. et al. (2004) - The age of the Neapolitan Yellow Tuff caldera-forming eruption (Campi Flegrei caldera, Italy) assessed by 40Ar/39Ar dating method. J. Volcanol. Geotherm. Res., 91(2–4), 285, https://doi.org/10.1016/S0377-0273(03)00396-2.

Alternative origin for the Middle Miocene mass transport deposits of the Marnoso Arenacea Formation

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Keywords: foredeep intrabasinal high, Miocene, seep-carbonates.

During the Miocene, the migration of the northern Apennine accretionary wedge produced a segmentation of the inner part of the foredeep. The segmentation was related to the growing of anticlines on top of blind thrust faults, creating various intrabasinal highs draped by fine-grained sediments (Conti, 2001). The progressive growth, deactivation, and migration of intrabasinal highs were coupled with an intense seepage activity, occurring at various levels of the pelitic intervals (Argentino et al., 2019; Conti et al., 2021). Various portions of pelitic sediments above the intrabasinal highs are involved in spectacular slumps. In some cases, pelitic intervals are associated with extraformational deposits sourced by Ligurian- Subligurian Units and were interpreted by some authors as mass transport complexes (MTC). Stratigraphic studies on Visignano pelitic interval (Upper Serravallian), located in the "Alto Mugello," along the border between the regions of Emilia Romagna and Tuscany (Northern Appennines), show elements in conflict with MTC interpretation, which should be limited to the extraformational portions of the intervals. The internal stratigraphic coherence, the concordance with enclosing deposits, the texture of fine-grained deposits, the presence of peculiar soft sediment structures, seep-carbonates, sinsedimentary faults, peculiar ichnofacies, transitional facies to basin plain turbidites, and glauconitic hardgrounds indicate that sediment instability was limited to the temporary slopes of the intrabasinal highs. The new data reveal a complex scenario useful to explain the evolution of pelitic intervals. The genetic model proposed, would be linked to structural highs characterized by depressions and axial culminations where migration and expulsion of fluids allowed authigenic carbonate precipitation, instauration of chemosynthetic fauna and limited sedimentary instability. Structural highs interact with mass transport deposits sourced by the slope of the accretionary prism. The highest culminations can also be the site of prolonged starving of sedimentations, with the consequent formation of glauconitic rich sediments.

Argentino C. et al. (2019) - Evidences for Paleo-Gas Hydrate Occurrence: What We Can Infer for the Miocene of the Northern Apennines (Italy). Geosciences,9, 134, https://doi.org/10.3390/geosciences9030134.

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Conti S. et al. (2021) - Trace fossils in seep-impacted sediments as a tool to decipher the origin of fine-grained intervals of the Marnoso-arenacea turbidite succession (Miocene, northern Apennines, Italy). Sedimentary Geology, 422, 105965, https://doi.org/10.1016/j.sedgeo.2021.105965.

Use of low-frequency GPR to refine stratigraphy and tectonics in the Ofanto River Valley (Southern Apennines)

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Keywords: GPR, Irpinia.

Calitri Town is located in the irpinian sector of the Southern Apennines. The stratigraphy of the pre-Quaternary substratum (Ascione et al., 2012; Giannandrea et al., 2014; Servizio Geologico d'Italia, 2024) is dominated by the presence of a strong competence contrast among clayey units (Andretta Synthem, Lower Pliocene; SAD) and silty-sandy dominated units (Ruvo del Monte Synthem, Lower to Upper Pliocene; RVM). RVM highly competence portions are responsible for setting of the SW-NE strike of Calitri and Calvario hills and the conformal trending of minor left tributaries of the Ofanto River. In detail, the Cascina Creek, that bounds the eastern slope of the Calitri hill, can be related to the outcropping of the para-conformal, tectonized, contact between SAD and RVM. E-W, N-S and NNE-SSW morphological lineaments are in good accordance with the tectonic setting of the area. The Quaternary deposits are mainly represented by slope-related and fluvial deposits. The drainage system seems to be greatly controlled by tectonics, the Ofanto R., the main hydrological feature of the study area, appears in its mature stage, associated with almost five orders of morphological surfaces. Finally, the study area is widely affected by the presence of landslide related morphologies. We reconstructed the tectonostratigraphic setting of the study area using a classical field geological survey, aided by aerial photointerpretation and geognostic data from available boreholes. Detailed delineation of main geological contacts has been defined using surveys with low-frequency Ground Penetrating Radar: a powerful tool able to high penetration and accurate resolution, enough to retrieve main stratigraphical features of the pre-Quaternary substratum and refine geometry of recent gravity-driven mass movements.

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Giannandrea P. et al. (2014) - Pliocene to Quaternary evolution of the Ofanto Basin in southern Italy: an approach based on the unconformity-bounded stratigraphic units. Ital. J. Geosci., 133, 1, 27-44, https://doi.org/10.3301/IJG.2013.11.

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Development of a foredeep basin in the Northern Apennines through a multidisciplinary approach: the example of the Miocene Marnoso-arenacea fm. (Umbria, Italy)

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Keywords: Umbria pre-Apennines, foreland basin systems, Marnoso-arenacea foredeep.

The Umbrian pre-Apennines are characterized by extensive outcrops of the Marnoso Arenacea Miocene turbidite foredeep succession whose tectono-stratigraphic history is still under debate. Until recent years, the physical stratigraphy of these successions was poorly known and the biostratigraphic data were also unevenly available. As a consequence, the correlations between the different successions were poorly constrained and some aspects of the tectonic evolution of the foredeep, including the timing of deformation, remained unresolved. In north-central Umbria, a unique opportunity to fill this gap of knowledge, is provided by the carrying out of new high-detailed geological mapping at 1:25.000 scale, in the framework of the national CARG Project. After three years fieldwork, supported by the application of the most suitable analytical methodologies, we are finally able to synthesize a large amount of data that highlight the main depositional and deformational events and the mutual relationships between tectonics and sedimentation in the Miocene foreland basin system. A detail geological-structural mapping was accompanied by elaboration of composite LOGs, obtained by correlating several stratigraphic sections measured in the field. The latter were constrained and correlated by quantitative nannofossil biostratigraphy and petrographic determinations, which led to determine and characterize the different sedimentary inputs that fed the foredeep. Finally, to implement the field data and reconstruct the three-dimensional geometry of the structures at depth, a study of the subsurface was carried out interpreting a set of commercial seismic sections down to the buried top of the Meso-Cenozoic carbonate multilayer (depth~ 1- 1.5 km). Such a multidisciplinary approach allowed us to: (i) elaborate original and detailed geologicalstructural maps showing the thrust-related internal subdivisions of the basin (tectonostratigraphic units); (ii) obtain an overall litho-biostratigraphic reconstruction of the successions cropping out in most of the Miocene foredeep basin; (iii) highlight the presence of peculiar sedimentary bodies, having limited extent but local stratigraphic importance, derived from transversal Apennine sources; (iv) highlight the subsurface geometry and continuity of the main contractional tectonic structures affecting the study area; (v) elaborate a synthetic evolutionary scheme of the Umbria foredeep related to the chronology of the compressive deformations.

3D Structural model of the Messinian Umbria-Marche Foredeep basin: insights from the Ascoli Piceno sector, southern Marche (Italy)

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Keywords: balanced geological sections, fold and thrust belts, 3D model.

Understanding tectonic structures and the relationships between stratigraphic units in depth is a fundamental challenge for geologists. This goal has been pursued through the interpretation of geological and geophysical data in one or two dimensions and through structural analysis. Three-dimensional geological modeling synthesizes geological data and knowledge, aiding in the comprehension of subsurface structures through improved visualization (Basilici et al., 2023). This approach has been particularly valuable in the study focused on the sector analyzed in the northern Apennines foredeep basin, specifically the Laga turbidites (Milli et al., 2007).

The Laga basin, a key depositional player during the Miocene, bridges the internally uplifted Lower Miocene Umbria-Marche fold-and-thrust belt to the west and the newer segment of the chain buried beneath synorogenic Plio-Pleistocene clastic deposits to the east (Bigi et al., 2009). It is comprised mainly of turbiditic sedimentary sequences defining a deep-marine foredeep to wedge-top basin. This study concentrates on the southern part of the Marche region, a transition zone to the largest turbiditic depocenter of the Apennine foredeep in the southern Abruzzo region (Artoni, 2003).

Recent outcomes of the updated 1:50,000 national geological mapping project for the Sibillini area (Sheet Ascoli Piceno-326) provide an opportunity to review and propose the first detailed 3D model of the area. Specifically, it examines the Messinian Laga siliciclastic turbidites from the Sibillini Mountains to the Montagna dei Fiori anticline, showcasing a general fining and thinning-upward trend indicative of eastward basin migration and its relationship with the main eastward Pliocene unconformities outcropping in the area.

Our methodology involved the integration of a variety of techniques including surface geological mapping, seismic interpretation and well data correlation, cross-section balancing and restoration, and gravimetric modeling. To characterize the complexity of structural style and stratigraphic variations of the area, we constructed thirteen W-E balanced cross-sections using a 10 m-cell size Digital Elevation Model and the brand-new geological map in a 3D environment. To outline deep structural frameworks, vintage seismic line datasets, and borehole data were interpreted, and depth-converted to perform a 3D structural model illustrating thrust belt geometry.

The resulting 3D model provides a comprehensive overview of the foreland basin associated with the northern Apennine chain and the geometrical arrangement of the geology in the study area, including major faults and key horizons (main stratigraphic tops and unconformity-bounded units), ensuring accuracy and fidelity with surface and subsurface data. This work highlights first-order N-S tectonic trends and their influence affecting the Mio-Pliocene depositional setting of the basin along strike and dip, which are largely driven by tectonic forces.

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Basilici M. et al. (2023) - Geological map, balanced and restored cross-sections, and 3D geological model of the Monte Fema area, Umbria-Marche Apennines (Italy). Italian Journal of Geosciences, 142(3), 339-358.

Bigi S. et al. (2009) - Stratigraphy, structural setting and thermal history of the Messinian Laga Basin in the context of Apennine foreland basin system. J. Med. Earth Sciences, 1, 61-84.

Milli S. et al. (2007) - Sedimentology and physical stratigraphy of the Messinian turbidite deposits of the Laga Basin (central Apennines, Italy). Bollettino della Societa Geologica Italiana, 126(2), 255.

Turbidite lobe deposits in a tectonically confined foredeep basin (Firenzuola turbidite system, Marnoso-arenacea Formation, Northern Apennines, Italy)

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Keywords: Marnoso-arenacea Formation, basin confinement, turbidite lobes.

This paper focuses on the Serravallian age turbidite deposits of the Marnoso-arenacea Formation (MAF, Northern Apennines, Italy) known in the literature as Firenzuola turbidite system and consisting of Unit V by Muzzi Magalhaes & Tinterri (2010). This Unit records the progressive infill of the MAF inner basin and the consequent depocenter shift towards the external basin due to the simultaneous uplift of two important structural alignments know in the literature as Mt. Castellaccio thrust and Verghereto high. Furthermore, the geometries and facies of the turbidite deposits of Unit V are also influenced by the emplacement of the Casaglia mass-transport deposit (MTD) about 500 meters thick in its source area (Tinterri & Tagliaferri, 2015). Unit V deposits were analyzed through fieldwork involving the measurement and detailed facies analysis of 28 stratigraphic logs located in Santerno and Senio Valleys and with a total thickness of about 3000 meters. Field activities were also supported by a laboratory work, involving grain size analysis of 260 samples using a laser diffraction particle size analyzer. The measured logs were correlated using a hierarchical approach, in order to reconstruct a general physical stratigraphy of the study area (see also Tagliaferri et al., 2018). This study includes the entire stratigraphic thickness of Unit V split into two sub-Units (Va and Vb) thanks to the presence of the Bedetta MTD, observed for the first time in the Santerno Valley during this study. The two sub-Units differ significantly in both stratigraphic and facies terms. The turbidites of Unit VA exhibit characteristics similar to basin plain deposits, whereas Unit Vb features a drastic increase in the net to gross ratio, mud draped scours, poorly sorted and crudely laminated medium to coarse-grained beds, often characterized by abundant mudstone clasts, flame structures and bypass surfaces. By combining facies with the stratigraphic cross sections, the observed beds could be classified into 7 categories, organized into two distinct facies tracts, one for each sub-Unit. The purpose of the facies tract is that to describe the downcurrent evolution of the flows that led to the formation of these deposits.Thanks to 5 detailed stratigraphic cross sections, Unit Vb could be subdivided into 17 turbidite lobes, separated by interlobe deposits. Consequently, where possible, the depositional lobes were further subdivided into their respective lobe elements. Finally, by analyzing the lateral and vertical facies distribution observed in the lobes, their evolutionary phases could be reconstructed.This work is part of a broader study that wants to show lateral and vertical facies distribution at different scales of a tectonically confined turbidite system characterized by lateral and frontal morphologies (see Tinterri et al., 2023).

Muzzi Magalhaes P. & Tinterri R. (2010) - Stratigraphy and Depositional Setting of Slurry and Contained (Reflected) Beds in the Marnoso-Arenacea Formation (Langhian-Serravallian) Northern Apennines, Italy. Sedimentology, 57, 1685-1720, https://doi:10.1111/j.1365-3091.2010.01160.x.

Tagliaferri A. et al. (2018) - Basin-scale, High-Resolution Three-Dimensional Facies Modeling of Tectonically Confined Turbidites: An Example from the Firenzuola System (Marnoso-Arenacea Formation, Northern Apennines, Italy). AAPG Bulletin, 102, 1601-1626, https://doi.org/10.1306/12081716521.

Tinterri R. & Tagliaferri A. (2015) - The Syntectonic Evolution of Foredeep Turbidites Related to basin Segmentation: Facies Response to the Increase in Tectonic Confinement (Marnoso-Arenacea Formation, Miocene, Northern Apennines, Italy). Mar. Pet. Geology, 67, 81-110, https://doi:10.1016/j.marpetgeo.2015.04.006.

Tinterri R. et al. (2023) - Turbidite facies tracts as related to flow criticality and efficiency in tectonically confined basins: an outcrop perspective. 1st In-Person Bouma Conference, Utrecht 17-21 April 2023, Abstract Book, p. 8.

New insights into the structural setting of North-Western offshore Sicily, Central Mediterranean

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Keywords: NW Offshore Sicily, inversion, extensional basins.

The North-Western offshore region of Sicily, located at the convergence zone of the Eurasian and African tectonic plates is characterized by intricate geological and tectonic setting. The opening of the Tyrrhenian back-arc basin led to the development of Plio-Quaternary extensional basins, which are characterized by inversion structures. These structures located in the extensional basins of the examined region, have been identified after the interpretation of several multi-channel seismic reflection profiles. The structural and stratigraphic analysis was performed in compliance with the grid of seismic reflection profiles and the boreholes available in the public ViDEPI database. The in-depth analysis of these inverted tectonic structures is attention-worthy. We identified three basins in the area that highlight the inversion of variable intensity. They were all formed during the Early Pliocene rifting phase, paired with extensive volcanic activity; the basins also suffered a contractional episode afterward that resulted in their tectonic inversion. An inversion is registered within these basins involving the Plio-Quaternary deposits. One among these basins shows a strong impact of inversion on the entire sedimentary fill and it affects the sea floor.

This contractional episode has been linked to the proximity of the Sicily Maghrebian thrust front (Argnani & Torelli, 2001) or a shift in the stress direction, signifying a compression in the N-S stress direction (Catalano & Milia., 1990; Sulli, 2000).

Our analysis of inversion features is in agreement with previous studies in the NW offshore of Sicily and provides insights into the deformation history of this region.

Argnani A. & Torelli L. (2001) - Pelagian Shelf and its graben system (Italy/ Tunisia). Mem. Mus. Natn. Hist. Nat., 186, 529-544, https://eurekamag.com/research/020/265/020265291.php.

Catalano R. & Milia A. (1990) - Late Pliocene-Early Pleistocene structural inversion in offshore western Sicily. In The potential of deep seismic profiling for hydrocarbon exploration. 445-449, Technip Paris.

Sulli A. (2000) - Structural framework and crustal characteristics of the Sardinia Channel Alpine transect in the central Mediterranean. Tectonophysics, 324(4), 321-336, https://doi.org/10.1016/S0040-1951(00)00050-0.

The External Ligurian Units of the Northern Apennines: a glimpse in the deformation of shallow accretionary prisms and implications for seismicity

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Keywords: accretionary prism, folds, Ligurian Units.

The External Ligurian Accretionary Wedge preserves tectono-sedimentary assemblages that were originally deposited at the transition between the Ligurian oceanic basin and the passive margin of the Adria plate (e.g. Marroni et al., 2010). It is characterized by the tectonic superposition of different terms of a Late Jurassic–Early Cretaceous to middle Eocene unmetamorphosed succession consisting of a basal clay-rich sequence, followed by a thick pile of calcareous and/or siliciclastic turbidites. The unconformable overlay of middle Eocene slope deposits (i.e., the Epiligurian Units, Ricci Lucci, 1987) constraints the timing of the accretionary stage, also documenting that deformation occurred at very shallow structural levels, up to the seafloor. The deformation style within the accretionary wedge, resulting from offscraping and frontal accretion is characterized by regional-scale folds with mainly overturned or recumbent geometries, and a plethora of associated brittle structures (Vannucchi & Bettelli, 2002; Nirta et al. 2024). These structures represent the product of rock buckling and shearing at the front of subduction zones.

Although such structures are ubiquitous products of deformation at shallow structural levels in both modern and ancient shallow accretionary prisms worldwide – e-g Barbados, the Miura-Boso accretionary complex, and the southern Shimanto belt in Japan or the Nankai or Hikurangi margins - they are not adequately considered in the dynamics of accretionary wedges at the timescale of the seismic cycle, favoring the role played by slip on major faults. Through a detailed structural analysis of the External Ligurian Units in the Northern Apennines, we review the deformation structures characterizing the frontal and shallowest part of the subduction complex. Our findings document that fold-related brittle structures might be associated with transient deformation events at elevated strain rates and in the presence of high fluid pressure, having the potential to cause distributed microearthquake swarms under low effective normal stress and affect the distribution of surficial displacement. The study of deformation in the exhumed ancient accretionary wedges, such as the External Ligurian Units in the Northern Apennines, is therefore highly significant to better understanding modern wedges and related seismic behavior.

Marroni M. et al. (2010) - Anatomy of the Ligure- Piemontese subduction system: evidence from Late Cretaceous–middle Eocene convergent margin deposits in the Northern Apennines, Italy. International Geology Review, 52(10), 1160-1192, https://doi.org/10.1080/00206810903545493.

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Tectono-Stratigraphic setting of the Abruzzo Sub-Apennines along the Colledara-Montefino transect (Abruzzo-Italy)

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Keywords: Messinian-Early Pliocene turbidite successions, geological mapping, sub-surface geology, 3D modelling.

East of the Gran Sasso chain, the sub-Apennine foothills, are characterized by extensive outcrops of turbidites belonging to the Laga and Cellino formations. Despite in the past decades they have undergone several investigations, the poorness of stratigraphic and petrographic data, and the complexity of the orogenic deformations left numerous unsolved questions. These latter concern the precise dating and the possible correlations between adjacent successions (which also imply problems of nomenclature), their basin of origin, and the amount of their tectonic translation.

Our work tries to fill this gap of data starting from an original, and updated, geological survey of a 20 km long – 4 km wide, W-E trending, area straddling the Colledara-Montefino transect.

This area, falls entirely within the 350 Penne geological Sheet, which will be surveyed in the coming years (CARG Project), therefore the mapping was mainly set on the stratigraphy of the 339-Teramo sheet, which contains the northern continuation of the studied structures.

The fieldwork was carried out using digital devices, which led to collect a large amount of stratigraphic and structural data. The initial stratigraphic scheme, already very detailed, has been further implemented with the distinction of newly found facies associations and key-horizons. The high-grade stratigraphic resolution has allowed us to precisely identify the main folds and thrust faults, synthesized in a balanced geological section.

The surface geology was subsequently used to constrain the interpretation of 11 seismic lines also calibrated at depth by the Logs of the public wells drilled for hydrocarbon exploitations (both sections and well-logs are available in the ViDEPI project).

Their correlation allowed us to: i) recognize the unconformity between the Lower Pliocene and the Upper Pliocene successions, ii) describe the deep geometry of the outcropping thrusts, and iii) highlight the complexity of the whole thrust systems, which also includes several blind splays.

Finally, a 3D subsurface geological model has been built, including the most important seismo-stratigraphic units from the top of the Triassic Dolostones to the top of Lower Pliocene turbidites and showing the geometry of the main tectonic structures.

The Palaeozoic succession of the Giglio Island (Tuscan Archipelago)

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Keywords: Palaeozoic successions, Giglio Island, palinology.

The Giglio Island is part of the NNW-trending Giglio-Formiche di Grosseto Ridge, a partially submerged structural high in the northern Tyrrhenian Sea bounded by normal faults, where an exhumed crustal sector of the inner Northern Apennines is exposed. On the Island, a Messinian monzogranite emplaced at 5.7 ± 0.4 Ma (Ibe et al., 2023) is widely exposed together with part of its host rocks. The latter are only preserved in a few limited exposures in the northern part of the island, and consist of metapelitic rocks affected by contact metamorphism. Due to their lithological characteristics, mainly consisting of alternation of quartz metasandstone and metasiltstone, and their low pressure metamorphism, the age of the protolith and its relations with the stratigraphic units exposed in the inner Northern Apennines have not been well constrained. For this purpose, we present the results of a microfloristic and palynological analysis of many key samples from the organic metasiltstone the form the host rocks. The palynological assemblage is quite preserved and diversified. It mainly consists on taeniate bisaccate pollen as *Protohaploxypinus* spp. (*P. limpidus* and *P. microcorpus*), *Striatopodocarpites* spp.. (*S. cancellatus* and *S. fusus*) and *Striatoabieites* sp. with taeniates as *Alisporites* sp. and *Sulcatisporites* sp. and polyplicates as *Vittatina costabilis*. Trilete spore sas *Calamospora* sp., *Densoisporites* sp. and *Kraeuselisporites* sp. were also documented. Microflora recorded shows close similarities with the palynological assemblages documented from different middle to upper Permian formations cropping out in Southern Tuscany and Elba Island (*i.e.*, Arenarie del Monte Argentario, Poggio al Carpino, Farma and Rio Marina formations) and from Bellerophon Formation cropping out in the Southern Alps (Italy) which were independently-dated by conodonts. Based on this correlation, the microfloristic assemblage from the host rocks of the Giglio monzogranite can be assigned to late Guadaluapian (Capitanian)-Lopingian age.

Ibe C.U. et al. (2023) - Rapid exhumation of young granites in an extensional domain: the example of the Giglio Island pluton (Tuscany). Geological Magazine, 160, 1241-1253, https://doi.org/10.1017/S0016756823000420.

Orogenic evolution of the northern Calabria-southern Apennines System: Tectonics

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Keywords: southern Apennines, stratigraphy, tectonics.

We present a review of the orogenic evolution of northern Calabria and the southern Apennines (Vitale & Ciarcia, 2013, 2018, 2022) in terms of stratigraphy (poster 1) and tectonics (poster 2). Three main tectonic complexes characterize this orogenic chain: (1) remnants of the overriding plate, including Variscan Paleozoic basement (Calabria-Peloritani Terrane; CPT) that tectonically cover (2) an Alpine metamorphic belt, corresponding to an exhumed subduction channel, formed by slices of CPT, metaophiolites (metamorphic Ligurian units), and some successions of the continental Adria plate (downgoing plate); in turn superposed to (3) a fold-and-thrust belt made of remnants of an oceanic accretionary prism (non-metamorphic Ligurian units) on the top, and an imbricate orogenic pile consisting in shallow-water to pelagic continental Adria successions, also including the buried shallow-water carbonates of the Apulian Platform. The exposed Apulian Platform domain (Puglia region) and the Adriatic Sea represent the current foreland. The orogenic chain results from the subduction of the Ligurian Ocean lithosphere beneath the European Plate/CPT starting during the Paleocene-Eocene.

After the complete closure of the Ligurian Ocean in the Early Miocene, the subduction continued with the involvement of the continental part of the Adria plate, triggering the crustal shortening up to the Middle Pleistocene. Complex geometries, reflecting the articulated paleogeographic domains formed by alternating shallow-water carbonate platforms and deep basins, controlled the shape of the thrust front-foredeep-forebulge system.

Thin- and thick-skinned thrusting episodes have alternated during the orogenic shortening; however, since the Early Pliocene, deep-seated ramp-dominated thrust faults, resulting in widespread envelopment thrusting and appearing as out-of-sequence structures in the allochthonous wedge, drove the crustal shortening. The alternating different tectonic styles also resulted from the involvement in the subduction system of the continental Adria lithosphere, thicker under the carbonate platforms and thinner under the interspersed pelagic basin and the western margin facing the Ligurian Ocean. This variable lithosphere thickness caused two main backstops that triggered the thick-skinned tectonics. The restored mean tectonic vergences indicate that the thrust front migrated to the south in the Eocene-Langhian period, turning to E during the Serravallian-Pleistocene interval.

Vitale S. & Ciarcia S. (2013) - Tectono-stratigraphic and kinematic evolution of the southern Apennines/Calabria-Peloritani Terrane system (Italy). Tectonophysics, 583, 164-182, https://doi.org/10.1016/j.tecto.2012.11.004.

Vitale S. & Ciarcia S. (2018) - Tectono-stratigraphic setting of the Campania region (Southern Italy). Journal of Maps, 14, 9-21, https://doi.org/10.1080/17445647.2018.1424655.

Vitale S. & Ciarcia S. (2022) - The dismembering of the Adria platforms following the Late Cretaceous-Eocene abortive rift: A review of the tectono-stratigraphic record in the southern Apennines. International Geology Review. 64 (20), 2866-2889, https://doi.org/10.1080/00206814.2021.2004559.

Multidisciplinary study of non-volcanic CO_2 degassing vents in Oliveto Citra area (southern Apennines)

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Keywords: non-volcanic degassing, southern Apennines, geophysical and geochemical surveys.

This study aims to investigate the CO_2 leakage mechanisms in relation to tectonic structures in some degassing vents in the Oliveto Citra area. These CO_2 emissions are associated with normal fault arrays that crosscut a tectonic pile formed by carbonates (Apennine Platform) tectonically covered by an oceanic succession (Ligurian Accretionary Complex) made of clay and turbiditic limestones (Vitale & Ciarcia, 2018; Vitale et al., 2020). We performed geophysical surveys, including 2D Electrical Resistivity Tomography (ERT), Induced Polarization (IP) Tomography, 2D Seismic Refraction Tomography (SRT), Magnetometry (MAG) and Self Potential (SP) mapping and geochemical investigations, consisting of soil pH and CO_2 flux mapping. All these surveys were accompanied by structural analysis and mapping of major faults (e.g., Vitale et al., 2023). The results of this multidisciplinary study indicate that most of the gas emissions are along the intersection between the major faults, and once fluids approach the surface following the main fault zones, their migration and leakage become mostly controlled by the surficial segmentation of faults and local permeability paths.

Vitale S. & Ciarcia, S. (2018) - Tectono-stratigraphic setting of the Campania region (Southern Italy). Journal of Maps, 14, 9-21.

Vitale S. et al. (2020) - Structural and Stratigraphic Setting of Campagna and Giffoni Tectonic Windows: New Insights on the Orogenic Evolution of the Southern Apennines (Italy). Geosciences, 10, 405.

Vitale S. et al. (2023) - Insights on the active Southern Matese Fault system through geological, geochemical, and geophysical investigations of the CO_2 gas vent in the Solopaca area (southern Apennines, Italy). Tectonophysics, 846, 1-12, 229657.

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The mesorif unconformity in the external rif (Morocco): new insights from stratigraphical and biostratigraphical constraints

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Keywords: calcareous nannofossils biostratigraphy, wedge-top basin, Mesorif (Rif Chain).

The Rif Chain (Northern Morocco) is in the westernmost extend of the Apennine–Maghrebian Belt, resulting by the convergence of the African and Eurasian plates during the Tertiary evolution of the western Mediterranean subduction system. Throughout the compressional tectonic phases responsible for the Neogene deformation of the External Zone (Rif Chain), three stacked tectono–paleogeographic sub-domains developed, from north to south and top to bottom: Intrarif, Mesorif, and Prerif.

In this study, we present new stratigraphic findings regarding Middle Miocene sedimentary successions belonging to the Mesorif Sub-domain. In Tamda area, 50 km east of Taounate City, a thick deposit of conglomerates, marls, and marly-limestones, with intercalations of calcarenites (Tamda section) unconformably overlies (Mesorif unconformity Auct.) a Late Jurassic-?Aquitanian continuous stratigraphic succession made up of silty-clay marls, marly-limestones, and limestones deposits (pre-orogenic succession).

The sedimentary succession of the Tamda section, which shows slight evidence of compressional deformation, sedimented in a late-orogenic depositional stage. In contrast, the pre-orogenic succession underlying the unconformity is highly affected by compressional deformation.

The investigated stratigraphic section starts with a thick to very-thick-bedded polygenic conglomerate with thin intercalations of marls and marly-limestones. Moving upward, the succession predominantly consists of calcarenites, marls, and marly limestones, characterized by several slumping horizons.

The quantitative biostratigraphic analyses performed on the marly samples collected along the section, provided a new age for this succession, which was previously referred to the Oligocene (e.g., Gimeno-Vives et al., 2020). In this regard, the total assemblages of the calcareous nannofossils from the Tamda section point to a late Serravallian age and allow us to refer the Mesorif unconformity to the Middle Miocene.

This result offers significant insights into the kinematic evolution of the Mesorif Sub-domain, bringing to consider the Tamda succession as deposited in a wedge-top basin on top of the deforming Mesorif Sub-domain. Our biostratigraphic results indicates that the Mesorif was involved in the Rif fold-and-thrust belt during the late Serravallian (~12 Ma). During this time, the leading edge of the Rif Chain was marked by the basal thrust of the Mesorif, while the Prerif Sub-domain was still part of the foreland domain of the Middle Miocene orogenic system.

Gimeno-Vives O. et al. (2020) - The structure of the Central-Eastern External Rif (Morocco): Poly-phased deformation and role of the under-thrusting of the North-West African paleo-margin. Earth-Science Reviews, 205, 103198, https://doi.org/10.1016/j.earscirev.2020.103198.

Improving climatostratigraphic signals at the Gelasian GSSP type-section

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Keywords: Gelasian GSSP, Monte San Nicola type-section, high-resolution climatostratigraphy.

As part of the GELSTRAT project (Head & Caruso, 2022), we present high-resolution climatostratigraphic results at the Monte San Nicola type-section (MSNt-s) in Sicily, the Global Stratotype Section and Point (GSSP) of the Gelasian Stage (Rio et al., 1998). The GELSTRAT project focuses on the reinvestigation, at high stratigraphic detail, of the Gelasian GSSP, which defines the base of the Pleistocene Series and of the Quaternary System. The interval falls within a critical shift in Earth's climate, including the progressive intensification of the North Hemisphere Glaciation. The mechanisms accompanying this crucial climate phase and the regional responses to this transition in the Mediterranean area are still debated. By improving the dataset on such a relevant section, we intend to strengthen the correlation potential of the MSNt-s and of the GSSP itself outside the type-area and illuminate a crucial phase of Earth history. Next to the recent climatostratigraphic reconstruction (Addante et al., 2024) performed on the type-section, across Marine Isotope Stage (MIS) G4-103, we now extend our study to the interval encompassing Marine isotope Stage (MIS) 104 to MIS 100, not yet studied in the type-section with a high-resolution detail. Based on the high-resolution sampling of 5 cm, which allows a sub-millennial scale resolution (~800 years), we provide an updating on planktonic foraminiferal ð18O record and calcareous plankton assemblage and we present new alkenone data (total C37 alkenone concentration and alkenone-derived SST°C). The stratigraphic pattern of C37, in conjunction with field observation, enhance positions of sapropels and allow precise tuning of the stratigraphic record to insolation cycles, improving chronology of the section. In addition, the implemented dataset constraints precise position of calcareous nannofossil biostratigraphic events close to the GSSP and provide clear documentation of both orbitally forced glacial-interglacial phases and suborbital cyclicity. The overall results contribute to frame the Gelasian GSSP within a global climatostratigraphic evolution, enhancing its correlation on regional and global scale.

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Seismo-stratigraphic analysis of middle-late Quaternary shelf margin prograding deposits in the Western Sicily offshore (central Mediterranean Sea)

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Keywords: shelf margin, seismostratigraphy, Adventure plateau.

Using seismic reflection profiles for the detailed seismo-stratigraphic analysis of prograding systems is a widely used technique also in the Adventure Plateau, characterized by a wide, shallow water, submerged plateau in the Sicily Channel offshore (central Mediterranean Sea) (Colantoni et al., 1985).

Here, we analyse a couple of shelf margin prograding systems, using Ultra High Resolution (UHR) seismic reflection profiles (acquired with a 48-channel sparker seismic source) which allowed a high-quality spatial resolution seismo-stratigraphic analysis.

One of these prograding systems is located along the western Sicily mainland continental shelf edge and consists of only one, wedge shaped, sedimentary unit made up by a succession of clinoform reflectors; the wedge, which is up to 25 m thick, pinches out at - 135 m water depth at its landward termination and at - 157 m water depth at its seaward termination. The basal surface is characterized by enhanced erosional truncation of underlaying reflectors and by downlapping terminations of the overlaying clinoforms which display an oblique-tangential geometry and erosional truncation of upper termination.

The other prograding system, in the northern margin of the Adventure Plateau, displays a more complex internal geometry: indeed, it consists of four laterally stacked wedges with clinoform reflectors displaying oblique-tangential configuration with downlap and erosional truncation as bottom and top termination respectively. To separate two adjacent prograding wedges, a thin lens of high frequency, continuous, prograding-to-aggrading reflectors lies in between of them. The four wedges show different width and vertical thickness, both controlled mainly by depth and dip of the bottom surface. The outermost wedge is up to 13 m thick and pinches out at - 140 m water depth at its landward termination and at - 163 m water depth at its seaward termination.

The analysed sedimentary systems show many similarities with other prograding depositional wedges observed along the Mediterranean continental shelf margins (Chiocci et al., 1997, 2004). Based on their stratigraphic relationship, seismic facies, and internal depositional geometry, we suggest the prograding wedges accumulated as shallow water deposits during sea level falling to lowstand stages related to high frequency (about 100 ky) and high amplitude (about 100 m) glacio-eustatic changes occurred during middle-late Quaternary.

The above illustrated differences in thickness, lateral extension, and seismic facies can be attributed to the different physiography of the margins on which the prograding systems developed, to their opposite exposure to fetch, and to the different sedimentary supply, also considering that during the highstands stages, the prograding depositional system of the Adventure Bank remained completely isolated from the emerged mainland (Civile et al., 2015).

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Chiocci F.L. et al. (2004) - Atlas of Submerged Depositional Terraces along the Italian Coasts. Memorie Descrittive della Carta Geologica d'Italia, LVIII, 194 pp.

Civile D. et al. (2015) - The lost Adventure Archipelago (Sicilian Channel, Mediterranean Sea): morpho-bathymetry and Late Quaternary palaeogeographic evolution. Global and Planetary Change, 125, 36-47.

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The stratigraphic signature of the Carnian Pluvial Episode in the northern Greater Adria

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Keywords: paleoclimate, Triassic stratigraphy, Adria.

The Triassic record is marked by a significant worldwide climate and biological crisis known as Carnian Pluvial Episode (CPE, ~232-234 Ma), linked to C-cycle perturbations and global warming, triggering many important consequences on the sedimentary, environmental and global ecosystem evolution: changes in shelf carbonate factories and demise of high-relief carbonate platforms, biological turnover of different taxa occurred together with radiation and extinction of some groups. In the circum-Tethyan region, the shift from the arid to semi-arid conditions towards more humid conditions favored an increased runoff with the development of siliciclastic successions. This occurred in conjunction with a relative sea-level drop that locally amplified the sedimentary effects linked to the CPE. The resulting stratigraphic signature is particularly evident in the northern part of the Adria plate, from the Southern Alps to the Outer Dinarides, but also in other inland settings such as the Tuscan nappe. In basinal settings the onset of the CPE (late Early Carnian) corresponds to the loss of calciturbidites shed from nearby high-relief carbonate platforms. This is associated with the shift to humid conditions, documented by various proxies. The upward sharp transition to coarse siliciclastics, well-expressed in the Dolomites and Julian Alps, reflects both the increased runoff related to the enhanced hydrological cycle and the seaward shift of the siliciclastic shoreline associated with the relative sea-level drop. The platform top of the demised carbonate platforms underwent subaerial exposure, developing karst surfaces (Dolomites), emersion breccia and spodic paleosols (Carnia) and bauxites (Western Julian Alps, northern Outer Dinarides). A subsequent relative sea-level rise resulted in some cases in a shift to outer ramp settings (Dolomites), while elsewhere established new accommodation space in previously emerged areas, coupled with a new siliciclastic pulse related the CPE. Common abundant plant debris, ambers (Dolomites) and coal horizons (Dolomites, Carnia, Lesno Brdo, Outer Dinarides) represent signals of humid climate and environmental stress. The lowermost Upper Carnian is characterized by the return of prevailing carbonate sedimentation, with a shallow ramp setting developed on an almost flattened paleotopography in the Southern Alps up to the Outer Dinarides. Another sea-level fall then produced a significant unconformity on the whole region. Above, alluvial to marginal marine settings within a semi-arid climate were established basin-wide, closing the stratigraphic and sedimentary window opened by the CPE and enabling the development of the epeiric Dolomia Principale / Hauptdolomit carbonate platform. The CPE therefore records one of the most prominent rearrangements of the stratigraphic framework of the Western Tethys, as evident in Greater Adria.

Ratifying the upper Campanian to Paleogene shallow-water carbonate unit to fill a lithostratigraphic "gap" within the Apennine Carbonate Platform succession

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Keywords: carbonate platforms, lithostratigraphy.

The uppermost Campanian-lower Paleogene of the Apennine Carbonate Platform usually refers to a shallow-water carbonate unit called "calcari cristallini" or "calcari saccaroidi", despite these designations do not comply with the International Stratigraphic Guide (Salvador, 1994). In this contribution, we aim to outline key elements necessary for ratification as a formal lithostratigraphic unit for inclusion in the official geological mapping (CARG) project at 1:50,000 scale.

We performed a new survey in the Gorga-Morolo area (Lepini Mts, Central Italy), where these rocks extensively crop out, and re-examined thin sections from samples collected by Molinari Paganelli & Tilia Zuccari (1987).

At Mt Filaro, above the rudist-rich "calcari a radiolitidi" intertidal succession with *Cuvillierinella salentina*, characteristic dolomitized mudstones with discorbids and ostracods occur (lowermost part of the unit; lithofacies 1). These are overlain by well-bedded, coarse grained, bioclastic packstones (cf. "calcari saccaroidi" or "calcari cristallini" *auctt.*; lithofacies 2) made by rudist and echinoderm fragments with *Orbitoides media, Sivasella monolateralis, Siderolites* sp., among others. Locally, interfingered with the lithofacies 2 are mudstones to wackestones with discorbids, miliolids and *Rhapydionina liburnica* (lithofacies 3). The whole faunal assemblage points to a late Campanian-Maastrichtian age, whereas both lithofacies 2 and 3 are eventually capped by paleokarst features like *Microcodium*, red/green veneers filling mesoscale dykes or forming beds. The uppermost part of the succession is made by a few tens' meters of gray-hazelnut mudstones with Characeae, ostracods, miliolids and dasycladacean algae of Paleocene, or possibly early Eocene, age (lithofacies 4), characterized by traces of subaerial exposure. Future analyses will allow us to understand whether the lithofacies 4 can be compared with the "Trentinara formation". The upper boundary is unconformable with the Miocene "calcari a briozoi e litotamni".

Listed lithofacies may exhibit latero-vertical variations in organization due to migrations of the facies pattern typical of carbonate platforms. The total thickness, reaching up to 500 m at Mt. Filaro, considered its maximum vertical extent, can significantly decrease or even be absent in other areas of the Apennine Carbonate Platform (including Abruzzi, Latium, Molise, Campania, and possibly north Calabria regions).

This upper Campanian-Paleogene *p.p.* unit is partially coeval with the Orfento Formation, "Mt. Sant'Elia dolostones" or to the "Ciolo limestone" of the Apulian Carbonate Platform, and the "liburnian limestone" of the Adriatic Carbonate Platform of NE Italy.

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A potential Mediterranean reference section for the GGSP of the Burdigalian Stage: St. Thomas section (Delimara Peninsula, Malta Island)

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Keywords: Burdigalian GSSP, Malta Island, integrated stratigraphy.

The Global Stratotype Section and Point (GSSP) of the Burdigalian (Lower Miocene) is still missing for the Miocene Epoch. In the recent literature, different criteria have been adopted to identify or approximate the base of the Burdigalian stage (Raffi et al., 2020). In terms of calcareous plankton, one of the criteria suggested by Haq et al. (1987) and also reported in the GTS 2020 is the FO calcareous nannofossil *Sphenolithus belemnos* with an age in open ocean of 19.01 Ma (Backman et al., 2012). A multidisciplinary study has been performed of S Thomas section combining calcareous plankton biostratigraphy, chemical analyses based on xrf data, magnetic susceptibility, colour signals and stable isotope records. Major aim of this study was to analyze St. Thomas record as potential candidate section for defining the criteria for the Burdigalian GSSP in the Mediterranean area.

The sedimentary record of St. Thomas section (91.15 m thick) is characterized by an alternation of calcareous marls and marly limestones with subordinated prominent bioturbated indurated limestones that are deposited in a deep marine environment (the Middle Globigerina Limestone member of Globigerina Limestone Formation). Foresi et al. (2014) presented a bio-magnetostratigraphic study of St. Thomas section and chronologically placed this central Mediterranean record in the lower part of the Burdigalian, between ~19.7 and ~17.2 Ma. We present oxygen (d18O) and carbon (d13C) stable isotope records (mean time resolution of 17 kyr) obtained from planktonic foraminifer *Globigerinoides quadrilobatus* (a warm to temperate and oligotrophic waters species). The d18 G. quadrilobatus signal shows light values, ranging between -2.5 to 0 ‰, well comparable with the other O isotope data available in the Lower Miocene deposits from Malta Island, and the obtained record as well as the d13C ones (ranging between 2.6 to 0.14 ‰) are almost in phase with the recent open ocean record of Westerhold et al. (2020). According to the chronology proposed by Foresi et al. (2014), the d18 G. quadrilobatus record shows, in the lower most part of the study section between 19.41 and 19.5 Ma, a cooling event that chronologically could correspond to the Miller's glaciation event Mi1aa. This cooing event seems almost in phase with a node of 1.2 My obliquity cycle as the other Miller's glaciation events (van Dam et al., 2006). In terms of calcareous plankton, this cooling event is also constrained by the FCO of planktonic foraminifera *Paragloborotalia acrostoma* (estimated age of 19.54 Ma) and, at the top, by the FO and FCO of calcareous nannofossil *Sphenolithus belemnos* (estimated age of 19.09 Ma and 19.04 Ma, respectively). As for the definition of the Burdigalian GSSP (Lower Miocene), the robust integrated bio-magnetic and isotope stratigraphies of S. Thomas section suggest that it is a GSSP potential candidate. In particular, the onset of Miller's glaciation event Mi1aa at ca. 19.5 Ma combined with the FO of *S. belemnos* at 19.09 Ma, could represent two valid criteria for the identification of this GSSP.

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Deltaic processes and depositional canyon-heads in a narrow continental shelf: examples from the north-eastern Sicilian margin

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Keywords: deltaic sedimentation, distributary channels, gully.

In this work, through the integrated analysis of Multibeam bathymetric and seismic/Chirp profiles, we analyse the proximal part of canyons in the area between Capo Milazzo and Capo Peloro (Messina). In particular, we discuss the interaction between river-borne sediment, seafloor instability and sediment-gravity flows in the evolution of canyon heads located.

The shelf has an average width of less than 5 km, and presents a varied bathymetric setting with numerous geomorphic elements (bedforms, distributary channels, gullies) which especially insist deltaic bodies, which form the current highstand wedge on the shelf. The analysis of the seismic profiles allows the contouring of the base of this wedge and the identification of the upper portion of the underlying deposits of the last lowstand stage.

In the distal offshore portion of the shelf, near the shelf break, several canyon-heads are concentrated and, sometimes, interconnected: Cocuzzaro, Rometta, Villafranca, Tarantona, Sindaro, Rosocolmo 1, Rosocolmo 2 and Rosocolmo 3 canyons. Here the interaction between the canyon-heads and the deltaic processes results in an articulated network of several distributary channels. The western canyons-heads (Cocuzzaro, Rometta and Villafranca) reach closer to the coastline (even <500 m) with a meandering pattern and a complex branching of gullies before merging into the main channel within the canyon containment. Conversely, the eastern canyons-heads (Tarantona, Sindaro, Rosocolmo 1, Rosocolmo 2 and Rosocolmo 3) develop further away from the coastline (about 3 km) with a markedly straight planform and poor branching of the distributary channels on the outer continental shelf. In the inter-channels areas, the seismic profiles show a depositional character with the presence of well-stratified reflectors: their setting highlights low-energy and fine grained flows, with a possible reworking by oceanographic currents along the shelf. Conversely, in the channels area the presence of laterally truncated reflectors is a proof of erosional flows associated with coarse-grained sedimentation and chaotic bodies, which are indicative of the action of higher-energy flows and seafloor instability. The distribution of the coarse-grained deposits within the canyon axis causes a high-amplitude floor, which does not allow the visualization of the deepest units.

In conclusion, our work shows the nature of the geomorphic elements and processes that contribute to the infill of the canyon-heads. It highlights that in margins with a narrow shelf, during the present-day highstand, deeply carved canyon heads form a peculiar deep-water and confined environment, where deltaic processes result in a unique geomorphologic and stratigraphic setting.

Sediment distribution in the Brazos Delta: Estimation and numerical modelling of sedimentation rates and the effect of bioturbation in event beds preservation

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Keywords: shelf, mud, sediment.

The sedimentology of twenty-five core samples from the Brazos Delta offers insights into its lithological composition. Analysis reveals five distinct facies characterized by varying colors and sediment grain sizes: red mud, brown mud, grey mud, brown silty sand and muddy, calcareous sand. These colors provide clues about the sediment sources, indicating a blend of materials from the Brazos River beds and the shelf-derived sediment of the Gulf of Mexico (GOM). Examination of the sediment grain size distribution indicates a composition of 40% clay, 50% silt, and 10% sand, emphasizing sedimentary processes, distribution patterns, and biogenic reworking. Swath bathymetry data unveils the asymmetrical nature of the delta, with notably deeper water depths observed across the shelf slope and the updrift area situated in the northeastern segment of the basin, in contrast to the shallower depths along the downdrift in the northwestern region.

The facies correlation highlights distinct sediment patterns along the river mouth to the downdrift and updrift areas of the Brazos Delta. The prevalence of red mud, brown mud, and muddy-calcareous sand facies characterizes the river mouth and downstream sections, while updrift parts are dominated by brown silty mud and grey mud. The grey and brown mud predominantly represent the basinal facies. XRF elemental analysis shows an increase in Mo/Al in the red and brown mud, indicating varying redox marine conditions, contrasting with the display observed in grey mud. Similarly, Ti/Al is significantly higher in red and brown mud, signifying the terrigenous inputs of the Brazos River. In contrast, the marine-sourced shelf grey mud, which consists of material from updrift rivers (Neches, Calcasieu, Mermentau, Atchafalaya and Mississippi), exhibits lower ratios.

Examination of sediment accumulation rates, determined through excess 210Pb geochronologies of six cores, discloses varying sedimentation rates characterized by deposition from fluvial flood events and remobilized sediment from the proximal shelf alongside relics from the older delta, contrary to steady-state accumulation patterns previously posited. Event beds were mainly preserved nearshore but displayed moderate to complete bioturbation deeper into the basin. The numerical model shows that preservation potential and biogenic activities are inversely related and dependent on physicochemical conditions at deposition.

The alternating layers from fluvial flood events and marine processes indicate the delta susceptibility to local climate dynamics. These findings underscore the profound impact of sediment processes (sedimentation rate) and biogenic events (such as bioturbation) on strata preservation within modern deltas. Moreover, they offer valuable insights that could inform predictions regarding sediment accumulation in ancient deltaic environments.

The Orfento formation of the Maiella Mountain (Central Apennines, Italy): depositional facies model of an Upper Cretaceous bioclastic wedge

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Keywords: bioclastic limestone, Upper Cretaceous, Apulia.

The Orfento formation is an Upper Cretaceous bioclastic wedge developed along the northern margin of the Apulia platform, magnificently exposed in the Maiella Mt., and characterised by a dynamic depositional history. Despite extensive research on this unit since the 1960s, the depositional facies model and the main factors controlling the sedimentation are still debated (Mutti et al., 1996; Vecsei, 1998; Eberli et al., 2019). New data acquired through geological field survey and drone-based remote sensing, across the Orfento fm outcrops in the Maiella Mt, provide new elements that contribute to clarifying the dynamics and sedimentary processes of the Orfento fm, and offer new insights on Upper Cretaceous bioclastic wedges and the evolution of the northern margin of the Apulia platform. The Orfento fm has been subdivided into two superposed intervals, characterized by different facies associations, thickness and geometries. These differences reflect two distinct depositional phases and facies models. The lower interval (a) (late Campanian - early Maastrichtian), is characterised by about 50 metres thick alternations of pelagic Scaglia-like limestones and tabular resedimented bioclastic deposits. This interval has been interpreted as the result of two delta fan systems, whose geometry was strongly influenced by earlier palaeomorphology, being developed at the mouth of two major indentations, incising the pre-Orfento platform margin. The delta fan systems were supplied by sediments produced within a narrow belt located in correspondence with the pre-Orfento platform margin. Sediment transport occurred under high hydrodynamic conditions, likely induced by accelerating currents generated by the morphological differences along the margin. The upper interval (b) of the Orfento fm (Maastrichtian p.p.) is characterized by a up to 250 thick succession represented by massive, tabular, and wedge-shaped biocalcarenites, with rare pelagic intercalations. This interval has been interpreted as the result of shallow water deposition with progradational sandwaves, incised by tidal channels. The production area expanded considerably with respect to the former interval, extending from the inner sector of the pre-Orfento platform to the pre-Orfento proximal basin. The produced bioclastic sediment was reworked by wave motion, tidal currents, and storms. NW-SE oriented synsedimentary faults locally interact with sedimentary processes, by creating asymmetric, relatively small depocenters, trapping the bioclastic reworked sediments. These faults belong to the same fault system that controls the sediment distribution of the Orfento fm-equivalent deposits along the Casal Bordino corridor, in the Rospo Plateau (Santantonio et al., 2013). The detailed analysis of the Orfento fm highlights the interplay between tectonics, local morphology, and sedimentation processes in shaping bioclastic deposits, providing a valuable framework for understanding similar systems in the region.

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Stratigraphic patterns of shelf-type deltas in the Lower Pleistocene of the Sant'Arcangelo Basin, Basilicata, southern Italy

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Keywords: shelf-deltas, aggradation, progradation, retrogradation.

This poster presentation summarizes the very preliminary results of a BSc-thesis project based at the University of Basilicata and focused on an outcrop section exposed in the north-eastern sector of the Sant'Arcangelo Basin (SA). The SA Basin developed first as a wedge-top depression and, later as a pull-apart basin during the Plio-Quaternary, at the forefront of the Apennine Orogen, southern Italy. Fan-deltaic sedimentation dominates over other deposits being replicated several times across four major depositional sequences, which represent the stratigraphic basin infill. Among the variety of spectacularly-exposed outcrop sections nowadays visible within the SA Basin, the Alianello Section is one of the best exposed and easily accessible. It is a 35-40 m high and ca. 420 m long cliff bordering the left margin of the modern Agri River Valley. The outcrop, which is E-W-oriented reflecting a landward-basinward cross-section, has for long been interpreted as the result of vertically-stacked, ancient shelf-deltas, entering a shallow-water embayment and resulting from flood-dominated high-sediment discharge episodes, whose rates outpaced the rate of tectonic subsidence. Strata are organized into a number of simple sequences or parasequences, consisting of well stratified delta-plain conglomerates (facies 1), passing laterally into coarse-medium-grained delta-front sandstones (facies 2), in turn merging basinward into indistinctly-stratified prodelta mudstones (facies 3). The section has been documented based on high-resolution drone ortho-photos integrated by a Li.D.A.R. DTM, with the aim of detecting possible shoreline trajectories during deltaic stacking, with the final goal of defining patterns of progradation, aggradation and retrogradation of the deltaic sequences. Our preliminary achievements indicate a complex interplay between river-dominated processes, entering a shallow-marine environment and producing rapid lateral wedging of the various deltaic tongues into prodeltaic fines.

Deflected deltas: what are they?

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Keywords: deltas, deflection, current-dominated.

Deltas form conventional fan-shaped morphologies along regular shorelines with no lateral constraints, delivering sediments radially distributed from the entry point basinwards, in both subaerial and subaqueous environments. River floods, waves and tides impact on sediments distribution and environment partitioning leading to a variety of deltaic shapes.

When dominant over other processes, along-shore currents modify the delta shape, generating asymmetrical coastal plains, deflected delta fronts and elongate sandbanks. This setting leads to sedimentary facies distribution and sandbody physical attributes that may depart from predictable models on deltas.

In this presentation, a series of modern delta examples are considered, particularly impinging confined coastal settings such as seaways or straits, where alongshore water circulation is amplified due to the lateral constriction. Then, a few case studies documenting ancient deflected deltas are presented. Common elements in these deltas are: (i) the progressive-upwards change in the dominant process of sediment dispersion recorded in the delta facies; (ii) the predominance of river- and wave-influenced lithofacies on early stages of progradation; (iii) current reworking on the delta front deposits during late stages of deltaic advancements, with consequent in-plan morphologies deflected/elongated in the direction of the dominant flow.

Deflected delta models suggest analogies with the spatial distribution of many hydrocarbon reservoirs investigated along the margins of confined, narrow, linear basins, the interpretation of which is challenging in subsurface exploration.

Coralgal buildup in a mixed carbonate-siliciclastic succession of the Upper Eocene San Martí Xic Formation (Orís, Vic, SE Ebro basin, Spain)

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Keywords: cluster reef, turbidity, mixed sedimentation.

The mixed carbonate siliciclastic deposits of the Upper Eocene San Martí Xic Formation (Orís, Vic, SE Ebro basin, Spain) shows the presence of two sedimentary cycles, characterized by coralgal bioconstructions, developed in a fine sedimentary matrix, mainly composed by marls. Such layers, characterized by cluster reef with lens-shaped geometries, developed on top of well sorted bioclastic wackestone to packstone rich in *Discocyclina* at the base of the succession and *Nummulites* at the top of the succession. Facies analysis allows to better constrain the paleoenvironment where coralgal buildup developed, mainly characterized by high sedimentation rate, mesotrophic conditions and turbid waters. The Upper Eocene mixed carbonate-siliciclastic succession of San Martí Xic Formation was strictly influenced by local factor associated with the evolution of the Ebro Basin. In particular, from the early Eocene to the Oligocene, the south-eastern margin of the Ebro Basin evolved as a consequence of the uplift of the Catalan Range thrust. The central part of this zone shows the most pronounced deformation, which took place from the middle to late Eocene accompanied by sin-sedimentary evolution of fan and fan-delta depositional systems. These deposits gradually evolved into basin sedimentation with shallow water limestones and clastic sediments corresponding to the last marine event in the Ebro Basin. In this view, such stressed environment shows the resilience of coralgal buildups. In particular, the first sedimentary cycle characterized by the presence of wackstone to packstone with *Discocyclina*, developed in a deeper and oligophotic environment associated with more humid conditions, while the subsequent sedimentary cycle shows more arid conditions testified by the presence of *Nummulites*. Coralgal buildups interdigitated with progradational and aggradational deltaic sediments of San Martí Xic Formation were strictly influenced by the evolution of delta fan system associated with the uplift of the Catalan Range thrust and was also controlled by climatic changes occurred during the late Eocene.

Vertebrate pits recorded in carbonate sedimentary succession: the case study of the Pliocene Macco formation (Tarquinia - Central Italy)

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Keywords: facies analysis, marine vertebrates, Pliocene.

The Macco formation (Middle to Upper Pliocene) predominantly consists of bioclastic limestones. Detailed facies analysis reveals a prevalence of packstone to rudstone rich in red algae and benthic foraminifera. These facies, in conjunction with paleontological evidence, suggest a depositional environment characterized by a bathymetric depth of approximately 30 to 40 meters. Notably, an outcrop of the Macco formation exposed in the town of Tarquinia exhibits peculiar lenticular concave shapes, ranging in depth from 1.36 to 0.96 meters and with a length from 1.04 to 3 meters. Intriguingly, microfacies analyses conducted within and outside these concave structures reveal similar textures and compositions. The absence of flame structures typically associated with fluid circulation within sediment, and the same sediment textures, suggests that the formation mechanism is unlikely to be linked to seismic events or debris flow mass transport. On contemporary sea floors, seabed pockmarks are among the most conspicuous and common morphological features. Such morphologies are generally attributed to the venting of hydrocarbon fluids from sedimentary deposits. However, several investigations in seafloor worldwide, at both shallow and deep depth, have highlighted similar pits, the origin of which seems to be tied to benthic foraging behaviours of marine vertebrates, particularly cetaceans. This perspective underscores the significant role of marine megafauna in processes such as bioturbation, sediment transport, and their impact on marine ecosystems worldwide. While the debate surrounding benthic feeding activity persists within the scientific community, the presence of such traces in the fossil record remains largely unexplored. Therefore, the concave structures observed within the Macco formation may represent a novel instance (the first one?) of benthic feeding registered in the geological record.

Environmental and human control factors on the Holocene evolution of Venice lagoon: sedimentological and geochemical approach

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Keywords: Venice lagoon, sedimentology, geochemistry.

The lagoons are among the most fragile environments on the Earth's surface, since they are naturally subject to submersion or filling after few millennia from their formation, without any human activity aimed at balancing the variables of the system. They are important sites for socio-economic reasons, because of the typically richness of nutrients and biodiversity. Lagoons play an important role in biogeochemical cycles due to their capability to bury C and N and to re-emit N into the atmosphere. The factors affecting their evolution worldwide are mainly related to climate change and human activities. Changes in sea-level, precipitations, temperature, meteo-marine conditions and of the relative contribution between marine and continental supply of water, sediment and OM are linked to climate change. Current and past human activities, in all its forms, largely affecting these areas with a range of environmental impacts. The high variability of physico-chemical and biological conditions of these environments is recorded in the sediments, due to their high degree of preservation. Sedimentology, chronostratigraphy and archaeological data from an archaeological site in Lio Piccolo (Venice lagoon), combined with geochemical proxies, can led to a better understanding paleo-depositional events related to paleoenvironmental and paleoclimatic variations of the Holocene. Proxies such as $\delta^{13}C$ combined with the C/N ratio, can distinguish between marine phytoplankton / algae (autochtonous) and terrestrial plants (allochtonous) (Lamb et al. 2004, Tue et al. 2011); $\delta^{13}C$ can discriminate the abundance between C3, C4 and CAM plants, which can be related to the climatic conditions, due to the adaptability of each species to certain temperature, precipitation and humidity (Liu et al., 2005); δ15N can distinguish terrestrial plants and algae, the latter more controlled by the isotopic composition of DIN, which is strongly influenced by human activities. Nitrates from agricultural runoff and animal sewage have high δ15N and can produce δ15N-enriched phytoplankton, which can enrich the sediments (Mayer & Wassenaar, 2012). The archaeological site represents a Roman inland production area with a wall structure over large wooden foundations, probably linked to salt production and storage. The site is close to a sunken Roman villa dating from the 1st century AD, suggesting the occupation of the area before the foundation of Venice. Preliminary research results will be presented, with the aim of outlining the Holocene stratigraphic-depositional facies, determining the changes in sedimentation rate and burial rates of C and N between the completely natural phase and the human occupation and identifying the origin of the OM in the Lio Piccolo cores, which can provide information on primary productivity and sedimentation patterns of the last millennia.

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On depositional processes governing along-strike facies variations of fine-grained subaqueous deltas in the Adriatic Sea

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Keywords: along-strike facies variations, Late-Holocene, palaeo-flood occurrence.

Depositional processes recorded by subaqueous deltas may vary widely along-strike, depending largely on the mode of delivery and deposition of sediments to the basin. In fine-grained systems in particular, depositional processes are difficult to reconstruct with standard facies analysis of sediment cores due to the ostensibly featureless and homogenous appearance of muds. In this study, sedimentological, palaeontological, geochemical and oceanographic data were combined in a detailed characterization of depositional conditions via sedimentary structures, type of organic matter, trace-metal geochemistry and benthic fauna assemblages (foraminifera and ostracods) along the 600-km-long shelf subaqueous delta of the West Adriatic shelf (Italy). Processes inferred from sedimentary facies and micro-structures were then considered in the context of the modern Adriatic oceanographic regime. Specific attention was given to the Little Ice Age stratigraphic unit (1500–1850 CE), which contains a continuum of genetically related fine-grained strata. The Little Ice Age deposit offers the opportunity to examine a source-to-sink system with the high resolution typical of modern analogs, at a time interval when Apennine rivers were not yet hydraulically engineered with man-made sediment traps along their trunks. Individual beds within the Little Ice Age muddy prodelta form hectometre to kilometre-wide bedsets that reflect the interplay between energetic meteo-ocean conditions (storm-dominated beds), flood supply (river-dominated beds or hyperpycnites), and along-shelf bottom-current dispersion (drift-dominated beds). The multidisciplinary approach applied at different scales of observations helped in understanding sediment provenance and the relative timing of sediment transport before final burial that strongly promoted organic matter oxygen exposure and the loss of carbon by microbial degradation. Overall, the distinctive depositional processes that acted in concert along the prodelta slope produced a subtle lateral heterogeneity of preserved sedimentary structures, faunal associations, and organic matter composition in a laterally-continuous lithostratigraphic unit deposited at centennial scale. These findings have implications on the forcing conditions that ultimately control the location and nature of fine-grained beds in both modern and ancient, mud-dominated subaquous delta systems.

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Advanced seismic microzonation in correspondence of deep sedimentary basins: the case of Foggia (Southern Italy)

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Keywords: seismic microzonation, Bradanic Trough, H/V patterns, earthquakes emergency planning

Site response analysis at the scale of municipality requires specific procedures aiming at evaluating lateral variability of seismic effect based on unevenly distributed and heterogeneous data. Retrieving subsoil seismic configuration at the scale of interest requires the joint interpretation of surface and borehole geophysical data, geological and geotechnical information collected during preliminary level microzonation studies. The problem is also made more complex when available information reveal the presence of significant heterogeneities at shallow depths and reference soil conditions are located at depths of the order hundreds of meters. This is the case of the city of Foggia which is in the middle of the Bradanic Trough and is characterized by high seismic hazard. The geological configuration of the study area indicates the presence of a buried carbonatic platform at depths of the order of sever hundreds of meters. Above this layer, pliocenic sediments including clay and sands develop up to few tens of meters from the surface, where conglomeratic lenses of different sizes and thicknesses exist. Inversely dispersive profiles are widespread in the area. A preliminary zoning was defined based on the cluster analysis of H/V spectral ratio curves widely available in the study area. This allowed the definition of a set of H/V patterns each representative of a possible subsoil configuration. Each H/V pattern has been inverted to retrieve a corresponding Vs profile down to the respective geological and engineering bedrocks compatible with information provided by available geological and geophysical data relative to areas where the considered pattern lies. This allows to differentiate a geological bedrock located at a depth of the order 600 m and a shallower engineering bedrock at depth of the about 150 m. Moreover, the lateral extension of conglomerate lenses and respective thicknesses have been tentatively estimated. Based on this information, a set of 1D simulations have been carried out to estimate amplification effects expected at each site where H/V measurements were performed. Based on these outcomes, a new detailed microzonation map of Foggia has been determined, which can be used to support land management activities and emergency planning to improving resilience of the local community against future earthquakes.

Depositional architecture and provenance analysis of the non-marine deposits of the Oldman Formation (Campanian, Belly River Group) at the U.S.-Canada border

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Keywords: non-marine deposits, depositional architecture, provenance anlysis.

The Oldman Formation (Campanian - Upper Cretaceous) is the middle unit of the Belly River Group, widely exposed in the southern plains of Alberta (Canada) and northern Montana (USA). This non-marine unit is known for its rich and diverse fossil fauna and has been the subject of multiple studies focusing on source-to-sink relationships during large-scale regressive events. Recent field surveys in the Milk River Valley drainage system along the Canada-U.S. border have led to the identification of a previously unmapped stratigraphic interval characterized by highly cemented, white quartz arenites, nicknamed 'Big White'. In 2022 and 2023, eight new stratigraphic sections representative of the lower 70 meters of the Oldman Formation were acquired along the Canadian bank of the Milk River and one in the U.S. side (Kennedy Coulee area): measured sections extend from the Taber Coal Zone (TCz) which marks the base of the Oldman Fm., to the Comrey Member sandstone, a sand-dominated interval associated in the literature to the maximum basinward progradation of the Belly River Group. In this process, 18 sandstone samples were collected for petrographic analyses.

Big White, occurring at about 30 metres above the TCz, comprises two distinct intervals: the lower part (c. 3 meters in thickness) is characterized by high-angle, epsilon stratification, typical of fluvial environments. The upper portion (2 meters thick) shows low-angle, fining-upward beddings overlain by a thin interval of massive deposits interpreted as beach environment. Overall, Big White is composed of unsorted clasts, with over ~90% quartz and ~10% feldspar in a phyllosilicate matrix. The lower part is clast-supported with sub-rounded and well sorted clasts, whereas the upper portion is matrix-supported with smaller, poorly to well sorted clasts. Big White sediments where then compared with sandstones representative of the TCz-Comrey interval: results indicate an overall trend toward quartz-enriched sandstones, with no major shifts in the matrix composition or clasts morphology. This trend changes in the deposits overlying Big White, as in the Comrey quartz clasts abruptly decrease to ~ 40%, and ~15% of clasts are represented by olivine, not present in the lower Oldman beds. Therefore, petrographic data suggest three sediment source areas during the lower Oldman Formation, a thickness interval of c. 70 meters representative of ~1Mya and a complex source-to-sink relationship for the basal beds of this unit. Similarly, in terms of depositional environments and sequence-stratigraphic interpretations, the identification of smaller-scale and higher frequency depositional cycles delimited by subaerial surfaces change current understanding of the processes leading to the deposition of the Oldman Formation.

Multi-proxy investigation of Pliocene transgressive-regressive high-frequency cycles in Geological Sheet 274 Empoli (Tuscany, Italy): insights from the CARG Project

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Keywords: Pliocene, multidisciplinary data set, paleo-depositional evolution.

We present a new multidisciplinary dataset (sedimentology, facies analysis, paleontology, biostratigraphy, geochemistry, geochronology) related to the sedimentary sequences of Zanclean to Piacenzian age outcropping in the geological sheet 274 Empoli (1/50000 scale) as part of the ongoing CARG project. The study area is part of the extensional basin systems formed in response to the opening of the Tyrrhenian Sea (starting from the Late Tortonian) and the contemporary counterclockwise migration of the foreland chain system (Malinverno & Ryan 1986; Patacca et al. 1990). In spite of this, over the latter years, several scientists have proposed that compressional tectonics have significantly influenced the development and progression of these basins (Buttinelli et al., 2024, and references therein). Depositional facies are mainly characterized by shallow-marine deposits that are replaced laterally by deltaic, lagoonal, and fluvial deposits. Within this depositional context, we observe multiple vertical stacks of high-frequency transgressive-regressive (T-R) cycles (*sensu* Embry & Johannessen 1993), offering a robust record of even minor relative sea-level fluctuations. In some cases, these cycles exhibit unconformities of different scale orders, while the transgressive surfaces are characterized by shell lag horizons (wave ravinement surfaces) and/or flooding surfaces. We document phases of both positive and negative relative sea-level changes within these sequences. Positive changes with the creation of new space of accommodation may or may not be compensated by the volume of sedimentary supply; depending on the ratio between these two components, they may result in progradational, aggradational or retrogradational sequences. Negative changes with subtraction of the accommodation space led to a forced regression, expressed as erosional unconformities or facies jumps. Building upon extensive, 1/10000 scale surveys, detailed stratigraphic section measurements and sampling for multiple proxy analyses, our study, allows for a preliminary reconstruction of the paleo-depositional evolution of the study area during the Pliocene. We also discuss the possible implications in terms of controlling factors, both local and general, that may have influenced the identified depositional sequences.

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How did the plant ecosystem adapt to climatic variations (shifts) during the middle to the late Permian? A case study from Northern Gondwana

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Keywords: Guadalupian, land plants, Northern Gondwana.

The Palaeozoic Era ended in two mass extinction events: the end-Guadalupian and the end-Permian. These were triggered by a combination of factors, including ocean anoxia and acidification linked to the onset of the Emeishan Large Igneous Province and the Siberian Traps, respectively. The volcanic activity released substantial volumes of greenhouse gases such as CO_2, SO_2, and CH_4 into the atmosphere, resulting in exceptionally warm global temperatures that had profound ecological impacts on both terrestrial and marine environments, leading to a drastic reduction in biodiversity. The case study examined the changes in microflora throughout middle to late Permian in various sedimentary successions, both as outcrops and subsurface in several regions of SW (Zagros Basin) and NW Iran (SW Azerbaijan and Julfa area). The data obtained from microfloral analysis enabled the identification of four palynozones attributed to the Roadian-Wordian, Wordian-Capitanian, Wuchiapingian and Changhsingian, correlated with the microfloristic assemblages recorded in other Northern Gondwana regions (Oman, Saudi Arabia, Southern Turkey, Iraq, Pakistan, etc.). This chronostratigraphic framework allowed to attribute the microfloral variations, and consequently those of parent plants, to specific temporal phases. Pollen-producing land plants such as conifers and pteridosperms appeared abundant throughout the Guadalupian and Lopingian, surviving across the end-Guadalupian extinction event. Conversely, Lycopodiceae producing spores decreased in abundance across the Guadalupian-Lopingian boundary and increased in the Changhsingian.The analysis of middle to late Permian microflora highlighted the resilence of plants to stresses caused by hyperthermal events and abnormal atmospheric CO_2 concentrations, as no major clade of terrestrial plants disappeared during this period. Instead, a gradual change in flora was observed, unlike marine organisms, which seem to have experienced a much more intense crisis. Furthermore, the microfloral variations of plant groups with xerophytic and hygrophytic affinity across the middle to late Permian interval revealed a clear overall trend. The xerophytic group showed a gradual decrease from the Roadian-Wordian to the Changhsingian, albeit maintaining appreciable percentages. In contrast, the hygrophytic microfloral group increased from the Roadian-Wordian to the Changhsingian. Correlating the temporal values of these two groups with global-scale geological and geodynamic events revealed a correspondence between warm and humid climate microflora and the eruptive episodes of the Emeishan and the Siberian Traps.

The end-Guadalupian anoxic event in Northern Anatolia: new constrains and correlation through palynological data

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Keywords: End-Guadalupian, anoxic event, palynology.

The final extinction event of the Palaeozoic Era stands as the most significant occurrence in the history of life during the Phanerozoic Eon. However, its two-phased nature has only recently gained widespread recognition. The decline in biodiversity during the Permian period unfolded in two distinct stages: first, at the boundary between the Guadalupian and Lopingian epochs, and second, at the boundary between the Permian and Triassic periods. The timing of the end-Guadalupian extinction seemingly aligns with the emergence of superanoxia in Panthalassa, marking another globally impactful geological phenomenon spanning the Permian-Triassic boundary (Isozaki et al., 2007). In addition to the anticipated negative shifts observed at both the Permian-Triassic and Guadalupian-Lopingian boundaries, a notable period of heightened productivity was recently uncovered during the Capitanian epoch (late Guadalupian). This discovery was based on a significant shift of elevated positive 13Ccarb values, ranging between +5 and +6‰ (Isozaki et al., 2007). Given that such positive values exceeding +5.0‰ are exceptionally uncommon in the Phanerozoic record, with only a few notable exceptions in the Palaeozoic era (e.g., Saltzman, 2005), this specific occurrence during the Capitanian epoch has been termed the "Kamura event." In this study, we examined the palynological content of a fluvio-lacustrine succession within the Çakraz Formation in the Zonguldak Terrane, spanning from Akçakoca to Eregli regions. Our aim was to characterize the Alaplı Member, which comprises black, dark-grey to greenish-grey shales, siltstones and limestones. Earlier palynological studies assigned this unit to the late Permian (Okuyucu et al., 2017). However, this study has instead yielded an older microflora attributed to the middle Permian. The palynological assemblage mainly consists of bisaccate pollen grains such as *Alisporites* spp., *Protohaploxypinus* spp., *Striatopodocarpites* spp., monosaccates as *Plicatipollenites* spp., *Potonieisporites* spp., and polyplicates as *Vittatina* spp.. Therefore, the occurrence of a black shale interval including a microflora association within middle Permian age informs us that possible equivalent of the "end-Guadalupian anoxic Event" is recorded within this fluvio-lacustrine environment in Pontides, NW Turkey for the first time. Geochemical analysis of the study interval will be carried out as a future study in order to clarify the level of "end-Guadalupian anoxic Event".

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Onset of the Permian 2nd tectono-sedimentary cycle from the Southern Alps: new constraints from palynological assemblages and regional-global inferences

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Keywords: palynology, stratigraphy, Southern Alps.

Analysis of palynological assemblages from the Val Daone Conglomerate Formation (VDC) provides new significant information on the age of this lithostratigraphic unit and, as a consequence, of the inception of the Permian tectono-stratigraphic cycle 2 (TSU2) in the Southern Alps (Gretter et al., 2013). The VDC Formation represents a nearly 100-metres thick, medium-grained fluviatile body which can be followed in western Trentino, from the NE part of the Permian Collio Basin to the west, up to the Tione Basin in Val Rendena to the east (Cassinis et al., 1983, 2008).

The microflora from the VDC Formation is from well- to poorly-preserved, in the Val di Scale (Val Rendena) and Ronchi (Val Daone) sections, respectively. Comparisons between the results of the present study with data from the Tregiovo, Val Gardena Sandstone and Bellerophon formations of the Italian Southern Alps reveal a sequence of distinct associations that are stratigraphically and perhaps palaeoenvironmentally controlled.

The stratigraphy of the microfloristic assemblages of the VDC makes it diagnosing for the late Capitanian-Wuchiapingian. Two different palynozones (Val Daone Conglomerate PalynoZone - VDCPZ) are established from the VDC Formation, the lowermost (VDCPZ1) from the Ronchi section, attributed to late Capitanian-early Wuchiapingian, and the uppermost (VDCPZ2) from the Val Rendena section, of Wuchiapingian age (Cortesogno et al., 1998). These VDCPZ biozones show close similarities with coeval associations recorded from other European and extra-European areas: this is consistent with the stratigraphic position of the VDC Formation and allow us: 1) to pre-date to at least to the late Capitanian-early Wuchiapingian the beginning of the Permian 2nd tectono-sedimentary cycle in this sector of the Southern Alps; 2) to estimate at about 16-18 Ma the duration of the depositional hiatus between the two cycles, that was caused by the intra-Permian tectonics, and straddled most of the Guadalupian. Moreover, the VDCPZ1 biozone is one of the few low-latitude associations time-equivalent or slightly younger than the end-Guadalupian mass extinction, a major climatic-driven event that significantly changed terrestrial floras and faunas.

Cassinis G. (1983) - Il Permiano nel Gruppo dell'Adamello, alla luce delle ricerche sui coevi terreni delle aree contermini. Memorie della Società Geologica Italiana, 26, 119-132.

Cortesogno L. et al. (1998) - New stratigraphic and petrographic data on the Tione Permian Basin (Lower Val Rendena, Trentino, Italy). Atti Ticinensi di Scienze della Terra, ser. spec. 7, 125-138.

Cassinis G. et al. (2008) - The Val Daone Conglomerate: a Middle Permian unit in the central Southern Alps (Trentino, Italy). Regional implications. Boll. Soc. Geol. It., 127(3), 519-532.

Gretter N. et al. (2013) - The transition between the two major Permian tectono-stratigraphic cycles in the central Southern Alps: results from facies analysis und U/Pb geochronology. Int. J. Earth Sci., 102, 1181-1202.

High-resolution multi proxy records across the Plio-Pleistocene boundary: a central Mediterranean perspective

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Keywords: Gelasian GSSP, sub-orbital climate variability, central Mediterranean.

The central Mediterranean region is traditionally acknowledged as a key reference area for investigating the Northern Hemisphere climate variability over the last few million years.

In particular, the extraordinary well exposed, well preserved and highly fossiliferous open-marine successions, currently exposed along the shoreline of Southern Italy and Sicily, offer plenty of paleoclimatic and paleoenvironmental archives spanning the Neogene to Quaternary interval, which can be tightly constrained in time and deeply investigated providing pristine sedimentary records (e.g., Cita et al., 2008; Capraro et al., 2017, 2022).

In this context, the Monte San Nicola (MSN) section, located in Southern Sicily, provides an exceptional stratigraphic record for studying the climate evolution throughout the Piacenzian to Gelasian interval. The MSN succession hosts the GSSP for the Gelasian Stage (ca. 2.58 Ma; Rio et al., 1998), which presently marks the base of both the Pleistocene Serie and the Quaternary System (Head et al., 2008). The section is currently under revision, especially in the interval straddling the Gelasian GSSP, which includes the definitive establishment of the Northern Hemisphere Glaciation (NHG), at around 2.6 Ma. This cooling event is marked by a triplet of glacial stages (i.e., MIS 100, 98 and 96) that are found just above the Piacenzian-Gelasian boundary.

In the wake of the emerging interest towards the MSN section, we are currently committed to reconstructing a high-resolution multi-proxy record (benthic and planktic foraminiferal δ18O, Alkenones-derived SSTs) in the lower part of the "Mandorlo" section at MSN (Capraro et al., 2022; Zanola et al., 2024). Results achieved so far provide new insights on the paleoceanographic and paleoclimatic evolution of the central Mediterranean at the beginning of the NHG, specifically on a sub-orbital time scale.

Capraro L. et al. (2017) - The Valle di Manche section (Calabria, Southern Italy): a high-resolution record of the Early-Middle Pleistocene transition (MIS 21-MIS 19) in the Central Mediterranean. Quat. Sci. Rev., 165, 31-48, http://dx.doi.org/10.1016/j.quascirev.2017.04.003.

Capraro L. et al. (2022) - The Monte San Nicola section (Sicily) revisited: A potential unit-stratotype of the Gelasian Stage. Quat. Sci. Rev., 278,107367., https://doi.org/10.1016/j.quascirev.2021.107367.

Cita M.B. et al. (2008) - The Calabrian stage redefined. IUGS Episodes, 31, 4, https://doi.org/10.18814/epiiugs/2008/v31i4/006.

Zanola E. et al. (2024) - High-resolution climate variability across the Piacenzian/Gelasian boundary in the Monte San Nicola section (Sicily, italy). Quat. Sci. Rev., 324, 108469, https://doi.org/10.1016/j.quascirev.2023.108469.

S40.

Source-to-sink processes and genesis of resources in sedimentary deposits: advances in understanding of geologic and environmental dynamics through a multidisciplinary perspective

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The disappearance of sand: just a false alarm or a global emergency?

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Keywords: georesources, aggregate extraction, environmental impact.

If we type "Sand War" into Internet search engines, we are directed to the border conflict between Algeria and Morocco, which was fought in September-October 1963. The conflict stemmed largely from the Moroccan government's claim to some portions of the Algerian provinces. One of the main reasons for this war was the discovery of important mineral resources in the disputed area.

But if we add a single 's' to the end of 'war' (i.e. Sand Wars) we land on another kind of war, this time a global one. The documentary film by director Denis Delestrac (2013) forces us to open our eyes, perhaps for the first time, to a new 'gold rush' for a material that has become a key raw material. The film premiered at Cinéma Publicis in 2013, where it became the highest rated documentary of 2013. Among many other victories, the film inspired the United Nations Environment Programme (UNEP) to publish a global environmental alert in March 2014 entitled Sand, rarer than you think (UNEP, 2014).

But why should scientists address this issue? Sand has become a vital commodity for our modern economies. Sand and gravel are mined worldwide and represent the largest volume of solid material mined globally (Steinberger et al., 2010). The volume extracted, at a rate far greater than their renewal (Krausmann et al., 2009), is having a major impact on rivers, deltas, and coastal and marine ecosystems around the world, resulting in land loss through river and coastal erosion, lowering of the water table, and decreasing sediment in natural systems. Despite the huge quantities of sand and gravel used, our increasing dependence on them and the significant impact their extraction has on the environment, this problem has been largely ignored by policy makers and remains largely unknown to the public. Furthermore, although more sand and gravel are extracted than any other material, reliable data on their extraction in some developed countries are only available for the last few years (Krausmann et al., 2009). The absence of global data on aggregate extraction makes environmental assessment very difficult and has contributed to the lack of awareness on this issue, which in turn results in a lack of action. There is in fact a large discrepancy between the extent of the problem and public awareness. As this is a highly topical issue, in-depth research and assessments of the impact of the uncontrolled exploitation of this natural resource are needed at local and global scale.

Delestrac D. (2013) - Sand Wars: An Investigative Documentary. In: Hollander M., Haley S. & Olaskoaga I. (eds), ARTE France Production.

Krausmann et al. (2009) - Growth in global materials use, GDP and population during the 20th century. Ecological Economics, 68(10), 2696-2705, https://doi.org/10.1016/j.ecolecon.2009.05.007.

Steinberger et al. (2010) - Global patterns of materials use: A socioeconomic and geophysical analysis. Ecological Economics, 69(5), 1148-1158, https://doi.org/10.1016/j.ecolecon.2009.12.009.

United Nations Environment Programme (2014). Sand, Rarer than One Thinks: UNEP Global Environmental Alert Service (GEAS), https://wedocs.unep.org/20.500.11822/8665.

Using a large dataset of field-based measurements to statistically estimate thickness of fallout pyroclastic deposits in the peri-volcanic areas of Campania region, southern Italy

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Keywords: pyroclastic deposits, thickness, Campania, Italy.

Determining spatial thickness of fallout pyroclastic deposits provides key information on hydrological, geomorphological (both erosion and deposition) and volcanological processes. However, this is a challenging line of research because: (1) field-based measurements are expensive and time-consuming; (2) the ash might have been dispersed in the atmosphere by several volcanic eruptions; and (3) the expected spatial distribution of the fallout pyroclastic deposits was altered by wind during an eruptive event and have been changed by soil-forming/denudation processes after ash deposition. In this research, we tried to bridge this knowledge gap by compiling a dataset of 19 variables including thickness of fallout pyroclastic deposits measured in some sectors of Campania region and 18 predictor variables mainly derived from digital elevation models and satellite imageries. Then, three methods already available in the literature (i.e. GPT: Geomorphological Pyroclastic Thickness; SAPT: Slope Angle Pyroclastic Thickness; and SEPT: Slope Exponential Pyroclastic Thickness), stepwise regression model and random forest (RF) machine learning technique were used for thickness estimation. Finally, Simple Average, Minimum Variance, Ordinary Least Squares and Least Absolute Deviation (LAD) methods were implemented for developing a less biased model through statistical combination of different predictions. The results showed that RF returns the most accurate predictions (RMSE < 82.46 and MAE < 48.36), while statistical combination of the predictions obtained from the above-mentioned five models through LAD improves prediction accuracy (MAE < 45.12) in the study area. The maps for the values estimated by RF and LAD illustrate that the spatial patterns did not alter significantly, but the estimations by LAD are smaller. This combined approach can help to estimate thickness of fallout pyroclastic deposits in other volcanic regions and to manage geohazards in the areas covered with unconsolidated pyroclastic materials.

From the micro to the macro-scale: the contribution of the "Provenance Centre" (Unimib) in the study of sedimentary archives

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Keywords: heavy-minerals, bulk petrography, Raman spectroscopy.

The Departmental Study Centre called "Provenance", as part of the DISAT (Dipartimento di Scienze dell'Ambiente e della Terra) - TECLA (TErra CLima Ambiente) Project, wants to maintain and promote basic geological culture in the educational field and broaden its skills in petrology and geophysical modelling, through an integrated management of instrumentation and resources. The ability to trace sediments from their sources to sedimentary basins is a prerequisite for quantitative analysis of Earth-surface dynamics (Caracciolo et al., 2016). The Provenance Centre has been carrying out investigations and training in the field of Sedimentary Petrography for many years, aimed at reconstructing the evolution of the Earth's surface over geological time, using the study of the petrographic and mineralogical composition of sediments, and preparing new generations of geologists for provenance studies (Garzanti & Andò, 2019). Modern laboratories are used, applying the most advanced quantitative provenance techniques (analysis of heavy minerals and bulk petrography; Raman spectroscopy; fission-track thermochronology on zircon and apatite). The aim of this multidisciplinary approach takes advantage from the study of natural continental and marine sedimentary records to understand and where possible quantify all the factors that determine and influence the generation and composition of sediments. Much attention is paid to the factors that act together in the large natural systems studied, considering the mineralogy and age of the outcropping rocks, the physiography and climatic conditions existing in the source areas, the compositional modifications connected to the processes of erosion, transport, deposition, and the chemical weathering, carried out during one or more sedimentary cycles. These studies find notable applications both for the analysis of current and past climate changes (e.g.: Ross Sea Project in Antarctica; Amazon Basin) and for recognizing the effects of anthropogenic activities on the Earth system. The Centre has recently expanded its sphere of interest towards research topics that require a multidisciplinary approach, such as provenance studies applied in the archaeological field (e.g., Stonehenge project in the UK; Bevins et al., 2023) and the quantitative study of plastic pollution in the marine environment (Ferrero et al., 2022).

Bevins R.E. et al. (2023) - The Stonehenge Altar Stone was probably not sourced from the Old Red Sandstone of the Anglo-Welsh Basin: Time to broaden our geographic and stratigraphic horizons? Journal of Archaeological Science: Reports, 51, 104215, https://doi.org/10.1016/j.jasrep.2023.104215.

Caracciolo L. et al (2016) - Sediment generation and provenance: processes and pathways. Sedimentary Geology, 336, 1 -2, https://doi.org/10.1016/j.sedgeo.2016.03.015.

Ferrero L. et al (2022) - Airborne and marine microplastics from an oceanographic survey at the Baltic Sea: An emerging role of air-sea interaction? Science of the Total Environment, 824, 153709, http://dx.doi.org/10.1016/j.scitotenv.2022.153709.

Garzanti E. & Andò S. (2019) - Heavy Minerals for Junior Woodchucks. Minerals, 9, 148, https://doi:10.3390/min9030148.

Diagenetic and hydrothermal changes in submarine quartzofeldspathic turbidite sandstones of the Butano Sandstone, central California, USA

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Keywords: sandstone diagenesis, Central California, Butano Sandstone.

The Butano Sandstone represents an Eocene deep-marine fan, deposited in central California within the La Honda Basin. The Butano fan includes three main sedimentary facies associations: inner-fan, middle-fan, and outer-fan facies, placed in the southern, central, and northern part of the basin, respectively. Despite the homogeneous quartzofeldspathic framework composition, the three outcrop belts exhibit several mineralogical differences, likely due to the post-depositional events ruled by the intricate tectonic history of the La Honda basin, resulting in deep-burial diagenetic processes and possible hydrothermal alterations. Both compaction and cementation reduced the intergranular volume (lower than 19 %), and the Compaction Index (average 0.9), indicates the major role of compaction in reducing original porosity. The outcrops of the southern proximal fan and northern distal fan show varying proportions of detrital quartz (43.5% in Qm) compared to the central outcrop of the middle fan (50.7% in Qm) (Critelli & Nilsen, 1996). During burial, plagioclase primarily and K-feldspar to a lesser extent experienced significant leaching and dissolution, especially in the central basin region, leading to the relative higher quartz volume. Additionally, this condition is quite consistent with the distribution of alteration degree of feldspar grains among the three outcrop belts, which occur more dissolved in the middle-fan sandstones (Civitelli et al., 2024). Extensive post-depositional alterations occur notably within the Butano Sandstone located in the central portion of the La Honda Basin, with a probable primary attribution to hydrothermal effects during burial.

Civitelli M. et al. (2024). - Interpreting post-depositional alterations in deep-marine sandstones: Butano Sandstone, central California, USA. Marine and Petroleum Geology 163, 106733, https://doi.org/10.1016/j.marpetgeo.2024.106733.

Critelli S. & Nilsen T.H. (1996). - Petrology and diagenesis of the Eocene Butano sandstone, La Honda basin, California. J. Geol., 104(3), 295-315, https://doi.org/10.1086/629826.

Detrital modes of the Pennsylvanian-Permian sandstones in Central-Eastern Sardinia (Italy)

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Keywords: Pennsylvanian-Permian sandstones, central-eastern Sardinia, Variscan and neovolcanic provenance.

Late Pennsylvanian-Permian sedimentary successions are exposed in Central-Eastern Sardinia (Italy). Here, the sandstone detrital modes of several scattered basins (Mulargia-Escalaplano, Ingurtipani, Perdasdefogu, and Montarbu basins) have been investigated to highlight how the tectono-magmatic processes influenced the sedimentation. Sandstones were collected along well-characterized stratigraphic sections that usually start with a Upper Pennsylvanian - Early Permian dark limnic succession (Rio Su Luda Fm, Ronchi & Falorni, 2004; Costamagna & Criniti, 2024) lying unconformably on the Variscan basement, and continue upward with red bed successions (Mulargia and Pegulari Fms: Costamagna, 2022; Costamagna & Criniti, 2024) until the Lower-Middle(?) Permian. The sandstone composition testifies a changing nature of the source areas feeding since it is quartzolithic metamorphiclastic in the Upper Pennsylvanian sedimentary strata of the Mulargia basin, abruptly passing to volcaniclastic sandstones upward in the Early-Middle(?) Permian of all studied basins. In particular, the Upper Pennsylvanian strata always display low-grade metamorphic detritus, including metaradiolarite (lydite) and phyllite fragments deriving from the Variscan chain. An increasing metamorphic grade of the feeding is supported in the upward successions. The disappearance or dilution upward of this metamorphic detritus suggests the emplacement of the volcanic activity during a progressive tectonic fragmentation of the basins and more in general of large portions of the supercontinent Pangaea. In fact, the Lower -Middle Permian successions of all studied basins display an increasing content and variety of neovolcanic detritus (Critelli et al., 2023) revealing frequently andesitic, and rhyodacitic-rhyolitic coeval sources, while spots of basaltic and basaltic andesite lavas and pyroclastic rocks; whereas, andesitic-dacitic neovolcanic sources, are rarely encountered in the Perdasdefogu and Mulargia basins.

Costamagna L.G. (2022) - Sedimentary evolution of the Pennsylvanian-Permian MulargiaeEscalaplano molassic basin (Sardinia, Italy): The most complete record in the Southern Variscan Realm. Geol. Magazine, 159, 1529-1568, https://doi.org/10.1017/S001675682200036X.

Costamagna L.G. & Criniti S. (2024) - Interpreting siliciclastic sedimentation in the upper Paleozoic Mulargia-Escalaplano Basin (Sardinia, Italy): influence of tectonics on provenance. J. Palaeog., 13, 18-34, https://doi.org/10.1016/j.jop.2023.10.005.

Critelli S. et al., (2023) - Temporal and Spatial significance of volcanic particles in sand (stone): implications for provenance and paleotectonics. In: Di Capua A., De Rosa R., Kereszturi G., Le Pera E., Rosi M., Watt S.F.L. (Eds), Volcanic Processes in the Sedimentary Record: When Volcanoes Meet the Environment, Geological Society of London Special Publication, 520, 311-325, https://doi.org/10.1144/SP520-2022-99.

Ronchi A. & Falorni P. (2004) - Formazione di Rio su Luda. Carta Geologica d'Italia scala 1:50.000. Catalogo delle Formazioni, Unità validate (a cura della Commissione Italiana di Stratigrafia). I Quaderni, serie III, del SGI 7 (fasc. V), 155-9.

Detrital modes of the Culm facies in the Betic-Rifean chain

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Keywords: Carboniferous detrital suites, Culm Cycle, Variscan Paleotethysian Orogeny.

Detrital modes of Carboniferous sandstones reveal the sedimentary budget of convergent plate boundaries during the Variscan s.s. to Paleotethysian orogenic time span (≈420–300Ma) within the Paleo-Mesomediterranean Domain. These sedimentary strata are usually referred to the regional Culm lithostratigraphic depositional unit, and cover an important gap of information to the area located between the Iberian-French massifs and the African Paleo-Atlas, in the western Paleotethys. The studied sandstones belong to the Middle Carboniferous deep-water turbidites of the Almogia and Marbella Conglomerate formations in the Malaguide (Betic Cordillera) and Ghomaride (Rif Chain) Complexes. Here, the sandstone composition is quartzolithic and records an important high-to-medium-low grade metamorphic content in both area (Criniti et al., 2023, 2024), with an increasing trend towards Morocco. The source area was a lithic-transitional recycled orogen with a signature of volcanic and ophiolitic detritus (≈330Ma and/or older). These supplies seem to be derived mainly from a mid-crustal deformed and thrusted terrane prior to the Early Carboniferous, that was involved into the plate convergence south eastwards of the Variscan s.s. orogenic system, rapidly exhumed and uplifted during the mid-Late Carboniferous time. Consequently, a metamorphic basement should be already structured during Middle Carboniferous when thrusting took place, allowing the Culm deposition in the Malaguide and Ghomaride Complexes, suggesting pre-Middle Carboniferous metamorphic highlands. The presence of ophiolitiferous detritus (≈330Ma and/or older) could indicate an obducted oceanic branch, while the synsedimentary volcanic activity (mainly andesitic) should be related to a lost magmatic arc, in good agreement with a nearby subduction area. As a consequence, the thick terrigenous Culm strata could be deposited in a complex foreland basin system connected northward with carbonate platforms and with a crystalline highland uplifted domain from the southern Europe Iberian-French massifs and southward with the African Paleo- Atlas Domain. The studied sandstone petrofacies deeply contributes to paleogeographic reconstructions since block fragmentation and spreading, during the Paleotethysian and Alpine orogenies, rearranged the Paleozoic paleogeography now part of the Cenozoic Perimediterranean Chains, removing the whole principal source rocks.

Criniti S. et al. (2023) - New constraints for the western Paleotethys paleogeography-paleotectonics derived from detrital signatures: Malaguide Carboniferous Culm Cycle (Betic Cordillera, S Spain). Sed. Geol., 458, 106534, https://doi.org/10.1016/j.sedgeo.2023.106534.

Criniti S. et al. (2024) - Detrital signatures of the Ghomaride Culm Cycle (Rif Cordillera, N Morocco): new constraints for the northern Gondwana plate tectonics. J. Mar. Pet. Geol., 165, 106861, https://doi.org/10.1016/j.marpetgeo.2024.106861.

Integrated study of erosion rates using cosmogenic and fallout radionuclides (^{10}Be and $^{239+240}$Pu) in a pilot stream catchment of Calabria, southern Italy

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Keywords: erosion rates, isotope tracers, coastal erosion hazards.

During recent decades there has been an increasing interest in quantification of Earth surface processes (e.g., weathering, pedogenesis, erosion and sedimentation) at different temporal and spatial scales, also investigating mutual relations between those acting on slopes and others occurring within the hydrographic network. In this frame, a major focus of the current work is devoted to estimate long-term erosion rates and sediment residence times (average exposure ages) in a pilot stream catchment of Calabria (southern Italy) using cosmogenic beryllium (^{10}Be), along with medium-term soil erosion rates through fallout radionuclides ($^{239+240}$Pu). The combination of such methods, although recording soil and sediment dynamics at different timescales (Balco et al., 2008; Loba et al., 2022), can be of great help in understanding possible interconnectivity between the drainage system and potential source areas. This approach can also shed lights on the amount of deposits able to feed the coastal sector and provide useful tools for the assessment, monitoring and management of coastal erosion hazards and risks. The research activities are part of an ongoing project "TECH4YOU – Technologies for climate change adaptation and quality of life improvement", supported by the European Union (Next Generation EU – PNRR M4.C2.1.5). The existing literature mainly applied the aforementioned isotope tracers separately (Cyr et al., 2014; Meusburger et al. 2016) or each single nuclide at transect or site scales. Conversely, the distinctive and innovative character of this research consists in their catchment-wide application, combined with detailed geological, geomorphological and pedological surveys, a multi-temporal comparison of historical aerial photos and Google Earth images to identify land-use, land-cover and landscape changes, the use of GIS technologies for thematic mapping, in situ monitoring of water flow dynamics and properties (e.g., turbidity, water level, temperature, electrical conductivity), the application of Passive Integrated Transponder (PIT) tags for the evaluation of short-term transport of fluvial sediments after specific flooding events, and the development of an integrated model for the estimation of sediment production and erosion rates. Such an advanced and interdisciplinary methodological approach is essential to unveil the complex dynamics underlying erosive processes from source to sink areas, and can be established as a standard replicable protocol to be adopted for studying other hydrographic basins in any geographic and geo-environmental contexts.

Balco G. et al. (2008) - A complete and easily accessible means of calculating surface exposure ages or erosion rates from 10Be and 26Al measurements. Quat. Geochronol., 3, 174-195, https://doi.org/10.1016/j.quageo.2007.12.001.

Cyr A.J. et al. (2014) - Distinguishing between tectonic and lithologic controls on bedrock channel longitudinal profiles using cosmogenic 10Be erosion rates and channel steepness index. Geomorphology, 209, 27-38, https://doi.org/10.1016/j.geomorph.2013.12.010.

Loba A. et al. (2022) - Meteoric 10Be, 137Cs and 239+240Pu as tracers of long- and medium-term soil erosion — A review. Minerals, 12, 359, 1-23, https://doi.org/10.3390/min12030359.

Meusburger K. et al. (2016) - A multi-radionuclide approach to evaluate the suitability of 239+240Pu as soil erosion tracer. Sci. Total Environ., 566/567, 1489-1499, http://dx.doi.org/10.1016/j.scitotenv.2016.06.035.

Sedimentological features of sandy sediments trapped in Sabellarian Bioconstructions along the Apulian Coastline (Southern Italy)

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Keywords: marine bioconstructions, coastal environment, worm reef.

Sabellarian bioconstructions, formed due to the activities of polychaetes of the genus *Sabellaria*, stand as remarkable structures within shallow marine ecosystems. Their dual role as natural breakwaters and biodiversity hotspots underscores their ecological significance. Along the Apulian coast of the Mediterranean Sea, *Sabellaria spinulosa* contributes to the formation of these bioconstructions, yet their sedimentological and morphological intricacies remain poorly known. This study delves into the sedimentological and morphological characteristics of Sabellarian bioconstructions along the Apulian coast, aiming to unravel their dynamic interplay with the surrounding environment. Through a comparative analysis of the sands trapped within the structures and those comprising the adjacent beaches, we elucidate the complex nexus between physical and biological processes shaping these bioconstructions. Utilizing a multi-scale approach encompassing textural and petrographic analyses, we decipher the temporal evolution of these structures with unprecedented resolution. Our findings unveil the profound impact of Sabellarian reefs on the sediment dynamics and ecological niches of sandy beach environments. By meticulously examining the morphology across macro-, meso-, and microscales, we offer nuanced insights into the intricate evolutionary pathways of these bioconstructions. In addition to advancing our understanding of Sabellarian bioconstructions, this research underscores the profound interconnectedness between ecosystems and coastal environments.

Integrated paleoenvironmental multi-proxy analysis of Late Quaternary fluvial sediments in the Côa Valley (northeast Portugal)

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Keywords: multidisciplinary approach, fluvial sediments, paleoclimate.

Late Quaternary fluvial sediments in northeast Portugal's Côa Valley represent a significant repository of paleoenvironmental information at local and regional scales. Understanding their depositional history and dynamics is essential for unravelling paleoclimate and geomorphological evolution. This work provides a comprehensive overview of the nature, timing, and frequency of the environmental changes that have characterised the study area during the last ~150 ka, encompassing late Marine Isotope Stage (MIS) 6 to MIS 1. The investigation is based on a multi-proxy analysis of the sedimentary record preserved at the Cardina/Salto do Boi archaeological site. A combination of intersecting sedimentological, geochemical, geomorphological, and geochronological analyses of a ~5-m-thick siliciclastic sedimentary succession was implemented. To ensure the highest level of accuracy and reliability in our findings, we used high-resolution application techniques such as grain-size, whole-rock and clay mineralogy, major/trace-element geochemistry, magnetic susceptibility, sedimentary petrography, and abundance of organic particles, coupled with absolute dating on feldspars by optically stimulated luminescence (using a multi-grain pIRIR protocol). In addition, advanced techniques like back-scattered electron imaging and elemental mappings obtained by SEM-EDS spectroscopy were spent to enhance our field characterisations and allow us to interpret the sediments' hydraulic history and origin. The main results show that the studied stratigraphic succession begins with fine sediments accumulated under low-energy diffuse water-flow conditions, where the dominant process was the suspension settling over bedload deposition. This accumulation occurred relatively close to the paleo-channel margin, resulting in overbank sedimentation under low-intense precipitation with periods of enhanced effective moisture (rainfall seasonality) during late MIS 6 and MIS 5e (~150-116 ka). The MIS 5d-5a interval (~116-71 ka) is dominated by a rapid decrease in water-flow energy linked to progressively colder and still humid conditions. Successively, sedimentary accretion became farther away from the fluvial paleo-channel margin, with a new phase of overbank sedimentation punctuated by incipient pedogenetic activity under the pronounced climate instability that characterised most of the Last Glacial Period (~71-23 ka). The uppermost sedimentary units reflect the subsequent period of progressive increase in humid conditions and chemical weathering (the last ~23 ka), attested by the more superficial disturbed slope sequence (colluvium) moved by gravity-driven processes and shallow surface water flow, with evidence of pedogenesis, anthropogenic inputs/disturbances and redeposition. This research significantly advances our understanding of Late Quaternary fluvial dynamics and paleoenvironmental changes, providing crucial insights into the landscape evolution of the western Iberian Peninsula.

Crystallization of Mn-hydroxides for interaction between limestones and clay minerals in the Apulian karst (southern Italy)

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Keywords: red carbonate crusts, Apulia karst, Mn-hydroxide.

The mineralization of Mn-phases was found within the carbonate crusts that cover the Mesozoic carbonate basement. These crusts form on ancient erosional surfaces, which serve as the substrate for paleodolines within the Apulia karst region. The petrographic and mineralogical characteristics of nodules and red crusts suggest a supergene origin (Micheletti et al., 2023). The primary ore minerals identified through optical microscopy, SEM-EDS, and Raman spectroscopy, are Mn-hydroxides and romanechite. These minerals may contain impurities such as Ca, Al, Si, Fe, Mg, Na, K, and Co. Mn-hydroxides are primarily found as extensive granular aggregates exhibiting high luminescence. Late diagenetic characteristics of Mn-phases are evidenced by bright romanechite veins, indicating the deposition of thin films along the walls of pore spaces and outlining previous iron oxides. Mn-phase occurrences are observed even on clay minerals; pseudomorphosis of Al-Si-Mn phases is characterized by grey portions enriched in Al and Si (clay minerals) and luminescent regions richer in Mn. The composition of romanechite varies depending on its Ba content: i) romanechite with approximately 11-12 wt% Ba exhibits low levels of Al and Si, while ii) romanechite containing 6-7 wt% Ba contains approximately 1.0 wt% Al, 1.2-1.3 wt% Si, and K about 0.5-0.7 wt%. The presence of low Ba-romanechite may be associated with the occurrence of clay minerals mixed with Mn-phase. A strong correlation is evident between the combined concentrations of Al, Si, and Fe with Mn, whereas no correlation is observed between Mn and Ba or Mn and Ca. This observation suggests that the structure of romanechite can accommodate varying proportions of Al, Si, and Fe when these elements are available, with Si and Al reaching concentrations of about 14 wt% and 11 wt%, respectively. On the contrary, there are Al-Si-Fe rich phases containing significant quantities of Mn, reminiscent of clay minerals hosting Mn-hydroxide. The relationship between the growth of clay minerals and Mn phases may be influenced by environmental conditions such as Eh and pH. A more thorough examination of growth structures reveals slight misalignments among nanoparticles forming local aggregates. These aggregates have the potential to evolve into bulk phases as misalignments among component nanoparticles gradually correct, forming irregular grain morphologies. This process appears to be associated with Crystallization of Particle Attachment (CPA in Zhu et al., 2021; Yin et al., 2022). The emergence of Mn-phases on a calcareous substrate is likely linked to the chemical interplay between predominantly clay material carrying Mn, Ba, Si, Al, and Fe, and the dissolution products of limestone. These findings underscore the necessity for a more thorough examination of the red crusts found on karst carbonate basements in the Mediterranean region, as they may contain mineralization conducive to the extraction of raw materials such as Mn, Fe, and Al.

Micheletti F. et al. (2023) - Petrographic and Geochemical Inferences for Genesis of Terra Rossa: A Case Study from the Apulian Karst (Southern Italy). Minerals, 13, 499, https://www.mdpi.com/2075-163X/13/4/499.

Zhu G. et al. (2021) - Self-similar mesocrystals form via interface-driven nucleation and assembly. Nature, 590, 416-422, https://www.nature.com/articles/s41586-021-03300-0.

Yin S. et al. (2022) - Replacement of magnetite by hematite in hydrothermal systems: A refined redox-independent model. Earth Planet. Sci. Lett., 577, 117282, https://www.sciencedirect.com/science/article/pii/S0012821X21005380.

Late Paleogene syn-sedimentary volcaniclastic deep-sea succession of the Candela Gorges (Southern Italy). New constrains for the evolution of the Southern Apennines

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Keywords: volcaniclastic turbidites, U-Pb zircon ages, late Paleogene.

A re-examination of the most representative succession of the Tufiti di Tusa along the Calabria-Basilicata boundary added new lithostratigraphic and depositional details to one of the internal turbidite successions of the Southern Apennines (Gallicchio et al., 2023). It also prompted new biostratigraphic, petrographic, geochemical, and chronostratigraphic studies to obtain more detailed information on the depositional age, the evolution of composition and sediment pathway; these collected data constrain the paleogeography of the depositional basin. The study section is exposed along the Candela Gorges (south of Rotondella Village, Italy) and comprises three main informal lithostratigraphic units from bottom to top: i) Unit I is mainly characterized by calciclastic turbidites, with poorly represented siliciclastic ones; ii) Unit II is mainly composed of siliciclastic turbidites with occasional intercalations of calciclastic ones and, iii) Unit III is dominated by volcaniclastic deep-sea gravity flow deposits.

Petrographic analysis and geochemical data of siliciclastic strata, allows us to detect the variability of siliciclastic supply over time. The selected samples derive from the three different units and represent siliciclastic strata with different grain size.

The samples of Unit I are represented by fine and coarse-grained sandstones in which calcitic fossils and carbonate cement occur. The silicatic detritus consists of micas, quartz and feldspars with many metamorphic, plutonic and volcanic lithic fragments. Some ophiolitic lithics with garnet and epidote locally occur.

The sandstone samples from Unit II have middle and coarse grain size. The framework is siliciclastic with minor bioclastic components. Single crystals and lithic fragments are similar to the samples of Unit 1 but a major amount of micaschists and ophiolites can be present, in addition some volcanic and acidic lithics are scattered.

In the sandstone samples from Unit III, volcanic detritus represented by porphyritic andesite lithics forms about 70% of the framework, while metamorphic lithics with garnet, glaucophane and muscovite prevail together with ophiolitic clasts. The geochemical data are in line with the petrographic evidences, the MgO (from 2.98%wt to 5.05% wt) and FeO (from 4.94% wt to 6.60% wt) contents increase upwards from Unit 1 to Unit 3 and the CaO contents depend on calcitic cement.

U-Pb spot ages detected on detrital and euhedral zircons from syn-sedimentary volcaniclastic sandstones of Unit III are about 33±1 Ma (Fornelli et al., 2020). This age is further supported by new calcareous nannofossil biostratigraphic data, which can be related with the late Eocene–early Oligocene. These results suggest a relationship with other volcaniclastic turbidite units of the Northern Apennines (Val d'Aveto, Petrignaccola, and Ranzano formations) and do not allow correlation with the Tufiti di Tusa Formation in Sicily, which is late Oligocene – early Miocene.

Fornelli A. et al. (2020) - Preliminary U-Pb detrital zircon age from Tufiti di Tusa Formation (Lucanian Apennines, Southern Italy): evidence of Rupelian volcaniclastic supply. Minerals, 10(9), 786, https://doi.org/10.3390/min10090786.

Gallicchio S. et al. (2023) - Depositional record of confined turbidites in syn-subduction intraslope basin: insight from the Tufiti di Tusa Formation (Southern Apennines, Italy). Mar. Petrol. Geol., 147, 105969, https://doi.org/10.1016/j.marpetgeo.2022.105969.

The Jurassic climate change in the northwest Gondwana (External Rif, Morocco): A probable control of successive mega-monsoons through the African Inter-Tropical Convergence Zone

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Keywords: paleoclimate, Jurassic, External Rif, Morocco.

This work focuses on Jurassic deposits belonging to the External Rif chain (Morocco). We performed elemental geochemistry analyses on selected samples of fine-grained Jurassic clay from nine stratigraphic sections belonging to the External Rif units. The main objective was to constrain the climate changes that affected northwestern Gondwana and its hyperextended conjugate Atlantic and Tethys margins during the Early-Late Jurassic. This work deals with the reconstruction of the paleo-floral landscape, paleo-humidity, and paleo-precipitation. We also aimed to unravel Early-Late Jurassic weathering, the source-to-sink transfer, and its impact on the paleoproductivity, paleo-redox, paleo-oxygenation, and paleosalinity of the flanking oceanic sinks. The obtained results indicate an early Jurassic dry-cool climate period with low rainfall and productivity, that evolved progressively to a warm climate under semi-moist and moist conditions, with high rainfall and evapotranspiration amounts in the middle Jurassic, leading to the increase of paleoproductivity. This period was marked by intense weathering with a huge terrigenous supply stored in a low-saline and well-oxygenated bordering sink(s) under oxic conditions. Later, the Upper Jurassic continuous as a warm climate under semi-moist to moist wet conditions with increasing rainfall and evapotranspiration and subsequent intense weathering triggered the transfer of huge terrigenous fluxes to the sink, before a shift to an arid cold climate in the late Oxfordian (Kairouani et al., 2024). This Jurassic climate change scenario in the northwest Gondwana hinterland may fit well with that proposed by Morgan et al. (1999) who suggested seasonal paleoclimatic changes in the Late Jurassic. The first order geodynamic control as plate tectonics reorganization, oceanic seafloor spreading triggering climate shift from dry "cool" to wet warm "greenhouse that seems to be controlled by successive mega-monsoons that occurred through the Inter-Tropical Convergence Zone (ICZ) over mid-latitudes margin and oceanic realms bordering the northwest Gondwana" during the Jurassic (Kent et al., 2015).

Kairouani H. et al. (2024) - The Jurassic climate change in the northwest Gondwana (External Rif, Morocco): Evidence from geochemistry and implication for paleoclimate evolution. Marine and Petroleum Geology, 163, 106762, https://doi.org/10.1016/j.marpetgeo.2024.106762.

Kent D.V. et al. (2015) - Tracking the Late Jurassic apparent (or true) polar shift in U-Pb-dated kimberlites from cratonic North America (Superior Province of Canada). G-cubed, 16, 4, 983-994, https://doi.org/10.1002/2015GC005734.

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Early Jurassic phosphatic sandstones (External Rif, Northern Morocco): evidence of mineralogical and biogeochemical processes related to the Early Toarcian Oceanic Anoxic Event

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Keywords: phosphatic sandstones, microbial biomineralization, Toarcian Ocean Anoxic Event.

Phosphatic-carbonate sandstones have been reported for the first time (Kairouani et al., 2023) within early Jurassic Prerif succession belonging to the External Rif Chain (Morocco). Considering the scientific relevance of this finding, this research proposes an integrated investigation by merging petrographic, mineralogical, and micro-textural data, with inferences about genetic conditions. Multi-method analysis was performed by Optical Microscope, X-ray diffraction, and Scanning Electron Microscopy with the aim to constrain biogeochemical and mineralogical processes controlling phosphatic grain genesis. The phosphatic sandstones are represented by moderately to well sorted fine-grained hybrid arenites with sub-angular to well-rounded clasts cemented by sparry calcite. The phosphatic grains represent ca. 25-30%, while the remaining other grains are dominantly made up of carbonate (mostly micritic grains and foraminifera tests) and secondarily by siliciclastic grains (quartz and feldspars). The phosphatic grains can be grouped into two main classes: i) phosphatic peloids and ii) phosphatic bioclasts (as fish bone, representing less than 5%). XRD data reveal that the main phosphate phase occurs as CFA (carbonate fluorapatite) also if in many cases it can be found as amorphous/cryptocrystalline collophane. SEM investigations evidence a not homogenous chemical composition of the phosphatic grains which are characterized by different types of microtextures. BSE images reveal brighter acicular and fibrous growths with lower C and higher F contents boarding the external textures of voids and internal gray portions with lower F and higher C contents. Centripetal microboring from outside to inside was observed in the phosphate-coated foraminifera and skeletal fragments. Probably the endolithic bacteria feed on organic matter in the phosphate skeletons of organisms by precipitating a bright phosphate with low C contents, the portions not digested by the bacteria are instead represented by phosphates with more C. In some case, the advanced stage of endolithic bacteria swarming is evident with gradual rounding of the phosphatic fragment edges until the complete conversion of the phosphate test into an a peloidal structure. The genesis of sedimentary phosphorites can be controlled by heterotrophic microbial communities with high biogeochemical activity or can be related to precipitation of phosphates by fluids during diagenesis (El Bamiki et al., 2023). Microbial pathways and palaeoenvironmental conditions involved in the formation of phosphorite grains. Both these processes take place under low oxygen conditions in marine environments (Salama et al., 2015). The palaeclimatic studies on Pleinsbachian-Toarcian samples (Kairouani et al., 2024) belonging to the same succession indicate low oxygen conditions. Consequently, anoxic conditions during Toarcian Oceanic Anoxic Event (T-OAE at ~181 Ma) are related to the genesis of these Mesozoic phosphatic sandstones.

El Bamiki R. et al. (2023) - Post-phosphogenesis processes and the natural beneficiation of phosphates: Geochemical evidence from the Moroccan High Atlas phosphate-rich sediments. Chemical Geology, 631, 121523.

Kairouani H. et al. (2023) - Provenance and source-to-sink of lower-middle Jurassic sediments from hinterland mounts to NW-Gondwana hyper-extended passive margin (Prerif sub-domain, External Rif, Morocco): First evidence from sedimentary petrology and detrital Zircon geochronology. Marine and Petroleum Geology, https://doi.org/10.1016/j.marpetgeo.2023.106492.

Kairouani H. et al. (2024) - The Jurassic climate change in the northwest Gondwana (External Rif, Morocco): Evidence from geochemistry and implication for paleoclimate evolution. Marine and Petroleum Geology, 163, https://doi.org/10.1016/j.marpetgeo.2024.106762.

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(Paleo)weathering or diagenesis as the principal control factor of sand(stone) framework grains dissolution?

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Keywords: (paleo)weathering, feldspathic sand(stones), dissolution.

Both (paleo)weathering and diagenesis are responsible for much labile Framework Grains Dissolution. Framework Grain Dissolution (FGD) involving feldspars was found to be significant to reservoir properties in grus and soil horizons developed on felsic plutonites of the Sila Massif (Calabria, southern Italy) bedrock under a Mediterranean climate. FGD porosity demonstrated an increase in well-connected porosity from negligible in the fresh rock to around 30-40% in the grus. In this surface weathering environment, the FGD, during the conversion from the original bedrock to the grus and soil, show a 14% loss of plagioclase and the total loss of K-feldspar. This dissolution led to an increase of porosity from 0,4% in the coherent rock facies to 28,0% of the soil. These results places constraints on the FGD and composition of ancient feldspathic arenites and the conditions designed to distinguish between paleoweathering from diagenesis. Previous studies of the stratigraphic record, in which the paleoclimate was more humid than the modern climate, suggests that FGD of unstable grain abundance, by ancient weathering efficiency, cannot be distinguished from unstable FGD occurred during burial diagenesis. Modern sands of humid climates have lower contents of unstable grains with a percentage decrease between 12% and 20% for unstable lithic grains and of 10% for feldspathic ones if compared to a provenance from the same source rocks under humid climate. Literature data from ancient feldspathic arenites and modern sands, derived from similar source rocks, demonstrate that pre-diagenetic near surface dissolution of unstable grains can be discerned from diagenesis only for those modern/ancient pairs where the modern climate is more humid than the inferred paleoclimate. In this case feldspar grains show a dissolution even higher reaching a 34% of loss of feldspars and a percentage decrease of unstable lithic grains ranging from 10% to 12%. Both intrastratal dissolution and replacement by authigenic clays may remove feldspars from the arenites framework thus affecting both the classification and the inferred tectonic setting of the arenites leading to an incorrect paleogeographic interpretation.

Tectonic forcing encoding in the geomorphic and stratigraphic records of a tight source-to-sink system (Northeastern Sicily, Italy)

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Keywords: NE-Sicily, source-to-sink system, tectonic forcing.

Recognizing tectonically- vs. climatically-induced base level change signals encoded within the stratigraphic and geomorphic records of coupled source-to-sink systems is still a challenge (Sharman et al., 2019). In this study, we integrate sedimentological, geochronological, and geomorphic approaches to investigate the relationship between geomorphic transience and sediment deposition in a tight tectonically-uplifted source-to-sink system. At the sink we built a luminescence-based age model for the late Pleistocene Pagliara fan-delta complex, located on the eastern side of the Peloritani Mts. (NE-Sicily, Italy), and explored the signal periodicities encoded by environmental proxies. At the source we modelled the base level fall history and the paleo-erosion in the catchment. The ~150-200m-thick Pagliara fan-delta complex deposits are exposed up to an elevation of ~300 m a.s.l. and onlap steep east-dipping bedrock at the coast. Infrared-stimulated luminescence (IRSL) ages of the delta deposits range from ~327 ka to ~208 ka, and provide a vertical long-term sediment accumulation rate as rapid as ~2.2 cm/yr during MIS 7. Cosmogenic 10Be concentrations measured in two samples collected along the delta indicate MIS 8-7 paleo-erosion rates consistent with the modern rate of ~1 mm/yr (Cyr et al., 2010). In addition, the Magnetic Susceptibility time series analysis evidences the occurrence of some millennial to sub-millennial periodicities pointing out to cyclical past environmental changes, and inspirationally allowing to speculate on the origin of sediment in the source. The Pagliara fluvial topography recorded an unsteady base level fall history, in phase with eustasy and superimposed on a longer, tectonically-driven signal, the rate of which increased from ~0.95 mm/yr to ~1.8 mm/yr in the past 150 ky (Pavano et al., 2024). Finally, we reconstruct the accommodation space history of the hanging wall basin that hosted the Pagliara fan-delta complex deposits. We reconstructed an integrated geomorphic and depositional dynamics of the Pagliara source-to-sink system, evolving in response to regional-to-local tectonic deformation, and climate forcings.

Sharman G.R. et al. (2019) - Conversion of tectonic and climatic forcings into records of sediment supply and provenance: Scientific Reports, 9, 4115.

Cyr A.J. et al. (2010) - Quantifying rock uplift rates using channel steepness and cosmogenic nuclide–determined erosion rates: Examples from northern and southern Italy. Lithosphere, 2(3), 188-198.

Pavano F. et al. (2024) - Integrated uplift, subsidence, erosion, and depostion in a tightly coupled source to sink system, Pagliara basin, northeastern Sicily, Italy. Basin Research, 36(1), e12851, https://doi.org/10.1111/bre.12845.

Heavy Minerals analysis of fluvial sand in the Crati River (Northern Calabria)

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Keywords: provenance, heavy minerals, Crati River.

The knowledge of the heavy mineral composition of sediments in a river basin and the controlling factors (e.g., provenance, transport processes, and chemical weathering) is crucial in the study of both source-to-sink processes and in the evolution of river drainage area. Heavy mineral concentrations in modern sand sample of the main and tributary streams of Crati River drainage area were analyzed using optical microscopy and RaMan spectroscopy, in order to determine the types and abundance of heavy minerals, assess their weathering textures and infer their provenance. Heavy minerals concentration ranges from 5,6% to 42,7% in the Crati River main channel with irregular patterns in the abundance of heavy minerals observed across the trunk river from the upper to the lower reaches. Most of the heavy minerals display sub-angular to angular shape, grains with sharp edges on the surface, conchoidal fractures, deep troughs, and breakage blocks inferring that the provenance is close to the depositional area. Subrounded to rounded grains with smoother surface, arcuate steps, also occur. These minerals mainly include garnet, epidote and sillimanite, followed by pyroxenes, amphibole, titanite, rutile, pumpellyite, andalusite, tourmaline staurolite and a minor amount of cassierite, brookite and apatite are also present in trace amounts. The zircon-tourmaline-rutile index (ZTR), ranging between 3 to 13%, indicates a mineralogically immature sediment and a short transport history and provenance. Some species like amphibole, pyroxene and epidote show corroded morphologies while garnet and sillimanite grains are characterized by mainly physical breakage. The heavy minerals suite of garnet, epidote, sillimanite, green hornblende and staurolite suggest a provenance from moderate to high-grade metamorphic source terrain,such gneiss, amphibolite, granulite and schist . A provenance from an igneous source complex,granite, granodiorite and gabbro, is marked by detrital species such as rutile, green-brown hornblende, titanite, tourmaline, zircon, pyroxene and opaque minerals. Moreover, the occurrence of rounded to sub-rounded zircon and rutile grains indicate polycyclic supply from sedimentary and meta-sedimentary source rocks. Therefore, results show that the Crati River sand is derived mainly from the metamorphic and plutonic rocks of the western side of the Sila Massif and the eastern side of the Catena Costiera, and to a lesser extent from the sedimentary rocks outcropping in the Pollino Massif. These features suggest that the locally source signal (detected also in the tributaries) are preserved in the Crati River main trunk, indicating that the control on heavy minerals composition is chiefly provenance influenced and not related to fluvial processes.

Weathering and erosion rates at different timescales in a granitic area of the Mediterranean (Sila Massif, Calabria, southern Italy): an overview on recent advances

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Keywords: weathering processes, landscape evolution, erosion rates.

Weathering processes and geomorphic dynamics including erosion, transport and sedimentation strongly contribute to shape past and modern landscapes worldwide. The Sila Massif (Calabria, southern Italy) represents a pilot area as a natural open laboratory in the central Mediterranean, where a variety of such physical, chemical and biological processes and corresponding landforms has been studied over more than three decades. Literature data span across different spatial scales, ranging from field (regional, catchment, slope, outcrop) surveys to microscopic and submicroscopic observations using optical and/or scanning electron microscopy. Among major research findings is the role of rock discontinuities, related to the specific geological history of the parent material, as weakness surfaces and predisposing factors of mechanical breakage patterns and preferential sites for chemical reactions. Similarly, microdiscontinuities at inter- and intra-mineral levels (fabric, contact surfaces, cleavage or twinning planes, compositional changes), coupled with a progressive development of neogenic products (clay minerals and iron (hydro)oxides), often act as upscaling factors, propagating their effects at the macroscale. This behavior leads to rock degradation and decomposition, with consequent sediment production and mobilization by water flows and mass movements. What has been less explored so far are the rates of weathering processes and erosion at different temporal scales. Some recent advances of the investigations in the Sila uplands focused on this topic. Different papers studied the formation of tors and spheroidal boulders as a result of past deep weathering, followed by their exhumation by erosion during the Pleistocene, in turn enhanced by tectonic uplift and climate changes. Their long-term rates of denudation were estimated using cosmogenic beryllium (10Be) and varied between 0.04 and 0.40 mm yr−1 during about the last 100 ka (Raab et al., 2018, 2019). Within the same range although more restricted are average erosion rates (ca. 0.10 mm yr−1) estimated using 10Be in river sediments for the low-relief upland landscape of the Sila Massif (Olivetti et al., 2012) and its surroundings. Medium-term erosion rates calculated by Raab et al. (2018) through fallout plutonium isotopes (239+240Pu) for soils in the same tor-and-boulder area of the Sila Massif are much higher and close to 1.23 mm yr− 1 for the last half a century. Short-term erosion rates of 13 to 0.30 mm yr−1 (mean value of 3.40 mm yr−1) were obtained through a multitemporal acquisition of 3D rock scarp retreat using terrestrial laser scanning (TLS) techniques (Scarciglia et al., 2022). Although obtained on varying morphologies and different methods, these rates can be of help for a deeper comprehension of how fast erosion can remove mobile weathering products through time also according to different modes and transport agents.

Olivetti V. et al. (2012) - Uplift history of the Sila Massif, southern Italy, deciphered from cosmogenic 10Be erosion rates and river longitudinal profile analysis. Tectonics, 31, TC3007, 1-19, https://doi.org/10.1029/2011TC003037.

Raab G. et al. (2018) - Denudation variability of the Sila Massif upland (Italy) from decades to millennia using 10Be and 239+240Pu. Land Degrad. Develop., 29, 3736-3752, https://doi.org/10.1002/ldr.3120.

Raab G. et al. (2019) - Climate and relief-induced controls on the temporal variability of denudation rates in a granitic upland. Earth Surf. Process. Landforms, 44, 2570-2586, https://doi.org/10.1002/esp.4681.

Scarciglia F. et al. (2022) - Weathering processes and rates of scarp retreat in a Mediterranean mountain environment: A multi-analytical approach from terrestrial laser scanning to microscale surveys. Geomorphology, 413, 108356, 1-17, https://doi.org/10.1016/j.geomorph.2022.108356.

Weathering processes and soil formation in Sila Massif and Catena Costiera (Calabria,southern Italy): Insight from heavy minerals

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Keywords: soil genesis, weathering,heavy minerals.

Sediment and soil formation have been widely studied to assess and quantify the extent and rates of geomorphic processes such as chemical weathering and denudation dynamics. The present study aims to demonstrate the advantages of an integrated method including pedological, petrographic and geochemical investigations with the goals of: 1) studying the effects of chemical weathering and pedogenesis on rocks from two mountain environments in Calabria (southern Italy), such as a gneissic bedrock in the Sila Massif, and both a migmatitic gneiss and a gabbroic bedrock in the Catena Costiera; 2) identifying the concentration and stability of primary heavy minerals, the major weathering products and compositional changes along the weathering profiles (transect bedrock/grus/soil), in order to constrain their genesis. Specifically, a detailed description and classification of the surface microtextures displayed by the different heavy minerals identified along the weathering profiles (bedrock-grus-soil) is provided . Differences in the amounts of heavy minerals in each soil profile seem to be be controlled by the nature of the local bedrocks. The addition of allochthonous parent material and a varying extent of chemical weathering, likely is influenced by topography and duration of pedogenesis. The heavy mineral shapes and surface microtextures, together with the distribution of major and trace elements, the values of the chemical index of alteration and the relative abundance of the clay mineral types along the profiles indicate the different weathering degrees. These features are consistent with iron/manganese oxy-hydroxides and clay neogenesis observed on femic heavy minerals. Moreover, they suggest a lithological discontinuity between the bedrock and the upper soil horizons, which led to rejuvenation by erosive and colluvial processes along the slopes and/or aeolian deposition of allochthonous material, presumably including a Late Pleistocene to Holocene pyroclastic input. Chemical weathering affecting the majority of heavy minerals is consistent with high rainfall rates, soil moisture availability and acidic pH conditions likely favored by organic acids, prone to chemical reactions and leaching processes. The clay coatings and iron/manganese segregations in the Bt horizons of all the profiles studied suggest their development in a warmer humid climate during the interglacial stages of the Pleistocene.

S41.

The evolution of sedimentary basins: from source to complex basin architecture

CONVENERS & CHAIRPERSONS

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The Upper Cretaceous Pietraforte formation (Monti della Tolfa, Northern Latium, Italy) in a source-to-sink perspective

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Keywords: Pietraforte formation, detrital zircon U-Pb geochronology, sedimentary source.

The Upper Cretaceous Pietraforte Formation is an allochthonous turbidite unit belonging to the External Ligurian domain of the northern Apennines. It croups out as discontinuous successions of channelized bodies and thick-bedded coarse-grained sandstones occasionally intercalated with shales intervals, extending from the Tuscany region to the Tolfa Mountains (northern Latium).

In this work, we report exclusive results regarding the detrital zircon U-Pb geochronology, and calcareous nannofossils analysis of the Pietraforte Fm cropping out in the Tolfa Mountains. In the study area, the Pietraforte Fm is characterized by a lower lithofacies "Argilliti Varicolori manganesifere" (Varicoloured clays), dominantly made of variegated clays with intercalations of very think-bedded of limestones and sometimes siltstones, and an upper lithofacies, which mainly consists of thin to thick-bedded of fine to very coarse-grained hybrid sandstones, sometimes intercalated with fine-grained deposits.

Biostratigraphic analyses on calcareous nannofossils assemblages from fine-grained deposits of the "Argilliti Varicolori manganesifere" yielded a maximum age of middle Coniacian for this lithofacies, previously considered to be Turonian-Santonian (Servizio Geologico d'Italia, 2020).

Zircons have been separated from two sandstone samples (PF1 and PF2) for U-Pb detrital geochronology through the LA-ICP-MS technique. Most zircons display oscillatory to sector growth zoning in cathodoluminescence (CL) images and Th/U > 0.3, which are characteristic of igneous origins. Sample PF1 exhibits prominent age groups younger than the Precambrian, with peaks at ca. 280, 320, 370, 450, and 520 Ma. Precambrian age populations show peaks at ca. 550 and 700 Ma, with other minor clusters at approximately 800, 1000, 1500, 1700, and 2200 Ma. Sample PF2 shows similar age populations but lacks Mesozoic ages, with a major age peaks in Ordovician-Cambrian.

The detrital zircon ages of the two samples suggest a significant contribution from Hercynian, Caledonian, and Pan-African sources, with minor contribution from older Grenvillian and Eburnian sources.

In conclusion, these results, together with the Tuscan affinities of the sedimentary lithics, indicate that the detrital grains of the Pietraforte sandstones were sourced by sedimentary and metasedimentary rocks of the Tuscan Domain at the western margin of the Adria Plate.

Servizio Geologico d'Italia (2020) - Carta Geologica d'Italia alla scala 1:50.000, F. 354 Tarquinia.

Linking sedimentary loading-unloading cycles and faulting in intermontane basins of the broken foreland of NW Argentine Andes: new prospective from numerical modeling and field observations

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Keywords: sedimentary loading and unloading cycles, intermontane basins, intrabasinal faulting.

The dynamics of sediment removal, redistribution, and storage in tectonically active mountain belts are believed to play a crucial role in controlling shallow crustal stresses, influencing fault activity, and ultimately impacting the spatiotemporal evolution of regional deformation processes. While it is widely hypothesized that sediment loading and unloading cycles within intermontane sedimentary basins may either inhibit or promote intrabasinal faulting, clear evidence validating this hypothesis has remained elusive (Ballato et al., 2019).

In our study, we integrate 2D numerical simulations that replicate contractional deformation within a broken-foreland context (where shortening is absorbed by reverse faults uplifting basement blocks at different times and locations) with field observations from intermontane basins in the northwest Argentine Andes. Our modeling outcomes indicate that thicker sedimentary accumulations (> 0.7-1.0 km) are likely to suppress faulting within basins, whereas thinner deposits (< 0.7 km) tend to delay fault activation. Conversely, the removal of sediment loads through fluvial incision and basin excavation promotes renewed intrabasinal faulting.

These findings contribute to a deeper understanding of the tectono-sedimentary evolution of intermontane basins situated along the eastern border of the Andean Plateau in northwestern Argentina. For instance, the Santa María and Humahuaca basins exhibit evidence of intrabasinal deformation occurring concurrently with, or subsequent to sediment unloading, while the Quebrada del Toro Basin shows a reduction in intrabasinal faulting activity attributed to the presence of thick, coarse conglomerate loads. Consequently, we conclude that sedimentary loading and unloading cycles exert a fundamental influence on the spatiotemporal patterns of deformation within intermontane basins located in tectonically active broken forelands.

Ballato P. et al. (2019) - Sedimentary loading–unloading cycles and faulting in intermontane basins: Insights from numerical modeling and field observations in the NW Argentine Andes. Earth and Planetary Science Letters, 506, 388-396, https://doi.org/10.1016/j.epsl.2018.10.043.

Integrated stratigraphy reveals Oligo-Miocene paleoclimatic phases: a Central Mediterranen insight from the western Hyblean sedimentary succession

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Keywords: integrated stratigraphy, Hyblean mountains, western successions.

In south-east Sicily, the succession outcropping in the western sector of the Hyblean Plateau is mainly composed of carbonate sediments interbedded with volcanic rocks, ranging in age from Early Oligocene to Quaternary. This succession has recorded the important climatic variations taking place during their formation.

The results of a refined integrated stratigraphic study, consisting of an accurate field mapping, integrated biostratigraphy (foraminifers and calcareous nannofossils), magnetostratigraphy and isotope stratigraphy, has provided the opportunity to carry out a thorough review of the successions cropping out in the area, whose last update dates back to the late ‘90s.

In the present study we present the results concerning the Lower Oligocene-Lower Miocene Leonardo Fm (ex Leonardo Mb. of the Ragusa Fm. *Auct.*) and its relation with the overlying Irminio Fm. (ex Irminio Mb. of the Ragusa Fm. *Auct.*).

An integrated study was conducted within the Leonardo Fm. sediments (Misericordia and Mangiagesso Caves) consisting of high-resolution calcareous plankton biostratigraphy and stable C and O isotopes content.

According to the biostratigraphic data, the succession is Early-Late Oligocene in age and is characterized by a hiatus corresponding to the MNP24 nannofossil biozone (27.14-26.81 Ma).

Preliminary analyses on carbon and oxygen isotope ratios, measured on bulk-rock samples belonging to the abovementioned sections, reveal a rather stable climatic phase, testified by the δ18O isotope record, during Chattian, characterized by several positive δ13C shifts. The latter are interpreted as moments of increased nutrient content into surface waters which, into deeper waters, correlate with the occurrence of cherty layer (e.g. Misericordia Cave).

Through Sr isotope analyses, coupled with detailed nannofossil assemblages’ analyses, we identified an interval of phosphogenesis and sedimentary condensation, marked by a well evident hardground, at the Leonardo/Irminio boundary.

This hiatus occurs at the base of the Aquitanian (23-22 Ma) thus coinciding with a global cooling event and glacial maximum (Mi-1 Event) and is interpreted as the result of the upwelling of nutrient-rich deep waters, increased weathering and phosphorous availability triggered by global cooling and enhanced circulation in the Mediterranean basin.

Coeval phosphatic hardgrounds also occur in the Oligo-Miocene succession of the Malta Island, lining up from South to North. This correlation supports the interpretation of increased bottom-water currents, which, originating in the deep Eastern Mediterranean basin, rose up to the eastern sides of the Central Mediterranean carbonate platforms during abrupt climate shifts.

Diagenesis and paleo-fluid characterization of the Bathonian-Callovian platform carbonates from the southern Paris Basin sub-surface

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Keywords: burial diagenesis, cement stratigraphy, fluid inclusions.

Past circulations of hydrothermal fluids in sedimentary basins are challenging to establish. They may severely affect the maturation of organic matter and mineral diagenesis reactions and, consequently, the accurate assessment of thermal history of the basin successions. This has a crucial impact on establishing thermal models for exploring sub-surface fluid resources. Past hydrothermal events are commonly of short duration (from a few to tens of Myr). However, they may perturbate the thermal regime for a longer time, causing thermal anomalies that persist up to the present. Therefore, the timing, sources, and pathways of past hydrothermal fluids are of interest for the exploration present-day geothermal fluids in sedimentary basins.

In this study, we investigate two well-cores drilled in potential geothermal reservoirs of Bathonian-Callovian platform carbonates from the intracontinental Paris Basin, where literature did not initially consider hydrothermal circulations. Only recently, progress in carbonate isotope geochemistry allowing Δ47/U-Pb thermochronometry, combined with fluid inclusion microthermometry of calcite, dolomite, and fluorite cements, suggested hydrothermal fluids may have locally ascended through deep-seated faults during late Mesozoic and Cenozoic times (Mangenot et al. 2018a, 2018b; Brigaud et al. 2020; Lenoir et al., 2024).

This study focuses on samples located between well-cores from the basin depocenter (Mangenot et al., 2018a, 2018b) and outcrops from the Burgundy/Morvan regions (Lenoir et al., 2024); samples contain calcite and dolomite cements precipitated during burial diagenesis.

An accurate petrographic analysis in transmitted-light, UV-light, and cathodoluminescence microscopy allowed the reconstruction of the cement stratigraphy. Further insights on the thermal conditions and composition of the fluids precipitating the cements were obtained via O-C stable isotope analyses and fluid inclusion microthermometry, allowing us to discriminate the type of paleo-fluid circulations in the area.

Brigaud B. et al. (2020) - Past hot fluid flows in limestones detected by Δ47–(U-Pb) and not recorded by other geothermometers. Geology, 48(9), 851-856, https://doi.org/10.1130/G47358.1.

Lenoir L. et al. (2024) - The origin of fluorite-barite mineralization at the interface between the Paris Basin and its Variscan basement: insights from fluid inclusion chemistry and isotopic (O, H, Cl) composition. Mineralium Deposita, 59(2), 397-417, https://doi.org/10.1007/s00126-023-01219-2.

Mangenot X. et al. (2018) - Basin scale thermal and fluid-flow histories revealed by carbonate clumped isotopes (Δ47) – Middle Jurassic of the Paris Basin depocenter. Sedimentology, 65, 123-150, https://doi.org/10.1111/sed.12427.

Mangenot X. et al. (2018b) - An emerging thermo-chronometer for carbonate-bearing rocks: Δ47/(U-Pb). Geology, 46(12), 1067-1070, https://doi.org/10.1130/G45196.1.

Control of the synsedimentary tectonics on turbidite channels dynamics: an integrated study between field and subsurface data

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Keywords: synsedimentary tectonics, turbidite channels, facies analysis.

A turbidite system can be considered as a fluvial system, characterized by a source-erosional zone, a transfer zone and a depositional zone (Mutti et al., 2003). Turbidity currents are among the most effective processes on Earth for redistributing sediment in deep-sea systems, and turbidite channels play a key role in this process. That is why the oil industry is particularly interested in turbidite channels in slope environments since they can control large accumulations of sediment and thus hydrocarbons worldwide. As is well known, channels can be "erosional" dominated by bypass facies, "depositional" characterized by depositional lobes and "mixed" characterized by fining-upward facies sequences, where coarse-grained bypass facies pass upward into depositional facies (Mutti & Normark, 1987). Although channel dynamics can depend on various types of allogenic controls, increasing evidence from subsurface and outcrop data suggests that tectonics can have a key role in creating morphological barriers that can control channel dynamics, i.e., whether a channel works as a sediment transfer or trapping/depositional zone. Thus, the objective of this work is to study the relationship between tectonics and sedimentation in controlling the turbidite transfer zone dynamics through a comparison between subsurface and field data coming from the Campos basin (Brazilian offshore) and Mediterranean-type foreland basins respectively. As to field cases, the Fontanelice turbidite system of the Marnoso-arenacea Formation (MAF) in the northern Apennines (Italy) and some channelized systems of the Broto and Cotefablo turbidite systems in the Ainsa basin (south-central Pyrenees) were taken into account.

These studies have been carried out through physical stratigraphy, well logs and 3D seismic interpretation and facies analysis in outcrops and subsurface cores. This analysis was carried out following the classic scheme by Mutti et al. (2003) and the more recent one by Tinterri et al. (2023), which proposes a facies scheme for turbidite systems characterized by tectonic confinement able to decrease flow efficiency, especially through the formation of transversal morphologies (i.e., perpendicular to the paleocurrents) as slope breaks and counterslopes.

Preliminary results support the hypothesis that transfer zones tend to be depositional in the presence of frontal morphological barriers, as in the cases of the Fontanelice system (Miocene, MAF) controlled by the transversal Forlì line, and of the Upper Cretaceous channel in Campos Basin, controlled by a topography known in the literature as "central high". Conversely, transfer zones tend to be erosional, i.e., dominated by bypass, especially in periods of tectonic quiescence and, therefore, with no transversal obstacle, as in the cases of Gerbè-Cotefablo channel (Eocene, Pyrenees) and of the Oligocene channel in Campos Basin. Consequently, a comparison between foreland and passive margin deposits supports similar conclusions.

Mutti E. et al. (2003) - Deltaic, mixed and turbidite sedimentation of ancient foreland basins. Mar. Petrol. Geol., 20, 733-755, https://doi.org/10.1016/j.marpetgeo.2003.09.001.

Mutti E. & Normark W.R. (1987) - Comparing examples of modern and ancient turbidite system: problems and concepts. In: Legget J.K. and Zuffa G.G. (Eds), Marine Clastic Sedimentology: Concept and Case Studies, Graham and Trotman, London, 1-38.

Tinterri R. et al. (2023) - Turbidite facies tracts as related to flow criticality and efficiency in tectonically confined basins: an outcrop perspective. 1st In-Person Bouma Conference, Utrecht 17-21 April 2023, Abstract Book, p. 8.

Detailed field mapping and revised litho-biostratigraphy of the Castelvetere Formation cropping out at the NW Campania-Basilicata border (Southern Apennines, Southern Italy)

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Keywords: Southern Apennines, Castelvetere Formation, litho-biostratigraphy.

The Castelvetere Formation is one of the most important foredeep/thrust-top deep-marine sedimentary units of the Southern Apennines, nowadays considered upper Tortonian-lower Messinian in age (Servizio Geologico d'Italia, 2002 and references therein). In the literature (e.g. SGI, 2002), it is described as an up to about 1000 m-thick succession, made up of an alternation of typically-coarse-grained sandstones, conglomerates, mudstones, olistostromes of "argille varicolori" *sensu lato* and olistholiths deriving from the Apenninic Carbonate Platform. Ongoing geological field mapping at a 1:10.000 scale and litho-biostratigraphic study (within the CARG Project, sheet n.469 Muro Lucano) in the outcrop type area of the formation, among the Muro Lucano, Castelgrande and Laviano villages (NW Campania-Basilicata border, Southern Italy) have resulted in the following main points.

The study interval of the Castelvetere Formation is highly deformed: it forms wide and at-times-overturned, partly fault-related folds with around E-W orientation of the hinge lines; moreover, it is affected by both around E-W-oriented contractional-to-extensional faults and N-to-NE-oriented high-angle faults.

It was deposited during the Langhian-Serravallian times, as testified by nannoplankton analyses of some tens marls-to-marly-clay samples collected from different sections spanning throughout its thickness.

It has a thickness of several hundreds of metres, lies on Apenninic-Carbonate-Platform deposits along an unconformity, marked by basal conglomerate, and passes upward unconformably to Pliocene conglomeratic and sandy deposits of the Tolve Synthem (SGI, 2013).

The Castelvetere Formation is mainly represented by tens of metres thick (in outcrop) packages of amalgamated medium-to-coarse grained sandstones including up to very-thick conglomerates with erosional base; the sandstones are ungraded to graded and they rarely show plane-parallel to cross lamination, convolute lamination, load casts and flame structures. The lower interval of the study succession is characterised by a Langhian huge olistostrome made up of Argille-Variegate-Group terrains containing m- to 10 m-sized olistoliths of the Apenninic Carbonate Platform. The upper interval is characterised by up to several tens of metres thick (in outcrop) packages of marlstones to marly claystones with intercalations of thin-to-very-thin siltstones to fine-grained sandstones, at-most-metres-thick medium-to-coarse-grained sandstones and large slabs of Sicilide-affinity terrains, as well as up-to-thousands-of-cubic-metres olistoliths coming from the Apenninic Carbonate Platform within mass transport deposits. Accordingly, the Castelvetere-Formation basin, floored by the Apenninic Carbonate Platform, was formed no later than the Langhian time and its deformation could start from the late Serravallian-Tortonian, unlike stated in current regional models (e.g. Vitale et al., 2020), which postpone both these events.

Servizio Geologico d'Italia (2002) - Carta Geologica d'Italia alla scala 1:50.0000, Catalogo delle Formazioni, Fascicolo III - Unità validate.

Servizio Geologico d'Italia (2013) - Carta Geologica d'Italia alla scala 1:50.000, F. 470 Potenza. ISPRA, Roma.

Vitale S. et al. (2020) - Structural and Stratigraphic Setting of Campagna and Giffoni Tectonic Windows: New Insights on the Orogenic Evolution of the Southern Apennines (Italy). Geosciences, 10(10), 405, https://doi.org/10.3390/geosciences10100405.

Turbidite systems in tectonically-confined foredeep and trench-slope basins: a comparison between Serra Palazzo Fm. and tufiti delle Gole Candela succession (Lucanian Apennines, Italy)

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Keywords: foredeep, trench-slope basin, confined turbidite systems.

One of the key controls on turbidite systems is the presence of confining morpho-structural elements with different topography and evolution over time, resulting in characteristic facies and architecture. In this study, two turbidite systems are compared: the Miocene Serra Palazzo Fm. (SPF) and the informal late Paleogene tufiti delle Gole Candela succession (tgc, classically referred to the Tufiti di Tusa Fm.), both cropping out along the outer border of the Southern Apennines, in Basilicata Region. The study area for the SPF is near the Campomaggiore village (Middle Valley of Basento River, in province of Potenza), where a c. 300 m-thick coarse-grained sandstone-rich succession crops out. This is compared to tgc, an about 230 m-thick muddy-sandy succession cropping out near the Rotondella village (Lower Valley of Sinni River, in province of Matera). Detailed facies analysis based on high-resolution physical stratigraphy was used to infer basin morphology and evolution for both systems (Cerone et al., 2021; Gallicchio et al., 2023). The SPF outcrop is characterised by palaeocurrents directed towards SE, with flows moving parallel to the thrust front of the chain. This configuration suggests that the flows, after reaching the slope base of the foredeep basin, were deflected by the inbound slope made up by the proximal flank of the forebulge, and that they then travelled along the basin long axis. The sandstone to mudstone ratio (S/M) is relatively high (over 2) and it does not show any upward increase, suggesting that the succession was not fully confined and that did not experience any change over time in confinement. Sedimentary features, such as load casts, convolute lamination and mud-draped scours, observed at several different stratigraphic intervals, indicate that flows decelerated due to a reduction in gradient and the possible presence of morphological obstacles. The studied tgc succession lies unconformably on highly-deformed terrains of the Argille Variegate. Unlike the SPF, it shows a very high-dispersion of the palaeocurrent directions and an upward increase in the S/M ratio from 0.6 to 2.5, reflecting an evolution from a flow ponding phase to a flow stripping phase. Biconvex ripples with sigmoidal-cross laminae, hummocky-type structures and thick mudstone caps are widespread throughout the stratigraphy. This evidence suggests that the tgc was deposited in a fully-confined setting represented by a trench-slope basin. In conclusion, the studied outcrops represent two examples of turbidite systems controlled by different morpho-structural configurations and evolution of basin topography and the presented facies and architectures can help interpret turbidite systems in less well-exposed areas or in the subsurface.

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Gallicchio S. et al. (2023) - Depositional record of confined turbidites in syn-subduction intraslope basin: insight from the Tufiti di Tusa Formation (Southern Apennines, Italy). Mar. Petrol. Geol., 147, https://doi.org/10.1016/j.marpetgeo.2022.105969.

Assembling and dismantling the supercontinent Pangaea recorded from provenance relations of Phanerozoic sandstones of the circum-Mediterranean Region

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Keywords: detrital signatures, sandstone suites, provenance relations, circum-Mediterranean orogens.

The composition and stratigraphic relations of clastic strata in diverse sedimentary basins of the circum-Mediterranean region reflect a complete record of provenance relations since break-up of Pangaea, neo-Tethyan rifting, and subsequent plate convergence between the two major plates of Europe and Africa, and other related microplates of Iberia, Adria and Mesomediterranean microplate (Critelli, 2018; Criniti et al., 2023).

Since the plate reorganization to the breakup of Pangea (Criniti, 2023), at the end of Paleozoic-earliest Mesozoic, clastic wedges filled sedimentary basins within geodynamic settings evolving from continental rifts, rifted-continental margins, protoceanic basins, arc-trench systems, remnant ocean basins, proforeland basin systems and back-arc basins within the circum-Mediterranean region (Critelli et al., 2008; Critelli, 2018).

The changing nature of clastic particles in these clastic wedges reflect the provenance relations from different source rocks within the spatial and temporal evolving geo-puzzle terranes, including relations between ophiolite-bearing, uplifted continental crust (both shallow to deep crust terranes), volcanic and sedimentary (particularly carbonate strata) source rocks. Typical sand(stone) suites are quartzose, derived from flexured cratonal area, followed by quartzolithic and quartzofeldspathic derived from the growth fold-thrust belt. Mixed siliciclastic and carbonate shallow- to deep-marine clastic wedges are diffuse in many filled basin systems along the Circum-Mediterranean region, as such as volcaniclastic sand(stone) that may also occur interbedded with typical quartzolithic suites, in both remnant ocean basins and foreland basins.

The variable mosaic of source terranes within the Circum-Mediterranean region, representing striking examples of proforeland sandstone suites, offered the possibility to investigate provenance relations in sandstones with a new plane of precision and sophistication, discriminating grain particles in clastic wedges using spatial (extrabasinal versus intrabasinal), and temporal (coeval versus noncoeval) distinction of detrital signals (Costamagna & Criniti, 2023). The spatial/temporal approach in deciphering particles in clastic rocks has been widely used to detail the basinal dispersal pathways in different geotectonic settings, wherever mixed silicate and carbonate terranes act as the major source rocks, from rifted-continental margins to collisional orogens.

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Critelli S. (2018) - Provenance of Mesozoic to Cenozoic Circum-Mediterranean sandstones in relation to tectonic setting. Earth-Science Reviews, 185, 624-648.

Critelli S. et al. (2008) - Compositional and geochemical signatures for the Sedimentary evolution of the Middle Triassic–Lower Jurassic continental redbeds from western[1]central Mediterranean Alpine chains: The Journal of Geology, 116(4), 375-386, https://doi.org/10.1086/588833.

Tectonic activity recorded by deep basin deposits: a sedimentological approach to unravel synsedimentary tectonics

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Keywords: mass transport deposits, Jurassic rifting, pelagic basin.

Mass-transport deposits are commonly referred to synsedimentary tectonics, but the presence of turbidites and/or calcidebrites in deep marine, fine-grained pelagic deposits, can be the result of several factors, such as tectonics, climatic events, sea level oscillations, gravitational instability among others. Here we present four cases of clastic deposits of syntectonic origin from the Jurassic and Cretaceous of the Umbria-Marche-Sabina (UMS) Apennine and Calabria. Two of them are strictly linked to the development of Early Jurassic rift faults related to the Western Tethys opening.

In UMS, the rift produced a puzzling pattern of horsts and graben, resulting in a complex Jurassic palaeogeography. Synsedimentary fault activity (earthquakes) is documented by huge megabreccia bodies sourced from footwall-blocks and deposited in rift-basin. These clastic deposits span from lower Sinemurian to lower Pliensbachian. Subsequently, the end of faulting is indicated by Pliensbachian *p.p.*-Tithonian pelagic successions lacking coarse clastic bodies (Fabbi & Santantonio, 2012), with few exceptions. In the Longobucco Basin (Calabria), the rift-related tectonic activity is continuous throughout the Early Jurassic, as recorded by megabreccias that are widespread from the Sinemurian to the middle Toarcian.

Other examples are most likely controlled by tectonic activity in passive margin, even though none of the faults producing the study clastics were directly detected. Growing evidence for Bajocian synsedimentary tectonics comes from the UMS, where megaclastic deposits occur embedded in basin-fill pelagites, and are usually associated to neptunian dykes filled with Bajocian sediments, backstepping of the footwall block-margins, the occurrence of erosional unconformities and soft-sediment deformation structures in condensed and basinal successions.

Comparable features occur in the Barremian-lowermost Aptian pelagic deposits of the UMS Basin. Megabreccias and slumps characterize pelagic units, and tectonic rejuvenation of Jurassic faulted margins coupled with neptunian dykes have been described (Cipriani & Bottini, 2019). The occurrence of "extrabasinal" loose benthic material associated with "intrabasinal" clasts of breccias provides clues to infer that synsedimentary tectonics affected margins of carbonate platforms contiguous to the UMS basin. In fact, earliest Aptian faults have been described by Fabbi et al. (2023) in carbonate platform successions.

Biostratigraphic analysis of pelagic sediment hosting megaclastic wedges or overlaying them as condensed deposits is crucial for constraining the minimum age of tectonic activity. Similarly, clast composition analysis is essential for determining the maximum age of the accumulation and, thus, the tectonic instability responsible for its formation. Intercalated clastic sediments in pelagic basins provide insights into a tectonic history that cannot be fully reconstructed through direct structural observation.

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Fabbi S. et al. (2023) - Stratigraphy and tectonic evolution of a portion of the Simbruini- Ernici Mountains (Central Apennines - Italy): Review and new data from detailed geological mapping. Geological Field Trips and Maps, 15, 1-40, https://doi.org/10.3301/GFT.2023.08.

Introducing TOOLS: climatic-tectonic modulation in the Langhian-Tortonian "megaturbidites" of the S. Mauro Formation (Cilento Group, Southern Apennines)

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Keywords: (mega)turbi5dites, organic matter, Miocene.

The wedge-top siliciclastic successions of the Miocene Cilento Group record a complex physiography of an evolving fragmented (broken) foreland characterised by different coeval and relatively short, laterally- and longitudinally-confined, source-to-sink, likely representing mixed fluvio-deltaic-turbidite systems. This tectonic-stratigraphic framework is in turn modulated by high-frequency and high-amplitude cycles of base-level variations, and a general trend towards increased rates of erosion and sediment transport, likely including the transfer and burial of vast amounts of organic matter. In the Langhian-Tortonian interval (i.e., S. Mauro Formation), at least 5 major sedimentary events took place with a recurring time of about 1–3 Ma. These episodic events generated tens of metres thick sandy-silty-marly megaturbidite deposits (MTs) of hybrid carbonate-siliciclastic composition that can be followed across the entire basin system for tens of kilometres, from the depocentres to the margins, and possibly beyond. Their anatomy is remarkably similar to other megabeds cropping out in the foredeep record of the Northern Apennines, the Spanish and French Pyrenees, the Southern Alps, and the Dinarides, indicating common flow reflection and ponding processes. Nonetheless, their anomalous thickness variations of the finer-grained populations and complex interactions with the background siliciclastic beds reveal an interplay of processes (e.g., settling-traction vs. flocculation-emulsion) yet to be fully understood. Notably, these outsized events seem to be clustered within an interval of globally reduced carbon burial, suggesting an intimate link between these types of events and short- to long-term sedimentary and biogeochemical cycles. The calibration of such a geological archive is essential for understanding the tectonic-climatic dynamics of the central Mediterranean area and its future evolution. As part of the TOOLS project (PRIN PNRR 2022, P2022T3A4E, "**T**esting the efficiency of submarine landslides **O**n **O**rganic carbon sequestration over geologica**L** time**S**") the aim of this preliminary work is to establish a robust, field-based, sedimentological-stratigraphic baseline to constrain the role of these exceptional sedimentary flows in the local to global biogeochemical cycles from a multidisciplinary and deep-time perspective.

Low-temperature Δ47/(U-Pb) carbonate thermochronology reveals the exhumation history of the Paris Basin southern margin

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Keywords: exhumation rates, clumped isotopes (Δ47), U-Pb dating.

Low-temperature thermochronology of sedimentary successions provides insights to constrain the thermal history of sedimentary basins, estimates the timing of hydrocarbon generation, determines the onset and evolution of the basin inversion, and quantifies the basin exhumation rates. Historically, these reconstructions rely on thermo-chronometers like fission tracks and (U-Th)/He analyses that are however not applicable in successions dominated by carbonate rocks. More recently, advances in carbonate geochemistry and mass spectrometry opened the possibility of quantifying the timing and duration of heating/cooling events in sedimentary basins by investigating carbonate diagenetic phases precipitated within any kind of sedimentary rock with carbonate Δ47-(U/Pb) thermo-chronometry (*sensu* Mangenot et al., 2018; Gasparrini et al., 2023).

Here we study the Middle Jurassic carbonate succession from the southern margin of the intracontinental Paris Basin that presently crops out in the Burgundy region. Basin inversion is known to have begun in the Late Cretaceous - Early Paleogene due to the onset of the Alpine orogeny (Beccaletto et al., 2011). The succession, exceptionally exposed in quarries, was sampled and macroscopic carbonate cements were analyzed using optical and cathodoluminescence petrography, O-C stable isotope geochemistry, Δ47 thermometry, and U-Pb dating via LA-ICPMS. The results reveal the sequential precipitation of four carbonate diagenetic phases (three calcites, one dedolomite) from fluids dominated by meteoric waters (δ18Ofluid between -5 and -8 ‰ SMOW) which cover most of the basin inversion period spanning from Paleocene-Eocene to Pliocene-Pleistocene. The temperature-time history reconstructed well reproduces the uplift dynamics of the basin documented via structural analyses (Beccaletto et al., 2011). It also records two compressional phases, in the Eocene and Miocene, attributable to the Pyrenean and Alpine cycles, respectively, and separated by an extensional phase in the Oligocene. The temperature-time data obtained from this study were then used to calculate the exhumation rates associated with the two compressional phases encompassing the last 50 Ma of the basin evolution and overall point at a total exhumation exceeding previous estimations (<700 m according to Barbarand et al., 2013).

These results illustrate the potential of carbonate Δ47/(U-Pb) thermo-chronometry to reconstruct and quantify low-temperature exhumation histories of sedimentary basins and mountain ranges and pave the way for applications in multiple domains of Earth sciences.

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Beccaletto L. et al. (2011) - Overview of the subsurface structural pattern of the Paris Basin (France): Insights from the reprocessing and interpretation of regional seismic lines. Marine and Petroleum Geology, 28, 861-879, https://doi.org/10.1016/j.marpetgeo.2010.11.006.

Gasparrini M. et al. (2023) - Dolomite recrystallization revealed by Δ47/U-Pb thermochronometry in the Upper Jurassic Arab Formation, United Arab Emirates. Geology, 51(5), 471-475, https://doi.org/10.1130/G50960.1.

Mangenot X. et al. (2018) - An emerging thermo-chronometer for carbonate bearing-rocks: Δ47/(U-Pb). Geology, 46(12), 1067-1070, https://doi.org/10.1130/G45196.1.

Correlation of biomarker, foraminiferal and nannofossil records to unravel past environments: new insight from pre-evaporitic Torrente Vaccarizzo section (Sicily)

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Keywords: biomarkers, microfauna, paleoenvironment.

Nowadays, the advancement in organic matter (OM) investigations led to solid results for paleoenvironmental reconstructions. Depositional settings are characterized by specific assemblages of micro-organisms, which actively contribute to the production of molecular fossils (biomarkers) in sediments. Phytoplankton is known to be the main productor of biomarkers (e.g. α-tocopherol, C27 diasterenes or shorter chain fatty acids). Therefore, terrigenous, deltaic, normal marine, and hypersaline environments usually show significant differences both in biomarker compositions and in past living organisms. The latter, such as calcareous zoo- and phyto-plankton, have been commonly used as indicators of palaeoenvironmental and palaeocenographic changes for decades. Benthic foraminifera are known to be sensitive to organic carbon (OC) content. Therefore, association changes strictly relate to OC in the seafloor. However, although both indicators have been extensively employed independently, the relationship between biomarkers and microfauna associations is not straightforward and deserves further investigation. In this work, the high preservation potential of foraminifer tests and nannofossils in marine sediments is combined with the analyses of preserved biomarkers, offering a new interdisciplinary tool to better define past environmental settings and related changes (e.g. oxygen, salinity, and organic carbon content). The new approach of correlation and combination of organic biomarkers with foraminifer and nannofossil assemblages allowed a high-resolution environmental analysis on a restricted thrust top basin in central Sicily. The studied succession of Torrente Vaccarizzo shows rich OM marly/clayey layers which deposited before the onset of Messinian Salinity Crisis, between 6.5 to 5.9 Ma. The abundance of tocopherols, steranes, hopanes, diasteranes, and fatty acids revealed a general OM immaturity, pointing to a shallow burial depth since Messinian time. The presented results are promising and pave the way for future applications in other basins and environmental systems.

Magnetostratigraphy and calcareous nannofossil biostratigraphy of upper Eocene turbidites (Ventimiglia Flysch Fm) from the western Alps foreland basin

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Keywords: Ventimiglia flysch, magnetostratigraphy, biostratigraphy.

The late Eocene Ventimiglia Flysch Fm (FYV) of NW Italy (Servizio Geologico d'Italia, 2012) is part of the greater Grès d'Annot system, a dominantly deep-water unit cropping out in of SE France as part of the sedimentary fill of the foreland basin of western Alps. Compared to the turbidites of SE France, FYV has received relatively little research interest to date. Yet, better understanding the chronostratigraphic significance of FYV is key, as it represent the fill of the most internal and oldest preserved depocentre of the foreland basin.

FYV constitutes the fill of a topographically complex basin. It crops out in three relatively small synclines in the west and a larger outcrop in the east, which constitutes a monocline largely dipping toward the west-northwest. The studied composite section belongs to the main outcrop of FYV which has a preserved thickness of around 1500m and is characterized by an overall sheet like architecture (Marini et al., 2022) suggestive of a confined basin-plain setting of deposition. The age of FYV is loosely constrained based on foraminiferal biostratigraphy of the hemipelagic marlstone below (late Bartonian) and an earliest Oligocene foraminiferal assemblage characterizing its upmost part. This contribution presents the preliminary results of an investigation aimed at providing a depositional age model for FYV through the integration of magnetostratigraphy and nannofossil biostratigraphy.

A total of 192 samples for palaeomagnetic analysis were collected targeting the mudstone component of a c. 1500m-thick composite stratigraphic section, previously logged bed-by-bed for sedimentary facies. Natural Remnant Magnetisation (NRM) of 168 samples was measured using a cryogenic magnetometer after subjecting samples to either alternating-field or thermal demagnetisation. Analysis of 24 additional palaeomagnetic samples from the upper half of the composite section and of a total of 25 samples for nannofossil biostratigraphy spanning the full preserved thickness of FYV is underway.

Results of NRM analysis indicate that a vast majority of samples have a relatively stable characteristic component (ChRM) of reverse polarity defined by an unblocking temperature range of 250 ~450°C that in the remaining samples is overprinted by a viscous normal polarity component resulting in great circles trending toward reverse polarity. This defines a reverse polarity magnetozone with a minimum thickness of c. 700. The current foraminiferal biostratigraphy framework (Dellagiovanna et al., 2012) suggest there are three reverse polarity chrones (i.e., the Priabonian C16r, C15r, and C13r, having durations between c. 0.2 and 1.4 ky; Ogg, 2020) representing plausible correlation targets for the identified reverse polarity magnetozone. Pending the results of the ongoing nannofossil biostratigraphy and in light of magnetostratigraphic results to date, the minimum sedimentation rate for FYV is estimated to be in the range 500-3500 m/Ma, which places it in the upper end of the range of turbidites deposited in large confined basins of tectonically active settings.

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Petrographic and geochronological records from turbidite successions of the Lucanian external chain: new insights for the tectono-sedimentary evolution of the Southern Apennines, Italy

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Keywords: petrography, detrital zircon ages, Lucanian external chain.

In-depth petrographic characterization of the lithic fragments coupled with detrital zircon ages allowed to obtain relevant information about supply provenance (Critelli & Martín-Martín, 2024; Fornelli et al., 2022).

Petrographic features and U-Pb spot ages on detrital zircons from turbidite sandstones of Tufiti di Tusa (TTF), Numidian Flysch (NF), Bifurto (BF), Gorgoglione (GF) and Serra Palazzo (SPF) formations, exposed in southern Italy, were detected to define provenance signatures aiming to better constrain the paleogeography and timing of the tectono-sedimentary main stages of the Apennines orogeny from Rupelian (TTF) to Burdigalian p.p. - Early Langhian (NF and BF) and Langhian-Serravallian -Early Tortonian (GF and SPF).

Detrital zircon ages from the epiclastic record of the Tufiti di Tusa Formation indicate a sedimentary basin mainly fed by Rupelian synorogenic magmatic centers located in the central Mediterranean, and by minor input from Variscan granitoids and metamorphic rocks from the Mesomediterranean Microplate.

Zircon data from Numidian and Bifurto quartz-arenites evidenced for the external Burdigalian-Early Langhian Apennines Foreland, an exclusive source area located on the Africa Craton; therefore, this sedimentary basin has not been fed by detritus from the Variscan or Alpine chain.

Detritus from both Variscan crystalline basement forming the Alpine chain (Calabria-Peloritani Terranes) and Variscan magmatic and metamorphic rocks unaffected by Alpine tectonics (like Sardinia and Corsica pro-parte block) supplied the Middle Miocene depositional domain of Gorgoglione and Serra Palazzo formations.

Based on these new petrographic, chemical, and geochronological data a revised paleogeographic history could be inferred for the Apennines foreland basins from Rupelian to Tortonian: i) in the early Oligocene abundant calc-alkaline products from a volcanic arc, probably located on the eastern domains of the Mesomediterranean Microplate, fed the internal domains of the Apennines foreland; ii) in the early Miocene the eastern domain of the Southern Apennines foreland was fed by quartz-rich sandstones coming exclusively from the African Craton; iii) important paleogeographic changes in the Middle – Miocene eastern foredeep were recorded: the Gorgoglione and Serra Palazzo sandstone composition and the detrital zircon ages indicate that their source areas were located on both internal (Mesomediterranean Microplate and Sardinia-Corso Block) and external geodynamic contexts (Fornelli et al., 2022).

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Paleo-fluid characterization of the Upper Triassic siliciclastic reservoirs from the Paris Basin depocenter (France)

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Keywords: carbonate cements, thermometry, Paris Basin.

The Upper Triassic deep (2000-3000m depth) reservoirs of the Paris Basin (PB) have been broadly exploited for oil & gas resources and are under evaluation for their geothermal potential and as CO_2 storage site. Assessing the cementation and paleo-fluid circulation history in these reservoirs is therefore crucial to predicting quality and productivity and reducing potential exploration risks. Previous authors have investigated the cementation history of the Upper Triassic succession from the depocenter of PB (Spötl et al., 1993; Worden et al., 1999). However, these studies could not rely on modern analytical tools and thus temperature, timing, sources, and pathways of paleo-fluids remained underconstrained.

This contribution aims at revising the cementation and paleo-fluid circulation history of the Upper Triassic from the depocenter of the PB (South-East of Paris) by means of analytical tools such as clumped isotope (Δ47) thermometry and LA-ICPMS analysis. Samples collected from well cores mainly consist of fluvial sandstones deposited in an arid to semiarid continental environment. Authigenic cements include calcite, dolomite and anhydrite precipitated during the Mesozoic subsidence and the Cenozoic uplift of the successions. An accurate petrographic analysis in transmitted-light, UV-light, and cathodoluminescence allowed reconstructing the cement stratigraphy. Insights on the thermal conditions and composition of the fluids responsible for each cementation event were obtained via O-C stable isotope analysis, trace element geochemistry (LA-ICPMS), fluid inclusion microthermometry and carbonate clumped isotope (Δ47) thermometry. Inferred precipitation temperatures combined with thermal curves of the investigated wells allowed proposing a possible timing for the cementations. Results from this study highlight the occurrence of multiple stages of cement precipitation from Jurassic to Paleogene times at temperatures spanning from 60 to 120°C. The fluids that precipitated these cements consisted of brines with salinities between 6 and 21% wt (NaCl eq.). The more saline brines derived from the mixing between the original formation waters and halite-saturated brines that migrated from the East during the Mesozoic subsidence. On the other hand, the occurrence of cementation from the less saline brine point to a meteoric-derived water influx within the reservoirs during the Cenozoic uplift. This study highlights that the late cementation and paleo-fluid circulation history in the investigated Upper Triassic siliciclastic reservoirs of the PB is therefore related to high saline brines that were locally diluted by meteoric waters. The timing of the cementation events and the pathways of fluid migrations, which has long been debated in literature, were more accurately defined.

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Worden R.H. et al. (1999) - Basin scale evolution of formation waters: A diagenetic and formation water study of the Triassic Chaunoy Formation, Paris Basin. Geochimica et Cosmochimica Acta, 63(17), 2513-2528, https://doi.org/10.1016/S0016-7037(99)00121-0.

Paleothermal indicators and H, O stable isotopes for constraining temperature and fluid evolutionary models of complex fault zones: a new approach

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Keywords: x-ray diffraction, stable isotope analysis, K-Ar dating.

Paleothermal indicators (e.g. mixed layered clay minerals, vitrinite reflectance) are used to constrain the maximum temperature experienced by sedimentary successions in orogenic belts or to assess the thermal maturity of kerogen-rich rocks, while stable isotopes analyses (e.g. C, O) are carried out to determine the origin of the involved fluids. In this research, instead, we show how mixed layers illite-smectite and H, O isotope studies from deformed siliciclastic units and basement rocks of the Carboneras fault zone (Betic Cordillera, SE Spain) can also provide valuable insights in the evolution of temperature and fluids during faulting. Importantly, the addition of K-Ar constraints on syn-kinematic illite separated from fault rocks, also allows this approach in the case of long-lived, mature faults, where multiple reactivation episodes can be discriminated and are responsible for the complex fault architecture at the outcrop. X-ray diffraction data (quantitative analysis of minerals and illite polytype determinations) allowed us to reconstruct the distribution of syn-kinematic minerals within the fault rocks and constrain their temperature of (de)formation, while geochemical results allowed us to unravel the origin of fluids during distinct events of faulting. The integration of mineralogical, geochemical, and geochronological data allowed us to build a time-constrained temperature and fluid evolutionary model for the Carboneras fault zone.

XRD results document an inherited assemblage consisting of quartz, carbonates, K/Na-micas (2M1 polytype), feldspar, chlorite, kaolinite, pyrite, and Fe/Ti-oxides, a syn-kinematic assemblage composed of muscovite-2M1 (Ms-2M1) and mixed layers chlorite-smectite (C-S) and illite-smectite (I-S, 1Md polytype), and a post-kinematic assemblage with smectite, chlorides, and sulphates. The coexistence of randomly (R0), short-range (R1), and long-range (R3) ordered I-S and discrete Ms-2M1 in adjacent fault rocks suggest for a complex history of multiple brittle-events at various temperature (from 70°C to >275°C) and depth. Stable isotope data show that meteoric fluids infiltrated within the fault zone, interacting with the host-rock at various depths, and developing R0 I-S and R1 I-S or Ms-2M1. Lastly, K-Ar dating on syn-kinematic muscovite and illite-smectite indicate that the recorded deformation occurred during three distinct thermotectonic events in the Oligocene, middle-late Miocene, and Pliocene-Pleistocene.

In conclusion, the data portray an exhumation history associated with three principal thermotectonic events that occurred at decreasing temperature and depth, where parental fluids of meteoric origin infiltrated into the fault zone, interacted with host rock at various degree, and formed distinct temperature-dependent clay minerals.

The stratigraphic record of the Ventimiglia Flysch Fm, north-west Italy (western Alps foreland basin, Grès d'Annot turbidite system)

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Keywords: Alps, Ventimiglia, sedimentological logging.

The Grès d'Annot turbidite system represents the deep-water silicilastic fill of the Alpine foredeep and it crops out in a series of outliers across the Maritime Alps of SE France and NW Italy. It was deposited in a series of topographically complex basins, with the age of deposition becoming younger to the west, reflecting the advancement of the orogenic wedge and the migration of the foredeep system (Ford et al., 1999). Sediment provenance is from the Corsica-Sardinia and Maures-Esterel massifs to the south. In addition to their importance in reconstructing the Alpine chain evolution, the outcrops of the Annot and Peïra Cava sub-basins have the provided the location for some of the most influential studies of turbidite sequences from the 1960s onwards (Bouma & Ravenne, 2004). However, the close attention of the research community to the Grès d'Annot in France has not been matched by similar efforts on the Italian outcrops. These are known as the Ventimiglia Flysch Formation and consist of three relatively small synclines in the west and a large northwest-dipping monocline in the east. No high-resolution stratigraphy of the Ventimiglia Flysch has been published to date, and thickness estimates vary between a few hundreds and a thousand metres. To fill this knowledge gap, new sedimentary logging is undergoing at various locations of the monocline in the area north of Ventimiglia to reconstruct a high-resolution composite section.

Eleven sedimentary logs have been collected to date with a resolution of 0.5 cm, using a high-precision Jacob's staff (Patacci, 2016), for a total of around 1000 metres of stratigraphy. The logs are scattered throughout an area 5x10 km, elongated in the N-S direction. The succession can be interpreted as the medial part of a confined basin-plain, with sandstone beds thinning to the N-NE and mudstone caps thickening in the same direction. Bed-by-bed correlation to allow the composite log is possible thanks to the tabular geometry of the succession and to the presence of a key correlation horizon (Olivastro MTD; Marini et al., 2022), mapped across the entire study area. The high-resolution composite section logged to date encompasses roughly 2/3 of the preserved stratigraphy of the Ventimiglia Flysch, therefore suggesting a revised preserved thickness of around 1500 metres. The sequence is characterised by the presence of thick mudstone caps (thickness 1-2 times that of the associated sandstone bed) throughout the stratigraphy, indicating full confinement persisting as the basin became filled. Hybrid event beds are dominant, with the cumulative thickness of the H3 muddy sand and mudclast-rich divisions reaching 1/3 of the total sand thickness in the lower half of the stratigraphy. The new dataset will provide the basis for a revaluation of the age and sedimentary evolution of the siliciclastic fill of the Ventimiglia sub-basin and it will allow a more detailed comparison with other sub-basins of the Grès d'Annot, with the aims of expanding current palaeographic and evolutionary models of the Alpine foredeep.

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Oligocene-Miocene exhumation history of the Epiligurian wedge-top basins (Northern Apennines) constrained by low-temperature thermochronology

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Keywords: low-temperature thermochronology, Epiligurian wedge-top basins, exhumation history.

The tectonic configuration of the Northern Apennines (NA) fold-and-thrust belt stems from the Neogene-to-Quaternary foreland-ward migration of thrust fronts coeval with the activation of post-orogenic extension at the rear of the belt in response to the eastward rollback of the subducting Adria slab. From a thermal point of view, previous works concluded that the NA experienced cooling and exhumation over the past 20 Myr at an average exhumation rate between ca. 0.3 and 1 mm/yr, with continental accretion becoming progressively younger towards the east. However, whereas low-T thermochronology has been successfully applied to the lowermost exposed structural units aiming at unravelling the timing of thickening and later dismantling of the fold-and-thrust belt, its application to the shallower wedge-top basins has remained largely unexplored and underutilised. We present new thermochronological data (apatite fission-track (AFT) and U-Th/He data (AHe)) from an Epiligurian wedge-top basin, which recorded Eocene-upper Miocene marine deposition on top of the growing NA. By analysing samples from the entire basin sedimentary succession, we aimed to better constrain the tectono-thermal record of the Epiligurian wedge-top basins, thus exploring their role in the dynamic behaviour of the NA belt. Our thermochronological results show that the studied Epiligurian basin has been exposed to a maximum temperature of ~ 90° C after deposition and underwent cooling from the early Oligocene onward**.** In particular, the lowermost Epiligurian formation (Lutetian in age) experienced significant Oligocene through Pliocene cooling which indicates that, although it was deposited under marine conditions, it experienced cooling-driven rock uplift during the structural thickening of the belt. This is consistent with the abrupt change of the depositional environment that affected the Epiligurian stratigraphic succession in the Burdigalian, when a shallowing upward trend from silica-rich marl to shelf and slope-basin facies occurred. The study shows that cooling recorded by the uppermost structural levels of the NA was not steady state but rather it occured in distinct episodes. We frame the exhumation history of the Epiligurian Basins within a two-stage tectonic scenario, including an early (Eocene-Early Miocene) overthrusting phase of the more internal units, followed by frontal accretion (middle Miocene Quaternary) during the eastward slab rollback.

Low efficiency turbidite systems controlled by the geometry of structurally-confined mini-basins (Valla and Fraschetto Systems, Oligocene, Tertiary Piedmont Basin, NW Italy)

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Keywords: turbidite systems, facies analysis, basin geometry.

This work presents a comparison between Valla and Fraschetto turbidite systems (Oligocene Molare Group) cropping out in the western part of the Tertiary Piedmont Basin, a large polyhistoric episutural basin (Mutti et al., 2002). In particular, this work aims to understand the relationship between basin geometries and flow dynamics through lateral-vertical distribution of facies, erosional structures, mudstone clasts, load structures, water escapes, paleocurrents and lastly of onlaps against the basin margins.

The Valla turbidite system represents the filling of a small WSW-ENE oriented structural depression (less than 1 km wide and few kms long) with a steep southern fault-related margin and a milder northern margin. Towards the east this asymmetric basin features a transversal paleo-topographic high related to the continuation of the NNW-SSE oriented Mioglia flexure (a fault-bend fold). The Valla system is characterized by lenticular and amalgamated beds of bouldery to pebbly very coarse to coarse grained sandstones deposited by extremely poorly organized and highly immature sediment gravity-flows resulting from the resedimentation of underlying fan delta deposits. The Valla system is a very low efficiency turbidite system in a very small basin, in which dense flows, from the west, evolve parallel to the WSW-ENE oriented fault-controlled basin margins. The lateral and vertical facies distribution is controlled by basin asymmetry and by a subtle frontal topography related to the Mioglia flexure. Dense flows deceleration against the steep southern margin forms very thick massive beds with erosional bases (often deformed by load structures) and pillar-type water escapes. Deflection and compensation processes produce a north-westward lateral displacement of the main depositional zone closely resembling that described by Tinterri & Civa (2021) in the time equivalent Fraschetto turbidite system (few kms far from study area) where the deflection of small volume dense flows against a structural high, parallel to the Mioglia flexure and oblique to the flow direction, produces laterally accreted deposits. These conclusions are also supported by comparison to other turbidite systems with higher efficiency but characterized by similar basin geometries, such as the Ranzano and Annot Sandstones (Tinterri et al., 2017).

This work is part of a broader study which tries to point out how basin geometry and confinement degree, which mainly depend on tectonic setting and tectonic structures orientation, are the major controlling factors of the efficiency degree of a turbidite system and thus of its lateral and vertical facies distribution (Tinterri et al., 2023). Growing evidence from field and subsurface data highlights that tectonic structures parallel or perpendicular to the flows can favour or hinder flow evolution respectively, and Valla and Fraschetto turbidite systems are two examples of these dynamic behaviours for the category of very low efficiency systems.

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Unlocking geothermal potential: syn-rift fluvial deposits in the West Netherlands Basin

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Keywords: multiphase rifting, basin inversion, geothermal energy.

Situated directly beneath one of the most densely populated regions in the Netherlands, the West Netherlands Basin emerges as an optimal location for geothermal energy exploration. Presently, the basin hosts 14 operational projects, with at least 3 more in the developmental phase. The primary target in the area are the syn-rift deposits of the Late Jurassic Nieuwerkerk Formation.

The geological history of the West Netherlands Basin is characterized by Mesozoic multi-phase rifting, followed by late-stage inversion during the Late Cretaceous. Comprehensive analysis of publicly available seismic and well data allows us to discern two rifting episodes during the Jurassic. A first phase in the Early Jurassic and a subsequent phase, partly influenced by structures of the former, during the Late Jurassic. This latter phase aligns with the sedimentation of the fluvial-deltaic Nieuwerkerk Formation.

The interplay of multi-phase rifting and fault evolution localized the creation of sedimentary accommodation space. This influenced the architecture of the fluvial system that deposited the Nieuwerkerk Formation. Consequently, the distribution of sandy facies within this formation is expressed by significant heterogeneity. This causes lateral and vertical variations in porosity, permeability, and net-to-gross ratios. Our reinterpretation offers valuable insights into the depositional environment of the Nieuwerkerk Formation, its structurally-controlled evolution, and thus, mitigating risks associated with geothermal well planning in fluvial sandstone reservoirs within inverted rift basins.

Architecture of migrating channel belts in a foreland basin: insights from the Tortonian Tachrift turbidite system, Taza-Guercif basin, NE Morocco

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Keywords: channel, Morocco, turbidite.

The present study focuses on reconstructing one of the distributary systems that acted as transfer pathways for clastic material from the Atlas chain to the Rifian Corridor (Morocco). The latter represents a remnant of the Rif foreland basin, a large-scale structure which was part of a series of ancient, relatively narrow seaways connecting the Atlantic Ocean to the Mediterranean Sea during the late Miocene. At present, the Rifian Corridor comprises the infill of three sedimentary basins, i.e. the Gharb, Fes-Meknes and Taza-Guercif basins.

The study area is located in the southern margin of the Taza-Guercif basin, which was established in the early Tortonian as the result of flexural loading by the advancing thrust sheets of the Rif foreland, combined with the concurrent re-activation of Middle Atlas tectonic structures.

We present the channel-levee Complex 6, one of the multiple turbidite channel-levee complexes making the Tachrift system, exceptionally exposed as part of the clastic fill of the basin. Goal is to document its 3D architecture, facies assemblages, and evolution, to be integrated with the ongoing surveys on the basin fill. The method integrates geological mapping, facies analysis on 46 logs, and 3D physical stratigraphic correlations. Statistical analyses on sedimentological variables supported quantitative comparison among depositional elements and their lateral transitions.

Complex 6, 13 m thick, consists of three sandstone-rich units, A, B, and C, that progressively increase in grain-size and are laterally stacked in a SE-ward shifting fashion. The tabular, fining-upwards sandy packages with rare concave-upwards erosional surfaces in unit A suggest a system of small sinuous and ephemeral distributary channels. Upwards, unit B and C display channel-fill deposits and genetically linked levees with different crossflow facies tracts, that record changes in flow parameters and morpho-dynamics of the parent channel. Unit B shows deposition in sinuous meandering channels, dominated by Lateral Accretion Packages (LAPs) that make transition to levees at the accreting inner bank, showing complex lateral relationship with the outer bank levee; unit C is characterized by relatively straighter channels where amalgamated sandstones (i.e., channel axis) laterally pass into sandy levee crests, then to mud-prone outer levee heterolithics. 3D stratigraphic architecture of complex 6 reveals an eastward channel belt migration and a progressive flow energy/density increase.

This detailed sedimentological study, integrated with those conducted on other channel-levee complexes outcropping in the area, together with the analysis of coeval and adjacent shallow marine, coastal, and deltaic sediments, will allow us to discern the role of interacting tectonics, climate change, and autocyclic processes controlling the deposition within the Taza-Guercif basin.

S42.

Geophysics for Tectonics and Energy Resources

CONVENERS & CHAIRPERSONS

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A multi-messenger geophysical approach for geothermal resource evaluation and sustainable energy exploitation: two case studies in Southern Italy

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Keywords: electrical resistivity, elastic/anelastic characteristics, geothermal reservoirs imaging.

This work shows the preliminary results of the activities carried out in the framework of the project TOGETHER - Sustainable geothermal energy for two Southern Italy regions: geophysical resource evaluation and public awareness financed by European Union – Next Generation EU (PRIN-PNRR 2022, CUP D53D23022850001).

Part of the TOGETHER project activities are devoted to implementing a geophysical multi-messenger approach for improving the imaging of geothermal reservoirs in terms of temperature and physical properties of the reservoir rocks and fluids. This approach is based on the joint evaluation of complementary information carried outby subsoil electrical resistivity and elastic/anelastic characteristics from seismic waves propagation: 1) measured electrical resistivity depend on temperature, porosity, percentage of fluid saturation, and permeating fluid type (Rizzo et al., 2022); 2) VP and VS parameters result in being mainly sensitive to lithology changes, whereas their ratio (VP/VS) provides precious hints on the fluid composition and its pore pressure; 3) the anelastic parameters, described by the quality factor Q, strictly depend on some rheological properties like the temperature and the percentage of fluid saturation in rocks (Amoroso et al., 2018).

The proposed method is being tested in two test sites in Southern Italy that are appropriate for low to medium-enthalpy geothermal extraction: 1) Contursi Terme, with fluids temperatures ranging from 21°C to 30°C, and numerous wells for balneotherapy with temperatures between 25°C to 47°C (Gori et al., 2023); 2) Tramutola, situated in Agri Valley (Basilicata Region) where, during the drilling of a hydrocarbon well in 1936, AGIP oil company intercepted a confined aquifer of sulphureous hypothermal water (28 °C with a flow rate of 10 l/s) associated with gases of mantle origins, primarily CH4 and CO_2 (Olita et al., 2023).

During the first project phases, multi-scale and multi-resolution 3D subsoil electrical resistivity is being estimated in test areas using Electrical and electromagnetic geophysical methods, such as Magnetotelluric (MT) and shallow and deep electrical resistivity tomography (ERT). At the same time, both local earthquake tomography (LET) and ambient noise tomography (ANT) will be adopted; the proposed methods will aim at a multi-scale and multi-resolution elastic/anelastic subsoil imaging in terms of both 3-D P-and S- wave velocity models and quality factor estimations.

New geophysical data are acquired using cutting-edge instrumentation purchased as part of two additional scientific projects: ITINERIS (Italian Environmental Integrated Research Infrastructure System, PNRR, MUR, M4C2, Investment 3.1 RI), financed by European Union – Next Generation EU, and GRINT (Geoscience Research INfracstructure of Italy, INGV).

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Comparative analysis of alarm-based earthquake forecasting models in Italy

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Keywords: earthquakes forecasting.

The importance of studying earthquake precursor signals is undeniable, especially at a time when the quality of seismic data is constantly improving. This allows a deeper understanding of seismic phenomena and a more accurate validation of forecasting models.

In this work, we explore and compare the ability of two different precursor signals to predict potentially destructive strong earthquakes. The precursor signals analysed are the spatio-temporal variations of the b-value of the frequency-magnitude relationship and the occurrence of possible strong foreshocks, respectively.

The analysis of spatio-temporal variations in the b-value of the frequency-magnitude distribution of earthquakes can provide valuable information on the stress state and probability of earthquake occurrence in a specific geographic region. In fact, as it has been observed in many cases, the b-value tends to decrease in the preparatory phases of a strong earthquake, and suddenly increases after the occurrence of the mainshock.

Similarly, the analysis of foreshocks can provide a valuable answer in the search for precursor signals for earthquake forecasting. Earthquakes tend to cluster in space and time, and foreshocks can indicate the approach of a mainshock. After a foreshock, the relative frequency of a large earthquake in the same area increases significantly compared to quiet periods, suggesting that foreshocks can be used as a basis for a forecasting experiment.

To evaluate such a hypothesis, in this work, different alarm-based forecasting methods are implemented. The forecasting methods have been retrospectively calibrated and optimized for the period 1990-2011 to forecast Italian earthquake of magnitude larger than 5.0.

The methods have been then applied pseudo-prospectively over the period 2012-2023 and the forecasting skills have been assessed using specific tests and statistics for alarm-based models. Such models have been also compared with those of the ETAS applied using the alarm-based approach.

Exploring the Greater East Shetland Platform (Northern North Sea, UK): integration and modelling of wellbore, seismic, gravity and magnetic data to evaluate its storage potential

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Keywords: geological modelling, seismic interpretation, gravity and magnetic forward modelling.

The reduction of anthropogenic greenhouse gas pollutants and securing new energy supplies will require sites of extensive geological storage capacity. Forward modelling of gravity and magnetic data can contribute to depicting the subsurface geological framework of underexplored areas, such as the Greater East Shetland Platform (GESP) and its intra-platform basins in the UK Continental Shelf (Northern North Sea), where data availability is limited and sparse. This region is characterized by a laterally discontinuous but locally thick (1-8 km) Devonian-to-Tertiary sedimentary sequence that unconformably overlies the Caledonian crystalline basement. The intra-platform basins are located 50-150 km from shorelines and are crosscut by pipelines, therefore representing attractive potential areas for geological storage by repurposing existing infrastructures to serve the energy transition (e.g., Leporini et al., 2019).

In this study, legacy wellbore data (i.e. lithology, seismic velocity, and bulk density) and a newly acquired 2D seismic survey have been analysed and interpreted. Furthermore, six profiles were depth-converted and served as constraints for the forward modelling of observed Bouguer gravity and magnetic anomalies.

Results suggest that the first-order contributors to the observed Bouguer gravity anomalies are related to the scattered distribution of the Mesozoic sedimentary sequences of the intraplatform basins. In particular, two gravity minima correlate with the main Triassic-Jurassic successions within the area (i.e. Dutch Bank Basin, East Orkney Basin), while shallow exposures of the basement underneath the Tertiary cover (i.e., Caithness Ridge, Fair Isle Platform) is spatially-related to gravity maxima. Furthermore, the main sources of the modelled magnetic anomalies are related to high susceptibility (≤0.05 SI units) bodies in the crustal basement that locally correspond to high reflectivity zones observed in the seismic profiles. Such deep sources are interpreted as paleo-domains inherited from the pre-Devonian tectonic evolution of the study area and assembled during the Caledonian Orogeny (De Luca et al., 2023).

Despite their scattered distribution, wellbore data analysis, when coupled with our findings, supports the interpretation that the GESP is an area offering new targets for fluid storage, either below or close to producing fields. Moreover, a potential storage area of 2000 km2 has been identified. Industry and government co-funded projects to build or re-use existing pipelines to transport carbon dioxide in areas close to the GESP have been recently proposed (e.g., Acorn and Sleipner, Pale-Blue, 2021; Furre et al., 2017) to support CCS (Carbon, Capture and Storage) and CCUS (Carbon, Capture, Utilization and Storage) activities. Thus, further investigation could define effective GESP capacity making it an area of strategic interest for future expansion of storage capacity and existing CCS projects in the North Sea.

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OTRIONS seismic network during ten years of analyses: the new microseismicity catalog of the Gargano area (Southern Italy)

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Keywords: seismology, earthquakes, detection.

The OTRIONS seismic network (FDSN code OT) is a local network installed in the Apulia region (Southern Italy) by the University of Bari Aldo Moro. Its primary objective is to investigate the seismic activity in the Gargano area (Northern Apulia) and the Salento area (Southern Apulia). OTRIONS started to operate in 2013 and in 2019 the network migrated on EIDA. Therefore, since then is managed by University of Bari Aldo Moro and the National Institute of Geophysics and Volcanology (Filippucci et al., 2021). A first catalogue of the seismicity in the period from 2013 to 2018 was released in 2021. It comprised events both manually and automatedly detected using SeisComP3 (Helmholtz-Centre Potsdam, 2008).

After ten years of operation, at present the focus lies on the microseismicity of the Gargano area and, in particular, on compiling a new seismic database from April 2013 to December 2022. This work has been conducted by employing CASP (Complete Automatic Seismic Processor), a software for automatic event detection, picking, and location (Scafidi et al., 2019). CASP operates on a remote server managed by RECAS-Bari, the computational infrastructure jointly managed by INFN and UniBa. CASP and NonLinLoc software (Lomax et al., 2000) where set specifically for the Gargano area. As velocity model, we adopted the 1D Gargano velocity model (de Lorenzo et al., 2017).

The recorded seismic events were organized into two catalogs: an automatic and manual catalog obtained from CASP's automatic location results, and by a manual revision of P- and S-wave arrival times, respectively. The reliability of CASP algorithm was evaluated by comparing the automatic and the manual catalogs.

The final revised catalog revealed a significant increase in events detection performance with respect to the earlier version derived from SeisComP3. Furthermore, the results show that the choice of the CASP parameters allows us to lower the minimum magnitude threshold of the recorded microseismicity in the Gargano area. Moreover, the application of PhaseNet deep neural network for earthquake detection showed that the number of the detected event can be further increased with respect to CASP. Finally, the preliminary results of the seismicity distribution suggest a deepening of the earthquakes trend moving northwards in the area.

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A comparison between moment magnitude scales

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Keywords: seismic magnitude.

Moment magnitude *Mw* was first defined by Kanamori (1977) and Hanks & Kanamori (1979) in the late 1970s, when the availability of new force balance seismometers made it possible to measure the seismic moment *M0* with virtually no limits in the frequency passband. For this reason, *Mw* does not become saturated even for the largest earthquakes ever recorded. *Mw* has been chosen in such a way that it coincides best with the previous definitions of magnitude (*ML*, *mb*, *Ms* etc.) on certain ranges of values but can deviate significantly from them within other ranges. A few years ago, a new moment magnitude scale *Mwg* was proposed by Das et al. (2019), with the aim of better reproducing the values of *mb* and *Ms* over their entire range and to better predict the energy *Es* adiated by earthquakes. In this work we show that there was no need to define such a new scale and that the latter is not even optimal to achieve the goal that the authors had set themselves.

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New insights on the deep electrical structure of the Molise-Sannio region: preliminary outcomes of a Magnetotelluric survey

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Keywords: Magnetotelluric, crustal model, Molise-Sannio region.

In the framework of MOlise SAnnio Integrated Crustal MOdel – MOSAICMO, a project led by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), a Magnetotelluric (MT) survey was carried out to provide information about the subsurface electrical resistivity distribution of the junction zone between the Central and Southern Apennines (Molise-Sannio region).

20 MT soundings were acquired along a ~25 km long profile SW-NO oriented and extending from Piedimonte Matese toward Campobasso. Thanks to the high sampling frequency used and to the quite long lasting of the records, each of the soundings provides impedance estimations in a wide period range [10-4 s - 103s]. Dimensionality analysis performed on the whole dataset justified the use of a 2D inversion strategy which resulted in a resistivity model of the investigated area up to a depth of 12 km b.g.l.

This crustal resistivity section well match both with the surficial geological information, clearly discriminating between the Matese and the Sannio units, and with other independent deep information (i.e. the analysis of the logs of the Campobasso 1 well).

The overall information coming from the MT survey will certainly contribute to the MOSAICMO project aims being a fundamental piece for the multiscale and multidisciplinary investigation of the investigated area.

Fault (re)activation and fluid-induced seismicity: an example from the Val d'Agri intermontane basin (Southern Italy)

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Keywords: Val d'Agri, numerical model, fluid-induced seismicity.

Over the last decades, the occurrence of fluid-induced, moderate-to-large earthquakes in several locations around the globe sparked interest in the relationships between fluids and seismicity. Several studies suggest that fluids can be one of the most prominent factors that can induce variations of the stress state of rocks, due to the increase or drop of the pore fluid pressure, and consequently trigger earthquakes. In this framework, the Val d'Agri is an important case study where we observe the relationships between fluids and seismic activity. In this area, the activity of reinjection of wastewater from oil extraction reactivated the Costa Molina blind thrust in the eastern sector of the valley and generated a well-defined microseismicity cluster. A few kilometers SW from this cluster, the water load associated with the presence of the Pertusillo reservoir generates and/or favors further seismic activity within the Apulian carbonatic platform. The formation, geometry and evolution of the seismically active structures in the region are still a matter of debate, especially if the polyphase compressional/extensional tectonics that characterizes the southern Apennine's geological history. As a consequence, the seismic potential in the whole region is largely unconstrained.

We built up a 2D thermo-mechanical model to define the principal mechanisms generating the present-day tectonic setting observed in the Val d'Agri and surrounding regions and to provide insight into the seismic hazard characterizing the area. We suggest the presence of a major dècollement layer decoupling the deformation of the sedimentary cover and the crystalline basement, which is constituted by the Triassic Burano Formation. Our model quantifies the stress field and allows us to estimate the Coulomb stress in the Val d'Agri crust, to assess the seismic potential of the region. We conclude that the Coulomb stress values are positive in a large part of the crust, and therefore that fluid injection is a high-risk activity for the reactivation of buried structures, especially within the Apulian carbonatic platform formation.

What is in the INGV ISIDe online database before 16 April 2005?

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Keywords: magnitude, seismic catalogs.

The Italian Seismological Instrumental and Parametric Data-Base (ISIDe) is the recipient of earthquake data collected in real-time by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), and used by the studies of earthquake forecasting and seismic hazard assessment in Italy in the last decade. When it went online, following a significant improvement of the seismic acquisition system of INGV, it was including only data since the second fortnight of April 2005. About ten years later, the data since the beginning of 1985 suddenly appeared without any prior notice than the updating of the starting date of the dataset. However, the characteristics of the added data appeared clearly different from the following period both in terms of the numbers of located earthquakes and of types of magnitudes provided. After having analyzed the numerical consistency and the calibration of magnitudes of ISIDe as a function of time from 1985 to 15 April 2005, we can say that such a dataset is incomplete and poorly calibrated compared to other catalogs of Italian seismicity (CSTI, CSI, and HORUS) available for the same period. Hence, we suggest not using it as is for statistical analyses of Italian seismicity. However, it provides some magnitudes that are missed by other catalogs and thus might be used for improving such catalogs.

Elaboration of new regional temperature-at-depth maps, aiding in the assessment of the geothermal potential in the Southern Latium

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Keywords: Geothermal energy, well analyses, seismic interpretation, Southern Latium.

In the upcoming years, significant enhancements in energy production systems will be imperative to achieve the decarbonization objectives of the European economy. According to the Integrated National Energy and Climate Plan (PNIEC, 2019), Italy aims to accelerate the transition from traditional fuels to renewable sources by gradually replacing coal for electricity generation with an increasing proportion of renewables in the energy mix by 2030. In this context, geothermal energy emerges as the most promising energy source. It holds the potential to substantially contribute to the adoption of low-carbon technologies for generating electricity, as well as for heating and cooling purposes.

An initial step in evaluating the geothermal potential of an area involves understanding the distribution of temperatures at depth and the geological and structural conditions of the subsurface. At national level, the temperature reference data are the maps at different depths from ground level (i.e., 1, 2, 3 km) available in the Italian National Geothermal Database (BDNG, Trumpy & Manzella, 2017). On the contrary, the National Mining Office of the Ministry of Environment and Energy Security, through the website of the project "Visibility of petroleum exploration data in Italy" (ViDEPI Project, 2019), provides public information and data on subsurface acquired by different oil companies during past exploration activities.

In this study, subsurface data from these extensive public datasets have been reanalyzed and combined to generate new temperature-at-depth maps in the Latium and Campania regions with the aim of evaluating their geothermal potential. The newly elaborated temperature maps combine values extracted from the public hydrocarbon wells dataset of the VIDEPI Project and from geothermal wells and temperature isolines reported in the BDNG database. To reconstruct the distributions of temperatures at depth, various operational data processing were performed in a GIS environment interpolating linear and point data, and producing isothermal surfaces from 50 to 350 °C, every 50 °C.

The analyses of the preliminary results highlight some areas characterized by high temperature values in correspondence to the Bracciano, Vico, and Bolsena lakes, Viterbo city, the Campi Flegrei and Vesuvius zones, and in the southern Latium region. In this latter area, thanks to the analysis of a confidential geophysical dataset (well-logs and seismic reflection profiles) provided by ENI national energy company, we reconstructed the depth and the geometry of the regional reservoir with the aim of evaluating its temperature range. The results of the reconstructed temperature values and geodynamic and structural conditions reveal several promising geothermal areas in southern Latium. These findings enable a qualitative assessment of the area's geothermal potential for different use applications.

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Multidisciplinary study to characterize seismic gap crustal properties

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Keywords: crustal structure, seismic gap.

Knowledge of the crustal structure of potentially hazardous but long-silent seismic gap areas is crucial for earthquake risk mitigation. Seismic sequences occurring in those well instrumented areas provide a valuable opportunity to characterize the crustal properties of the seismogenic volume. Here we present the result of analyses of the crustal properties of two seismic gap areas: the Mt. Pollino area (Italy) and the Northern Thessaly area (Greece).

The first area was affected by a 4-year long sequence, started in 2010, characterized by more than 10,000 earthquakes with a predominant swarm-like behavior and, to a lesser extent, as a mainshock-aftershock sequence following the two main events (ML 4.3 and ML 5.0) that occurred about two years after the sequence began. In the second case study, the aftershock sequence, following three moderate-magnitude events (Mw 6.3, Mw 6.0 and Mw 5.6), dissipated in less than a month during March-April 2021.

Velocity, attenuation and focal mechanism tomographies have been performed at local scale for the Mt. Pollino seismogenic volume using the events of the 2010-2014 seismic sequence, and the detailed structures at smaller scale highlighted by relative location of microearthquakes. These results have been also compared with the most recent geological findings. The likely role of over-pressurized fluids, already suggested in previous works, the main structural barriers and the lithologic units involved have been revealed by this analysis.

With regard to the Thessaly seismic gap the lithologic units, the likely role of fluids, and the blind fluid-filled inherited structures involved in the sequence have been highlighted by the integration of seismic tomography and InSAR geodetic models. The results have been also corroborated by geological studies and focal mechanisms of the main events performed by different seismological agencies.

As highlighted by the two analyzed case studies, the integration of different techniques is fundamental for a more complete understanding of complex seismogenic volumes with the goal of reducing their associated seismic risk.

New insights in Andean geothermal exploration: preliminary results from the Tocomar geothermal system case study (Puna, Argentina)

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Keywords: geothermal, 3D Model, Andes.

The Tocomar Geothermal System (TGS), situated in the back-arc region of the Central Andes on the Puna Plateau in northwest Argentina, represents a significant potential for high-temperature geothermal fields, making it a promising site for alternative power generation. Evidence of current and past geothermal activity, including thermal springs, phreato-phreatomagmatic structures, travertines, and saline deposits, underscores its geothermal significance (Filipovich et al., 2020). The TGS, located and controlled by the westernmostsegment of the Calama – Olacapato – El Toro lineament (COT) and associated with the homonymous volcanic center, has been interpreted as fault-hosted reservoir (Filipovich et al., 2022). However, despite its potential, proposed conceptual models for the TGS have limitations and fail to fully explain the geothermal system's dynamics.

While geological studies have been conducted in the area, geophysical investigations imaging the geothermal fields and their elements are scarce. Notably, a 3-D inversion of audio-magnetotelluric data around the TGS provided insights into its main elements, including the clay cap and potential reservoir, at depths of ~1000 m. New gravity and airborne magnetic geophysical data were collected to delineate geological structures controlling geothermal manifestations and estimate the extent of the geothermal field. This data, integrated with petrophysical characterization of cap and reservoir rocks, revealed insights into the geothermal system's properties, including low permeability and thermal conductivity of cap rocks and the thermal conductivity and electrical resistivity of reservoir rocks (Ahumada et al., 2023). Probabilistic assessments estimated the power production capacity of the TGS positioning it as a significant contributor to renewable energy in the region. These findings, coupled with its strategic location and the tectonic control characterizing the Tocomar area, suggest the reservoir's potential may be larger than previously assumed(Filipovich et al.,2022).

This preliminary study proposes a comprehensive geological model of the TGS, integrating surface geological mapping, macro and reservoir-scale balanced and restored cross-sections, geoelectric and gravimetric/magnetic modeling. The resulting geologic framework model represents a significant advancement in understanding the reservoir rocks or basement of the TGS. Utilizing a macro-scale 3D geological model, the study characterizes the reservoir complexity by defining the geometry of the main tectonic elements and the depth of the host rock (basement). Further, a detailed 3D model of the Tocomar basin will be generated, facilitating the development of an integrated 3D static model depicting the spatial evolution of the rock properties. These insights provide valuable information for future evaluations, such as fluid flow simulation and updated volumetric calculations.

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Geoelectromagnetic map for central Italy: preliminary results of the MARGE project

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Keywords: magnetotelluric, space weather.

In recent years, the Magnetotelluric technique has become a potent instrument for defining the lithosphere's physical characteristics, geometries, and structures This is performed by reconstructing the distribution of the physical parameter electrical conductivity (Bahr & Simpson, 2005; Bedrosian, 2007).

The MARGE project, which stands for Geoelectromagnetic Risk Map for Central Italy, is being carried out by the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in collaboration with the University of Bari and the Institute of Methodologies for Environmental Analysis of the National Research Council (CNR) and aims to create an extended map of the electrical conductivity of the subsurface of central Italy by analysing natural electric and magnetic fields.

Preliminary results from the MARGE project are presented, focusing on the collection of broad-spectrum and long-term magnetotelluric data on a grid of points approximately 50 km apart. The project has two main objectives: to study lithospheric structures and large-scale geodynamic processes in the central Apennines through 3D modelling of magnetotelluric data, and to develop geoelectric field maps of central Italy to support Space Weather modelling and the analysis of the vulnerability of critical infrastructures (Kelbert, 2020).

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GNSS CORS network of the University of Bari: an open infrastructure for research and educational

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Keywords: GNSS, post-processing analysis, NRTK.

In recent years, many analysis have been performed to obtain three-dimensional (3D) positioning by using the Global Navigation Satellite System (GNSS) Continuously Operating Reference Stations (CORS). Nowadays this methodology is widely used all over the world in different parts of the continents (Snay & Soler, 2008) to evaluate positioning in real-time (Network Real-Time Kinematic, NRTK) and in post-processing analyses. The purposes of the developed local academic GNSS network are multiple: to support the scientific research to better understand the geodynamic phenomena taking place in the Apulian region; provide support to university educational activities, through apprenticeship and degree theses; for private and public users that could enquire the GNSS data. These objectives were achieved by realizing a new infrastructure composed by GNSS- CORS, managed from the "Dipartimento di Scienze della Terra e Geoambientali" (DiSTeGeo) of University of Bari in collaboration with INGV (Istituto Nazionale di Geofisica e Vulcanologia). This network has been implemented starting from 2022 and is actually composed by four stations named DSTG, MARU, MOTT and TARD, respectively located at Bari, Maruggio, Mottola (two countries near Taranto) and Taranto. In the context of data sharing, DSTG station is part of the RING (Rete Integrata Nazionale GPS), the national GNSS network managed by INGV. The development of this network allows to obtain three-dimensional (3D) positioning, both in real-time (Network Real-Time Kinematic, NRTK) and in post-processing analyses. For the real-time service, through the NTRIP protocol (Networked Transport of RTCM via Internet Protocol) the RTK/DGPS differential corrections are distributed. For the post-processing service, the data are shared with the FTP protocol, international standard for the geodetic community. The first data analyses enabled to verify the network operating service and the quality of the recorded data during the first period of functioning of the infrastructure (2022-2024).

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New insights from analyses of geophysical data in the Northern Apennine buried structures for evaluation of their geothermal potential

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Keywords: geothermal energy, geophysical data, InGEO project.

Geothermal energy is arguably the most attractive of low-CO_2 renewable resources, being broadly distributed and available in every period of the year. The main aim of the InGEO project (*Innovation in GEOthermal resources and reserves potential assessment for the decarbonisation of power/thermal sectors*) is to develop an innovative exploration workflow integrating geophysical data and other direct and indirect information, organized to make available a sort of decision support system of geothermal projects. To this purpose, we chose as a target area the Northern Apennine buried structures belonging to the Romagna and Ferrara Folds (RFF). This area extends from the termination of the Emilia Folds in the West to the Adriatic coast in the East and from the outcropping edges of the Northern Apennines in the South to the undeformed Po foredeep in the North. The RFF area has been the subject of previous geothermal studies revealing relatively low geothermal gradients within the deep carbonate units (on average 14 °C/km) and more significant thermal gradients (on average 53 °C/km) in the overlying impermeable formations (Pasquale et al., 2013). This feature in temperature distribution with depth is clear evidence for fluid thermal convection occurring in the deep-seated carbonate units of Mesozoic age, which constitutes the local geothermal reservoir. The shallow crust of this area has been investigated by several previous studies and through a total of 535 deep exploratory wells (VIDEPI database: https://www.videpi.com/videpi/videpi.asp), having final depths ranging from 0.5 up to 6.5 km below ground level. They provide essential information, concerning lithostratigraphy, temperatures measured during drilling stops and geophysical logs, commonly electrical resistivity, gamma ray and sonic. Several geophysical investigations, recently carried out in the Alps and Po plain, revealed both the shallow ad deep structures of the study area, in terms of lateral variations of Bouguer anomalies, seismic velocities, and main discontinuities (Nouibat et al., 2023; Zahorec et al., 2021). The analyses of the data collected revealed a good correspondence between the low seismic velocities, characterizing the shallow crust of the RFF, and the negative Bouguer anomalies. We reconstructed the Moho depth of the area, estimating the depth of the iso-velocity contour of 4.1 km/s (Nouibat et al., 2023) and observed its deepening from NE to SW, towards the Apennines, from ~27 km to ~48 km. Seismic tomography of the upper mantle (Rappisi et al., 2022) reveals that the velocity in the shallow and deep lithosphere is low in the central part of the study area, possibly related to a local asthenospheric upwelling and tends to increase beneath the Apennines. The results of this ongoing research will be the input of the thermal model and contribute to the development of an open-source and web-based GIS tool, and to the calculation of the deep geothermal energy potential for both hydrothermal resources and deep heat exchangers.

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Reliable long-term CO_2 storage as clathrate hydrates in seawater and marine sediments: the CO_2-RESTO project

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Keywords: CO_2 clathrate hydrate, laboratory measurements, modeling.

CO2-RESTO project aims at developing a technological solution for the carbon dioxide (CO_2) sequestration as clathrate hydrate, both in seawater and under the seafloor. Clathrate hydrates are nonstoichiometric solid compounds formed by cage-like crystalline structures of water molecules where a guest molecule – in this case CO_2 - is entrapped under proper conditions of temperature and pressure. The CO_2 storage as clathrate hydrate has been chosen in accordance with their desirable properties if compared to other geological storage pathways, such as higher density than seawater (resulting in a negative buoyancy effect); stability at moderate oceanic depth, storage in solid form, less susceptible to perturbations than fluid flow; storage within porous media (as the sediment of the ocean floor) with a cementing effect. CO_2-RESTO addresses some crucial issues, being devoted to obtaining a body of knowledge, significantly beyond the state of the art on engineering, chemical and geophysical aspects of CO_2 clathrate hydrate science. The project will investigate the proper approaches of CO_2 storage as clathrate hydrate, through in-lab experimental activities for the understanding of hydrodynamics, thermodynamics/kinetics, stability of CO_2 clathrate hydrate formation/dissociation, microscopic characterization of CO_2 clathrate hydrate, the effect of salinity, other chemical compounds and of the presence of other gaseous components. A theoretical model applicable to a CO_2 clathrate hydrate reservoir will be developed to characterize a possible natural site for CO_2 clathrate hydrate storage and help the choice and an efficient technological solution for CO_2 injection will be proposed. The project addresses important national long-term PNRR targets. One of the further objectives to 2040 is the installation of CO_2 capture and sequestration plants, both in the electricity and industrial sectors, to bring the energy system to complete decarbonization by 2050. In addition, the option to store CO_2 as clathrate hydrate is particularly relevant to those economies that produce substantial amounts of CO_2 in their industrial and power operations, but do not have proper local geologic storage. The estimates completed so far show that there is a huge capacity for clathrate hydrate storage worldwide, including Europe.

Seismic-electromagnetic effect in the Pollino area: measurements, analysis and numerical modelling

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Keywords: seismic-electromagnetic, fluids, modelling.

Seismic-electromagnetic is the name given to the phenomenon where seismic and electromagnetic fields are coupled. Two main conditions are required: porosity and fluids. This coupling ensures an exploration potential of both fluids and media characteristics, jointing seismic resolution and electromagnetic sensitivity. Even if in literature numerical modelling and laboratory / active experiments are present, the phenomenon earthquakes related is less explored. Here we present a systematic analysis of the seismic-electromagnetic effect recored during the Pollino seismic swarm (Southern Italy | 2011-2014). The acquisition was made up by magnetotelluric and seismic station in the same place. The analysis that will be discussed has been conducted in the time-frequency domain. Similarities and differences between seismic and electromagnetic waves will be described. Digitalisation problem will be discussed. Moreover, pre-seismic electromagnetic signals were observed: we used numerical modelling to explore the nature of these signals.

S43.

Groundwater resources innovation and sustainability: from characterisation to management of saturated and unsaturated zone

CONVENERS & CHAIRPERSONS

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Characterising rainfall-runoff processes and recharge rates in Mediterranean ephemeral streams with small impoundment dams

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Keywords: infiltration, field saturated conductivity, mediterranean ephemeral streams.

Three main features characterise Mediterranean catchments: limited water resources because of high spatiotemporal variability of precipitation, dry summers and high-intensity rainfall events that generate flash floods (Zribi, Brocca et al. 2020). Understanding the relationship between rainfall, evapotranspiration, recharge, and runoff is critical in quantifying the water cycle at different time scales and understanding how the changing climate will impact local hydrological regimes and water resource availability in Mediterranean catchments. Monitoring hydrological processes within the unsaturated zone is difficult and expensive (Castiglione et al., 2005), but given the importance of groundwater in the region, characterising the unsaturated zone and understanding factors controlling infiltration and quantifying recharge will provide invaluable insights to inform water management decisions.

The proposed work aims to utilise the methodologies developed by Caputo, De Carlo et al. (2010), which employed large diameter infiltration tests on bedrock alongside geophysical techniques to monitor the unsaturated zone in carbonate rock formations. Characterising this zone is challenging due to its inherent heterogeneity and cracks and fissures in the rock. This work utilised infiltrometers installed directly on the rock surface within the valley bed to measure the field-saturated hydraulic conductivity. These results were compared to infiltration rates obtained through monitoring of the fill and recession rates of water behind retention dams built across dry valley systems to harvest stormwater for recharge and agriculture over these outcrops and corresponding climatic parameters to measure precipitation and calculate losses through evapotranspiration.

Seven consecutive basins were studied, with the first two situated above exposed Lower Coraline Limestone and the others downstream overlying Globigerina Limestone. The low-cost setup consisted of a gauge board and trail camera for each basin (with infrared for night photos). The volume of each basin at each stage was measured using a consumer drone to produce a digital surface model through photogrammetry using aerial photographs. Processing the stage height at a frequency of 10 minutes allowed the generation of hydrographs for runoff reaching each of the basins during rainfall events. Monitoring the recession rate was used to estimate recharge after attributing evaporation losses by using climate data.

This study underscores the complexity and variability of hydrological processes in Mediterranean catchments and demonstrates the critical role of field monitoring in enhancing our understanding of these dynamics. The research provides valuable insights into the interactions between rainfall, evaporation, and recharge processes by employing cost-effective techniques such as trail cameras to monitor multiple points along dry valley systems.

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Castiglione P. et al. (2005) - Improved tension infiltrometer for measuring low fluid flow rates in unsaturated fractured rock. Vadose Zone Journal, 4(3), 885-890.

Zribi M. et al. (2020) - Water Resources in the Mediterranean Region. San Diego: Elsevier.

Evaluation of recharge sources and nitrates origin in a karst spring: a case study from the F.na Nurighe spring (NW Sardinia, Italy)

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Keywords: karst spring, nitrates, ZVN.

According to the European and Italian regulation, the threshold for nitrates contamination in groundwaters addressed to human consumption is set to 50 mg/l. Identification of nitrates sources is not easy to assess and detailed hydrogeological investigations are required to delimitate Nitrate Vulnerable Zones (ZVN).

Miocene limestones and calcarenites from the Mores Formation, which widely outcrop in the Logudoro basin (NW Sardinia, Italy), host a karst aquifer that gives rise to several springs. One of these, the Funtana Nurighe spring, supplies the Cheremule's municipal aqueduct, a small village of about 400 inhabitants. Results of the hydro-geochemical monitoring carried out by the Regional Agency for Environmental Protection of Sardinia (ARPAS) since 2013 have highlighted continuous exceedances of the nitrate threshold value in the spring waters. This implies a significant impact on the water supply of the municipality and on the inhabitant's health.

Based on the ARPAS monitoring results and the reconstruction of a detailed geological model of the area, a preliminary ZVN has been defined, which currently constrains over a wide area. The main goal of the present research is to deepen the hydrogeological knowledge of the study area and to provide useful information for the re-delimitation of a more effective ZVN. The study includes i) a comprehensive review and interpretation of chemical analysis from the ARPAS monitoring, ii) the collection of new samples from springs located in the nearby area (June 2020 and June 2023), and ii) a new monthly monitoring of flow rates and the sampling of the spring waters since June 2023 for the determination of nitrates, major ions, trace elements, and water isotopes.

Multi-temporal geochemical analyses from ARPAS show that chemistry of the F.na Nurighe spring is characterized by a bicarbonate alkaline-earth type during the winter/spring period and a chloride-bicarbonate alkaline-earth type during the summer-autumn period. Compared to nearby springs, which are also fed by marls and basalt formations, the compositional ratios of the F.na Nurighe waters (i.e., Mg/Ca vs. SO_4/Cl; Mo/U vs. SO_4/Cl) indicate significant mixing processes, and therefore possible lateral recharge from other hydrogeological units, especially during the dry season.

Flow rate measurements collected so far are representative of the baseflow recession curve (BRC), with yield decreasing from 5,4 to 2,9 l/s, and the initial part of the subsequent rising limb where yields have reach values of 18 l/s. Nitrates show a progressive increase from 71 to 120 mg/l during the BRC, followed by an abruptly collapse to 49 mg/l; this value remains almost constant during the recharge period and then rise sharply to over 100 mg/l in the late Aprile measurement. Such preliminary results have provided useful information about the possible alimentation sources of the spring. However, the lack of a clear correlation between flow rates and nitrates concentration requires further investigations and monitoring.

Review of laboratory-scale studies to assess factors affecting the fate of microorganisms in porous media

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Keywords: laboratory tests, groundwater contamination, microorganisms transport.

Groundwater has traditionally been considered the water resource least susceptible to microbial contamination, because active biological and filtration processes in the subsurface reduce the load of microbial contaminants before they reach groundwater. This belief was once supported by the assumption that groundwater could not harbor microorganisms. In addition, knowledge of groundwater microbiology was poorly understood until the 1970s due to the lack of reliable methods for sampling groundwater environment. In recent decades, scientific evidence of groundwater contribution to waterborne diseases has been documented (Murphy et al., 2017). Indeed, microorganisms capable of causing waterborne diseases has been detected in groundwater. The detection of pathogens in groundwater is primarily due to the release of illicit or inadequately treated wastewater on soil or surface waters, the application of manure to enrich soils, or the reuse of wastewater for irrigation. Physical, chemical, and biological factors influence the presence of microorganisms in the soil and affect their transport and fate in the subsurface environment (Bitton & Harvey, 1992). Specifically, soil texture controls microbial survival by affecting water holding capacity, while the availability of organic matter creates favorable conditions for their survival (Obayomi et al., 2019). Structural heterogeneity, instead, can influence hydraulic properties such as water content and hydraulic conductivity. Chemical parameters such as ionic strength, ion valence, and pH play an important role in microbial retention; biological factors such as cell type, hydrophobicity, surface charge, and bacterial type contribute to mechanical and physicochemical processes (Bai et al., 2022). Since the interaction of these multiple factors and variables are very complex and poorly understood across spatiotemporal scale, recently scientific research is facing this topic by means of both field and laboratory studies, aimed at understanding how these factors may affect the microorganisms transport through a porous media. Specifically, this scientific contribution presents a systematic review of laboratory-scale studies published in the period from 2013 to 2022. This study was carried out in the framework of the SCA.Re.S. (Evaluation of Health Risk Related to the Discharge of Wastewater on the Soil) project, funded by the Regional Government of Apulia (DGR 1346, 04/08/2021) to evaluate the risk of groundwater contamination due to the discharge of wastewater treatment plant effluents into drainage trenches. The objective of this research is to contribute to a more realistic assessment of the risk of microbiological contamination of groundwater, as well as to increase current knowledge regarding environmental remediation.

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Bitton G. & Harvey R.W. (1992) - Transport of pathogens through soil. In Mitchell R. (Ed), Environmental Microbiology: New York, Wiley-Liss, 103-124.

Murphy H.M. et al. (2017) - Review: Epidemiological evidence of groundwater contribution to global enteric disease, 1948-2015. Hydrogeol. J., 25, 981-1001, https://doi.org/10.1007/s10040-017-1543-y.

Obayomi O. et al. (2019) - Importance of soil texture to the fate of pathogens introduced by irrigation with treated wastewater. Sci. Total. Environ., 653,886-896, https://doi.org/10.1016/j.scitotenv.2018.10.378.

Integrated assessment of climate impacts on ecosystem functions and productivity of critical-zone eco-hydrology: the Italian case study of the INTERACTION project

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Keywords: water-scarce critical zone, coastal aquifer salinization, wetland.

This presentation reports the main advances of the project titled "Integrated Assessment of Climate Impacts on Ecosystem Functions and Productivity of Critical-Zone Eco-Hydrology"- INTERACTION, funded by the Belmont Forum's Collaborative Research Action (CRA). The project, involves international research team from Italy, Qatar, and the USA. It offers a novel approach to managing the environmental risks, climate change, and anthropogenic impacts on Water-Scarce Critical zones (WSCZ) combining scientific research with stakeholder engagement. To tackle this challenge, INTERACTION adopts a multi-disciplinary approach involving heterogeneous expertise ranging from environmental and socio-economics analysis, numerical modeling, soil and groundwater hydrogeology, and climate change modeling and assessment. More in detail, INTERACTION deals with coastal aquifers in arid and semi-arid regions affected by high population density, extensive groundwater usage, climate change impacts, and rising sea levels which result in groundwater quantity and quality degradation, salinization of agricultural soils, disruptions of coastal wetlands, and consequently ecosystem degradation. The long-term effects of anthropogenic activities on these systems are not yet fully understood, hindering their management. Traditional approaches tend to study the components of such a system in isolation, overlooking their nonlinear relationships. INTERACTION adopts a holistic perspective considering relationships among physical, anthropogenic, and socio-economic factors to provide more effective solutions for integrated management in water-scarce coastal areas. The Italian case study is focused on the Torre Guaceto protected wetland in Apulia, South Italy. In this area, soil and groundwater salinization issues exist mainly induced by the intensive agricultural activities in the surrounds, critically encroach upon the evolution of coastal wetlands and water management measures. The area is characterized by a dry sub-humid climate, but trends towards more arid conditions have been identified. The location, morphology, and hydrogeology of the area, together with the observed changes in the rainfall regime and overexploitation of groundwater for irrigation, explain the critical level of groundwater salinity. The unwanted scenario is a relevant water scarcity risk that may affect agricultural activities as well as wetland conservation. INTERACTION, through integrated monitoring of the main natural elements of the site, stakeholder involvement, and suitable system dynamics modeling carries out an in depth analysis of current and alternative land use and water management strategies to cope with the changing dynamics of water demand and supply and prevent further deterioration of groundwater dependent ecosystems.

Column test to study the influence of lithological characteristics of rocks on the hygienic-sanitary quality of groundwater

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Keywords: laboratory test, microorganisms fate, saturated rock.

Groundwater is an important source of water supply to meet drinking and irrigation needs. They play a crucial role in regions, such as Apulia, where particular geological features, such as the extensive outcrops of fractured and karst rocks, determine surface water scarcity (Maggiore & Pagliarulo, 2004).

However, groundwater is also the most vulnerable resource to contamination from surface pollution sources, including wastewater treatment plants in case of malfunction or poorly managed increase in incoming load. In these situations, pathogenic microorganisms can be detected in inadequately treated effluent, which by reaching groundwater, pose a serious risk to human health (Montagna et al., 2020; De Giglio et al., 2022). In this regard, the Apulia Region has funded the SCA.Re.S. (Assessment of the hygienic-sanitary risk related to the discharge of wastewater on the ground) project (DGR 1346, 04/08/2021).

This study, part of the SCA.Re.S. Project, aimed to investigate the migration behavior of microorganisms in a saturated rock column to figure out the impact of the different rock lithotypes on the contamination, due to the infiltration of treated wastewater through the subsoil. In the last decades, many studies have been conducted to investigate transport processes of microorganisms through porous media (Madumathi et al., 2017). In the present research, laboratory-scale tests were carried out to investigate the interaction of pathogenic microorganisms with different carbonate rocks, by monitoring over the time the microbial load. Specifically, the experimental column test was set up using a saturated porous rock sample (ø=10 cm, h=50cm). A suspension (500mL) of *E.coli* of known titer (2.4x106ufc/mL), followed by a sterile saline solutions, were poured at the top of the core sample. The percolated water, collected every half hour for 3 consecutive days was subjected to quantitative analysis of the microorganisms. The experiment was repeated three times under the same laboratory conditions (T=23°C). Overall, a suspension containing 3x109 *E.coli* cells was poured onto the porous rock sample. On average, 8x106 cells were eluted at the end of the experiments with a decrease of 97.2%. The study increased the knowledge on the interaction occurring between the type of microorganism and the physical and hydraulic parameters of the rock, in order to minimize the impacts of microbiological contamination in groundwater and consequent risk to human health.

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High-altitude minor springs in Central Italy tapped for drinking supply: hydrogeological characterization and aquifer potentialities evaluation

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Keywords: spring, groundwater.

In central Apennines' high altitude villages the water used drinking purpose is guaranteed by springs with seasonal and limited discharge.

The small villages located in the south-eastern portion of the Abruzzo region's mountain area and the north-western part of Molise region, also known as Alto Sangro area, have reached self-sufficiency because of the presence of many springs located at altitude higher than 1100 m and tapped for drinking purpose; some lack in water availability during summer season were point out, this is due to the impossibility of tap into lower elevations' springs which are used for the more urbanized coastal areas supply.

Despite the strategical position of these springs, the managing companies have preferred different exploitation and distribution policies; currently, water supply from springs or well fields with major potentials is chosen, even if it require more effort for water distribution.

In this work, these high altitude aquifers were deepened, defining their characteristics, potentialities and residual capabilities. The geological and tectonical framework is peculiar because the relationships between litholigies are mainly due to faults and low angle thrusts. Consequently, the hydrogeological set-up reflects the geological one, the low angle thrusts put in contact terrigenous lithologies with different permeability (i.e. Gamberale-Pizzoferrato formation), within the so-called Molise units, with the carbonatic succession of the central Apennines and the Sicilidi calcareous-clayey formation (Festa et al., 2014).

In this complex hydro-geological framework, groundwater is allowed to emerge as spring: usually, the calcarenites within Molise units, or the Apennines limestone formations work as aquifer, while the clayey complex of the *Sicilidi* or clay within Molise units, as aquiclude. In some cases, even coarse slope deposits work as aquifer, they were found over the impermeable complex, originated from carbonate deposits located at higher altitude. Analyzing the hydrogeological set-up, these springs were mainly classified as "for permeability limit" (Civita, 1973).

These high-altitude springs have an average discharge between 1 l/s and 2 l/s, and the preliminary results about groundwater potentialities were obtained through infiltration coefficient: the found recharge volumes were about 100 Mm3, over a 615 Km2-wide area.

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Festa A. et al. (2014) - Geology of the Aventino River Valley (eastern Majella, central Italy). Journal of Maps, 10(4), 584-599.

The effect of rainfall extreme events in the unsaturated and saturated zone: the case study of Pianosa Island (Tuscan Archipelago, Italy)

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Keywords: extreme events, small island, groundwater recharge.

In the recent decades, the frequency and intensity of rainfall extreme events are increasing due to climate changes (Fowler & Ali, 2022). Increased temperature and extreme precipitation can have a significant impact on groundwater recharge, modifying the relationship between superficial and groundwater and causing a deterioration of the resource, in terms of both quantity and quality. Several studies show that groundwater recharge is decreasing in many areas around the globe. However, a few researchers highlighted an increase in recharge under certain conditions (Pulido–Velazquez et al., 2015 and references therein). Insular aquifer systems are the ones that mainly suffer the effects of climate changes in terms of atmospheric temperature and precipitation regime, and the Mediterranean region has been identified as one of the climate systems most responsive hotspots in relation to the increasing of greenhouse effect, particularly due to marked warming and large decrease in precipitation (Diffenbaugh et al., 2007).

In this frame, Pianosa Island represents a strategic site to study the effects of climate changes on aquifer systems along a significant period and a good proxy for the whole Mediterranean area. The importance of Pianosa is due to the very low anthropic pressure, a consequence of the closure of penal colony in 1996 and controlled tourist access in spring and summer. Pianosa is characterized by medium-low annual rainfall (about 550 mm/year on average). The mean annual atmospheric temperature is about 17°C and windy conditions are present during most part of the year. Despite its relatively dry climate, its small extension, and a flat morphology (max altitude of 28 m a.s.l.), significant freshwater resources are stored in a shallow unconfined aquifer and in some deeper aquifer layers in confined/semi-confined conditions (Doveri et al., 2012). The study of the aquifer system and processes in the unsaturated zone is of paramount importance to better understand the recharge mechanisms as well as the evolution of water availability, thus supporting a correct management of groundwater resource. The study was carried out through (1) analysis of continuous monitoring data of rainfall, temperature, piezometric level, infiltration water, and soil humidity, (2) analysis of chemical composition, and (3) isotopic signature of water. The study focused on the analysis of the hydrogeological processes occurred during extreme rainfall events on the island. The most significant one occurred since 2014 is that of 25 November 2022, with a cumulative rainfall of about 276 mm in a few hours. During this event, groundwater recharge was efficient, since the piezometric level increased and maintained values higher than that recorded before the event. The timing of water quantity transit through soil and unsaturated zone of the aquifer, as well as the evolution of electrical conductivity, chemical and isotopic signals in water, suggested the rapid response mechanisms of the system to extreme rainfall.

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From geochemistry to treatment: a multidisciplinary study for reuse of safe natural waters

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Keywords: membrane processes, heavy metals, groundwaters.

The main challenge of the present day is to provide consumers with safe water for daily use. The increase in industrial activities represents a real problem regarding water resource protection. However, in some specific sites, natural pollution plays a predominant role in water contamination. When pollution is associated with anthropic activities, the possibility of site restoration can be possible assuming that a critical condition has not already been reached. Instead, when pollution has a natural origin, the high concentration of pollutants represents a natural background level, and the issue cannot be solved at its root. For instance, groundwater contamination due to the natural rock-to-water release of heavy metals such as Chromium or Arsenic represents a primitive environmental issue that cannot be solved because the natural process cannot be stopped. However, using valid techniques to produce safe water could represent a solution in naturally polluted sites, providing safe water to people who live in the surrounding areas. In the frame of PNRR project (CUP B83C22003980006), a multidisciplinary study was proposed. The main topic of this specific action (Spoke 2, PP2, Action 7) is the geochemical investigation and mapping of potential pollutants in Calabro-Lucanian aquifers coupled with membrane treatment processes. Based on strong-based geochemical information, representative polluted waters were selected for laboratory tests. Subsequently, the most suitable site will be identified to install a prototype membrane-based and energy self-sufficient to purify the contaminated water, providing a safe product for drinking and/or agricultural purposes. Among available membrane techniques, nanofiltration (NF) was chosen as the most valid technique to achieve the project's objective (Figoli et al., 2019; Fuoco et al., 2020).

The project can have a positive scientific and applicative impact. It can be realized in other polluted sites, allowing the reuse of waters that cannot be used for drinking or agricultural purposes in their natural state.

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Rhythmic response of cave animals to external cycles

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Keywords: bioodiversity, cave biology, springs.

Organisms inhabiting caves are usually described as lacking biological cycles, since they exploit environments with largely constant conditions. However, recent evidence is emerging on the rhythmicity of cave-dwelling animals, with experimental, observational and genetic analyses. There are still many uncertainties, as some organisms may have regular or irregular rhythms, and some others seem to lack them. In this study, we analysed the activity of two groundwater-dwelling species: the European cave salamander (*Proteus anguinus*) and the crustacean isopod *Monolistra pavani*. Both species are usually thought to be arhythmic and exclusively found in caves; however, for the cave salamanders, recent studies have described the non-random activity in surface freshwater springs. We used GLMMs and N-mixture models to test the relationship between abundance and detection probability of cave species and both external cycles (circadian, lunar, and seasonal) and flooding events (upstream cumulated rain), analysing in two different models the surface and underground sites. We found that cave salamanders are generally more abundant during the night. Their detection probability in springs was higher during the night, with higher moon illumination (i.e., full moon) and after upstream rains; in caves, detection probability was higher during winter. For isopods, the detection probability was higher in early summer and in the evening. Our results suggest that depigmented cave-dwelling organisms are vulnerable to sunlight and tend to avoid it, exploiting the spring environment during the night, when ecological conditions are more similar to caves. Higher activity in springs may as well be related to food availability, as floods may foster it. Future studies to clarify these patterns are needed, and a molecular approach may be necessary to finally disentangle the role of adaptations and plasticity. These results are in accordance with previous studies on cave-dwelling invertebrates. In conclusion, cave animals may exhibit a rhythmic behaviour both in springs and in caves.

Evaluation of nitrate leaching processes during infiltration and transport in the unsaturated zone

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Keywords: nitrate, unsaturated zone, monitoring.

The increase in intensive agriculture and animal husbandry has led to the large-scale application of organic and chemical fertilizers to the soil. This use has led to the release of various chemical pollutants into the soil, which then enter the water table through the leaching of rainwater and irrigation water. Despite the implementation of strict regulations laid down in the Nitrates Directive, groundwater quality has not significantly improved in many Nitrates Vulnerable Zones.

Studies on vulnerability to aquifer contamination often focus more on the groundwater body negleting the unsaturated zone. The vadose zone is a fundamental part of the hydrological cycle, capable of storing water, providing water for vegetation, transporting solutes, and breaking down pollutants before they reach the aquifer.

The study area is the Arborea plain (Sardinia), designated as an NVZ since 2005 due to heavy nitrate contamination in its aquifer. Consequently, the research aimed to monitor nitrate leaching during infiltration and transport through the unsaturated zone and evaluate any processes of natural attenuation.

In the plain, an agricultural field was selected as a pilot site where an unsaturated zone monitoring system was set up to obtain information on the processes taking place through the soil profile to the saturated zone. TDR probes were installed to measure volumetric water content, while suction cups were placed at different depths to sample pore water for the analysis of ionic nitrogen species and nitrate isotopes. The experimental approach was coupled with the use of a physically based flow and transport model in the unsaturated zone FLOWS (Coppola et al., 2014, 2019; Hassan et al., 2023) for the simulation of the flow and transport of nitrate in the pilot site.

Monitoring the unsaturated zone combined with models are a useful factor in assessing the vulnerability of the aquifer and contribute to a better understanding of the processes occurring in the transported solute, thereby optimizing agricultural practices and measures to protect groundwater resources.

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River Magra aquifer system groundwater flow model, for correct water management in the perspective of climate change (Liguria Region, Italy)

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Keywords: seawater intrusion, alluvial aquifer, coastal aquifer sustainability.

Magra River flows for 70 km between Tuscany and Liguria regions and is one of the main estuarine rivers in Italy. It drains a watershed of 1700 km2 and its terminal path is characterized by the confluence with Vara River. After the confluence, the Magra River feeds one of the most important aquifers, currently exploited for drinking water purposes. The aquifer is set on an asymmetric Graben, with a N-S development, marked by La Spezia normal fault, which represents the west boundary. The Val Magra aquifer is composed of recent fluvial sediments, such as coarse-medium sand, and gravels and Pleistocene non-consolidate conglomerates deposited as alluvial fans by secondary tributary. The absence of a continuous surface clay layer makes it an unconfined aquifer. The vulnerability of the aquifer has been partially tested by Critelli et al. (2023). The groundwater over-exploitation and the proximity to the seacoast make it vulnerable to climate change (Costall et al., 2020). In particular, the most dangerous effect linked to climate change is the seawater intrusion phenomenon, which could compromise the quality and quantity of groundwater, damaging agriculture and gradually desertifying the territory. This phenomenon may be accelerated by poor water management. Innovative studies are therefore needed to better understand the vulnerabilities related to the aquifer. A good reconstruction of the alluvial and coastal aquifers and a 3D hydrogeological model is necessary. In this study, a new hydrogeological model of the lower Val Magra aquifer is developed. The model realized in MODFLOW was calibrated using PEST against hydraulic head records. It is based on geological sections which are elaborated thanks to borehole stratigraphy and seismic surveys. Marine intrusion's spatial and temporal evolution has been strongly monitored from 2022 to 2023 through water electrical conductivity measurements and water sampling campaigns, for successive water isotope analysis (Sabattini et al., 2024) to evaluate groundwater mixing following the approach reported in Ronchetti et al. (2023). The results obtained in this study will enable us to: a) identify the most vulnerable groundwater exploitation sites; b) formulate detailed rules about seawater wedge intrusion and understand its effects on the coastal aquifer; c) predict the evolution of aquifer water flow related to climate change consequences. All these observations will help stakeholders to implement a future water management plan.

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Costall A.R. et al. (2020) - Groundwater Throughflow and Seawater Intrusion in High Quality Coastal Aquifers. Sci. Rep., 10, 9866, https://doi.org/10.1038/s41598-020-66516-6.

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BIOflushing technology for in situ applications of the Soil-Omic protocol. Operational scale prototype of a plant for the decontamination of soil in the saturated and unsaturated zone

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Keywords: innovation, soil decontamination, bio-based solution.

Teseco Bonifiche, Department of Biology (UNIPI), CNR-IRET and CEBAS-CSIC (ES) have developed a technology for the remediation of contaminated soils and aquifers, which is based on an original chemical-physical-biological and on the use of a system specifically designed for its on-site application. The process, for which a patent has been filed, is registered under the name Soil-Omic ®. Soil-Omic ® is a protocol that uses omics sciences and advanced environmental engineering tools and exploits, amplifying it exponentially, the ability of the indigenous soil microbiota to degrade and remove recalcitrant and persistent contaminants.

The technology was designed for the in situ decontamination of soil and groundwater, which are used as a medium for an original biological and chemical flushing concept named BIOflushing ®. The technology is site-specific, meaning its development and effectiveness are connected with in-depth knowledge of the characteristics of soil and groundwater of the site.

The conceptual model of the site is built starting from the acquisition of a variety of data, obtained from chemical, physical and mineralogical analyses, which involve all the natural components and contamination factors, and through the examination of the microbiota, its evolution during treatment, and its metabolites.

Soil-Omic ® consists of the integration of consolidated physico-chemical approaches with metagenomics and culturomics, to evaluate and govern the process of abatement of organic and inorganic pollution in environmental matrices.

The protocol also analyses and models the forms in which the organic contaminant is adsorbed to the matrix, thus determining the best conditions to make it bioavailable even when it has been subject to aging processes.

At the same time, through original sequential extraction protocols developed directly on site-specific matrices, the technology allows the development of chemical solutions suitable for the desorption, transformation and solubilization of inorganic contaminants.

The Soil-Omic® process and the BIOflushing® system were designed and validated during full-scale pilot tests for the abatement of recalcitrant organic environmental contaminants deriving from anthropic activities, such as Hydrocarbons (TPH) (Di Gregorio et al., 2016; Becarelli et al., 2019), polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs) (Siracusa et al., 2017), volatile chlorinated compounds and BTEX -benzene, toluene, ethylbenzene and xylene, organochlorine compounds, and for the removal of metals and metalloids, such as Pb, Cd, Zn, Ni, As, Cu, Cr. The technology was designed to operate on both the unsaturated and saturated zone of the soil.

The technology was developed and tested following the awarding of the pre-commercial contract POSIDON PCP, financed by the European Horizon 2020 Program (Grant agreement No. 776838).

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Siracusa G. et al. (2017) - PCB in the environment: bio-based processes for soil decontamination and management of waste from the industrial production of Pleurotus ostreatus. New Biotechnol., 39, 232-239, https://doi.org/10.1016/j.nbt.2017.08.011.

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Hydrological processes in the aquifer system unsaturated zone: insights from the small Mediterranean island of Pianosa (Tuscan Archipelago)

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Keywords: unsaturated zone, evapotranspiration, effective infiltration.

Climate change significantly influences water resources and the hydrological cycle (Held & Soden, 2006). To comprehensively evaluate the potential effects of climate change on groundwater resources, it is crucial to understand and quantify changes in groundwater recharge (Doveri et al., 2016). Groundwater recharge, the process through which groundwater is replenished by the effective infiltration and seepage of surface water, plays a fundamental role in maintaining water supplies. However, accurately estimating recharge rates requires access to high-quality and spatially distributed data. For this reason, it is important to identify tools and methods to explore the complex interactions between atmosphere, soil's unsaturated zone, and groundwater. This is essential for sustainable water management and for developing effective adaptation strategies in response to the challenges posed by climate and global change.

The recharge of aquifers is influenced not only by climatic conditions and by the characteristics of the aquifer itself, but also by the properties of the overlying layers. Various methods, including the analysis of land cover, surface water data, and the characteristics of the unsaturated zone, can be employed to estimate both current and future recharge rates (e.g., Brussolo et al., 2022).

In this study, the focus is specifically on two surface-subsurface processes concurring in groundwater recharge: evapotranspiration (ET) and effective infiltration (EI). Experiences on the small Mediterranean island of Pianosa (Tuscan Archipelago) are described. The island hosts the Pianosa Research Base (www.brp.cnr.it), managed by the Istituto di Geoscienze e Georisorse (IGG) of the National Research Council of Italy (CNR). The island is equipped with an extensive hydrological and hydrogeological monitoring network. Among other features, this network includes the measurement and characterization of total and effective infiltration water and precipitation. To obtain these measurements, the network uses specialized equipment such as a rain-gauge sampler and a high-precision lysimeter equipped with probes for soil moisture, soil tension, and soil temperature at various depths. Additionally, portable and automatic customized non-steady-state dynamic flux chambers, paired with Infrared Gas Analyzers (IRGAs), were employed to measure ET (Raz-Yaseef et al., 2017).

Preliminary results are presented, comparing various approaches, including both theoretical methods and experimental techniques. The data as a whole indicate that the ET process predominates in contrast to EI, which occurs only for a short period during the winter-spring months. This suggests a strong seasonal pattern in the occurrence and intensity of EI.

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Held I.M. & Soden B.J. (2006) - Robust responses of the hydrological cycle to global warming. J. Climate, 19(21), 5686-5699, https://doi.org/10.1175/JCLI3990.1.

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ERT characterization of treated water pathways from large infiltration trenches in unsaturated fractured/karstified calcarenite

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Keywords: infiltration trenches, preferential pathways, geophysical methods.

In Italy, during the last decades, infiltration trenches have been increasingly used to spread and buffer effluent in the subsurface, because of its natural filtering capability against organics, chemicals and contaminants.

This unconventional water source can provide an unintentional recharge of water to aquifers but, according to the Italian regulation, a monitoring of the chemical and physical parameters of the mixed water is crucial to avoid potential contamination sources.

In this context, geophysical methods are a powerful tool to identify preferential pathways in the unsaturated subsurface.

Such methods are non-invasive and cost effective, they have high applicability in challenging environments, being capable to cover wide areas with a high level of resolution.

Despite imaged targets cannot be directly observed, the water flow can be tracked over space because of the significant contrast in resistivity between the conductive plume and the surrounding rock.

In the framework of the DY.MI.CR.ON Project, financed by European Union - Next Generation EU, an Electrical Resistivity Tomography (ERT) survey has been performed in an area near the wastewater treatment plant of Carpignano Salentino, where domestic effluent is spread in infiltration trenches dug into the calcarenite rock.

Clear evidences of the presence of preferential paths outside the trench are observed: despite a high daily flow rate, a negligible amount of water accumulates in the trench after several months.

Several ERT profiles were carried out to track infiltration patterns and support the network of wells to be monitored.

EMI and ERT characterization of plant-scale irrigation and ET: an orange orchard-case study and methodological challenges

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Keywords: agriculture, irrigation, geophysics.

EMI allows time-lapse profiling of electrical conductivity (EC). In recent years, progress was made in the study of the intra-field variability and soil-plant correlations at the scale of a few meters. On the contrary, some methodological challenges still hinder the possibility to resolve the spatiotemporal complexity at smaller scales. These smaller scales are typically associated with irrigation and evapotranspiration (ET) dynamics and thus central to the agroecosystems and precision agriculture, particularly in orchard farming. This EMI study characterizes the 3D EC variability in an orange orchard in eastern Sicily (Italy).

To the best of our knowledge, this is the first 3D investigation capturing both irrigation and ET effects at the meter scale. The characterization successfully distinguishes plant rows, interrows, and quaterrows. The conductivity in the plant rows increases upwards, from the drier root-water-uptake region to the drip irrigation region above. In the interrows, the conductivity increases downwards from the drier evaporation-dominated layer to the deeper soil where the irrigation water accumulates without significant ET. The quaterrows show yet another conductivity profile, being surprisingly homogeneous and relatively conductive. Local effects, such as the plant size, further complicate this conceptual model and add both inter- and intra-row heterogeneity. While the characterization results confirmed the EMI potential, the following methodological challenges were equally important. First, a Geophex GEM-2 and a CMD Mini-Explorer were used, the latter in vertical and horizontal configuration. The choice of instruments and surveys appears now suitable for this field site but it is surely not obvious a priori and/or always possible. It is highlighted how the use of a single instrument would surely lead to misinterpret the root water uptake or the evaporation contributions. Second, the quantitative use of the two instruments required alignment and joint inversion. However, the standard GPS systems did not provide a reliable alignment of the surveys. Time-consuming GIS corrections were needed for both intra- and inter-dataset shifts.

Third, after the GPS alignment the surveys were interpolated over a common grid to allow the joint inversion. Because of the strong anisotropy of the agroecosystems, this required the careful parametrization of a Kriging algorithm.

Fourth, the individual EMI datasets also differed because of their drift and calibration. The lack of convenient alternatives initially motivated an ERT-based calibration, but ultimately two of the twelve datasets were discharged. Fifth, noise and errors required the use of a moving median. This common practice poses a trade-off between smoothing and resolution that hinders high-resolution surveys. Sixth, a sub area of the orchard was investigated in much higher detail. This proved fundamental for the identification of the quaterrows and other meter-scale details. Again, the implications of a particular survey design are hard to predict, also considering the successive effect of smoothing and grid interpolation. Overall, this study presents a state-of-the-art EMI application that focuses on small-scale aspects that were less considered in previous studies. The presented challenges explain the lack of similar studies and should be considered when discussing the EMI convenience and adoption.

Assessing surface water-groundwater exchange dynamics for managed aquifer recharge design: a case study in Muravera, Southeastern Sardinia, Italy

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Keywords: managed aquifer recharge, manage groundwater resources, hyporheic zone.

Climate change requires early planning of mitigation and adaptation strategies to effectively manage groundwater resources. The implementation of managed aquifer recharge systems can help mitigate the effects of climate change and alleviate the need for withdrawals, particularly under conditions of imbalanced natural recharge. In the coastal plain of Muravera (southeastern Sardinia, Italy), already affected by significant salinization phenomena, understanding the dynamics between surface water and groundwater is central for managing hydrodynamic balance and assessing potential managed aquifer recharge projects (Porru et al., 2024). As part of the Project eINS Ecosystem of Innovation for Next Generation Sardinia (Code ECS0000038 - CUP F53C22000430001), we investigated the exchange dynamics between surface water (SW) and groundwater (GW) within the hyporheic zone of the Muravera coastal aquifer. Mini piezometers of two lengths (100 cm and 200 cm) as those described by (Wanty & Winter, 2000) were deployed along transects moving from upstream towards the sea, and an additional transect with five mini-piezometers was installed orthogonal to the SW flow direction at the groundwater discharge zone. Parameters including temperature, specific electrical conductivity (C.E.S.), redox potential (Eh), and pH were measured, with water samples collected for chemical analysis. To evaluate potential leakage into the aquifer from a channel receiving treated wastewater from the Muravera wastewater treatment plant, a sodium chloride (NaCl) tracer test was conducted. Additionally, groundwater samples from nearby wells were analyzed for the presence of gadolinium, a contrast agent typically found in domestic wastewater discharges, as it is not removed during the treatment process in wastewater treatment plants (Cidu et al., 2013). Our findings revealed areas where groundwater flows into and out of the Flumendosa River within the hyporheic zone, with water quality exhibiting layering even on a small scale. This study significantly advances our understanding of surface water and groundwater interactions in the lower part of the Flumendosa River basin, particularly exchange processes in the lower valley. By exploring the hyporheic zone, where dynamic exchanges occur between surface water and groundwater, we identified chemical and physical properties, pressure heads, and gradients that distinguish discharge direction between SW and GW.

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Methodological approach to simulate the evolution seawater intrusion with climate change

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Keywords: climate change, numerical modelling, seawater intrusion.

Seawater intrusion is a major environmental problem in coastal areas around the world, significantly contributing to the depletion of water resources. Even a small amount, less than 1% of seawater intrusion in an aquifer, can render freshwater unfit for drinking. Furthermore, locally, water quality impairment can also lead to soil degradation, limiting its use or causing land abandonment.

In the framework of the Return project (founded by the Next-GenerationEU, NRRP), this paper presents a new methodology for simulating seawater intrusion, accounting for the decrease in natural recharge caused by climate change.

To simulate the coupled effects of groundwater density and solute transport, this study utilizes iMOD-WQ software developed by Deltares. This software incorporates SEAWAT, a well-established tool for modeling density-dependent interactions between freshwater and saltwater in aquifers. iMOD itself is a modified version of the source code specifically designed for parallel processing. This approach significantly accelerates computations by up to two orders of magnitude, depending on the available computer resources. This efficiency is crucial, especially when simulating long time periods essential for studying climate change impacts. While iMOD offers a graphical user interface, Python scripting was chosen for this study due to its superior data manipulation capabilities.

A Soil Water Balance code was used to quantify the impact of climate change on natural recharge. This code, implemented by the USGS, allows the variation of recharge to be simulated in both time and space. In addition to climate data, the code is based on soil characteristics. Four inputs are needed: land use, available water capacity, hydrological soil group and Flow direction.

The area under study where this approach was applied is the coastal plain of Muravera (Sardinia, Italy), where the problem of seawater intrusion has been causing not only environmental but also socio-economic problems for more than 50 years. Thanks to a large dataset base, all the necessary inputs to the codes used are derived from measurements obtained on the field over the years.

This approach can make an important contribution in water resource management by enabling the development of effective strategies to mitigate salt intrusion under anticipated climate change impacts. Its applicability to similar areas makes it a valuable tool for broader water resource protection.

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Monitoring saltwater intrusion in the area surrounding the Grado lagoon (NE Italy)

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Keywords: saltwater intrusion, electromagnetic induction (EMI) techniques, climate change.

Coastal aquifers are heavily influenced by seawater intrusion, a phenomenon exacerbated by current climate change, which is affecting the availability of freshwater for drinking and irrigation purposes. This occurrence also leads to a progressive salinization of agricultural lands, adversely affecting crop yields.

Despite the importance of groundwater salinization management for coastal agriculture in the Friuli Venezia Giulia region (NE Italy), there is currently a lack of detailed study on the topic. To partly fill this gap, a first field campaign was carried out in the inland areas surrounding the Grado lagoon, as part of an ongoing PhD project focusing on the regional issue.

The Grado lagoon is a low energy environment characterized by higher salinity compared to the Adriatic Sea and the nearby Marano lagoon, due to shallower depth and limited presence of freshwater tributaries. In the inland regions of the Grado lagoon, which are mainly situated below sea level and predominantly utilized for agriculture, ensuring environmental sustainability rely heavily upon effective water resource management. In order to tackle this challenge and manage the water resource effectively, it is crucial to establish a comprehensive hydrogeological model of the area.

Non-invasive geophysical investigation techniques have commonly been employed for this purpose in similar contexts. In this study, Electromagnetic induction (EMI) technique has been utilized for studying saline intrusion in the subsurface, thanks to its ability to explore large areas in relatively short times, detecting depth and lateral variations in electrical conductivity which can be associated with soil salinity changes. During this campaign, more than 30 km electrical conductivity profiles were collected along the lagoon margin, highlighting electrical conductivity variations, directly linked to the presence of saltwater in the aquifers closer to the saltwater body.

The data obtained from EMI surveys were validated through Electrical Resistivity Tomography profiles performed in selected location and through direct sampling of groundwater, conducted via manual boreholes drilled to varying depths relatively to the groundwater level. The material retrieved from the drillings also enabled us to obtain short stratigraphic logs, which have contributed to a better understanding of the salinity distribution in the coastal aquifers.

The combined approach has demonstrated its worth by providing crucial insights into the extent of salinization in the coastal phreatic aquifers. A thorough understanding of seawater intrusion is essential for future strategic planning of water resource management and agricultural development in the study area.

Renewable energy application: sustainability techniques in Torino Urban City

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Keywords: groundwater heat pumps (GWHPs), urban sustainability, aquifer protection.

Italy is one of the top 10 countries for geothermal electricity generation and among the first 15 for heating and cooling applications. In 2021, there were 226 active installations in Italy for the exploitation of direct geothermal energy for the sole heat production purposes. These are, in most cases, individual heating and thermal plants.

For about 2 years, Torino has been among the 100 European cities and the 9 Italian cities that have the objective of achieving an 80% reduction in CO_2 emissions by 2030 compared to 2019 values. The journey started long ago when the European Union's Mission Smart and Climate-Neutral Cities was launched, with the aim of accelerating the transition towards climate neutrality in 100 selected European cities as a reference by 2030 (anticipating 2050 foreseen by the Green Deal) and opening a call aimed at all European cities. Torino was thus one of the selected Italian cities. The priority objective of Torino and the other selected cities was the preparation of the so-called Climate City Contracts (CCC) (Comunicato Stampa Comune di Torino, 2024), i.e. contracts which, although having no legal value, will serve to formalize a clear, transparent and well-defined political commitment towards the Commission and national/regional authorities, including citizens, research organizations and the private sector.

In this context, Groundwater Heat Pumps (GWHPs) are an efficient solution for reducing carbon emissions in heating and cooling systems in urban areas with favourable geological conditions (Taddia et al., 2019). These systems draw water from shallow aquifers, undergo heat exchange processes, and return water at a modified temperature. It is important to preserve the groundwater quality of aquifers, which serve as renewable energy sources, for urban sustainability. In order to promote the adoption of GWHP, urban planning should be carried out while ensuring the long-term protection of groundwater. Torino Urban City has an alluvial shallow aquifer that is a valuable source of low-enthalpy geothermal energy (Berta et al., 2024). However, it is essential to conduct a comprehensive site assessment to evaluate the environmental impacts, taking into account well characteristics, locations, pumping rates, and thermal effects on local groundwater resources. The thermal plumes, which are shaped by water extraction and reinjection rates, have an impact only on downstream neighbouring plants. Accurate hydrogeological characterization is crucial for constructing new facilities, as positive aquifer responses to long-term disturbances demonstrate. The proposed urban-scale model is a valuable tool for experts and authorities, enabling the assessment of thermal disruptions at both localized and urban levels. Using this tool ensures the sustainable use of aquifer resources in complex systems, promoting informed decision-making for urban heating and cooling strategies.

Berta A. et al. (2024) - The role of standards and regulations in the open-loop GWHPs development in Italy: The case study of the Lombardy and Piedmont regions. Renewable Energy, https://doi.org/10.1016/j.renene.2024.120016.

Comunicato Stampa Comune di Torino: https://comunicatistampa.comune.torino.it/2024/03/la-citta-di-torino-presenta-il-climate-city-contract-alla-commissione-europea/ (Accessed on April 2024)

Taddia G. et al. (2019) - Groundwater Heat Pump Systems Diffusion and Groundwater Resources Protection. Geoingegneria Ambientale e Mineraria, 156.

An integrated numerical modelling approach to the management of a coastal plain aquifer (Southern Italy)

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Keywords: hydrogeological modeling, groundwater recharge, seawater intrusion

Groundwater, a vital resource for meeting domestic and agricultural water demands, faces imminent threats in coastal aquifers from seawater intrusion and declining recharge rates. This study focuses on the Metaponto coastal aquifer in south Italy, where rising seawater levels and increased evapotranspiration contribute to both seawater intrusion and reduced groundwater recharge. Addressing the interconnected impacts of these phenomena requires a variable-density hydrogeological model to comprehend the current and future status of groundwater resources. One significant challenge in modelling the water balance and groundwater together is the bidirectional interaction between surface water budget and groundwater models. While conditions from the surface water budget model inform the groundwater model, feedback from the groundwater model to the surface water model is often overlooked. To address this challenge, this study combines the modelling of the surface water budget and groundwater, with the results of the water budgeting implemented as boundary conditions for the groundwater model at each time step. The novelty of this research is the consideration of agricultural irrigation contributing to groundwater recharge along with other factors. The regional model for the Metaponto coastal aquifer was developed using the MODFLOW code for steady-state groundwater flow and the SEAWAT code for salt transport. The objective of this study was to evaluate the impact of climate change on salt concentrations in the Metaponto coastal region over an 80-year period, encompassing all aspects of the hydrologic cycle. The methodology involved in this research integrates a regional-scale three-dimensional groundwater model with variables such as sea level rise, changes in agricultural practices, shifts in groundwater demand, increasing sea salinity levels, and reduced river flow and upstream flux. The results of this study demonstrated a comprehensive hydraulic head and salinity distribution in three dimensions by combining diverse influences of climate change and human activities. This study offers valuable insights into potential future scenarios, proving beneficial for both scientific research and practical water resource management in the Metaponto region.

Use of GPR imaging for early detection of water leaks in pipelines

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Keywords: water leakage simulations, ground penetrating radar (GPR), early detection.

Italy faces significant challenges related to excessive water consumption, a substantial portion of which is attributed to leakages in distribution networks. These leakages have serious repercussions on water supply and social, infrastructural, and environmental dimensions. Traditional leak detection methods, such as pressure/flow monitoring and acoustic detection, often only identify advanced leakages and are hindered by their low resolution, particularly in urban settings (Tavera, 2008; Ahmed Negm et al., 2023). This study explores the efficacy of Ground Penetrating Radar (GPR), a non-destructive geophysical method, for the early detection of water leaks in underground distribution networks. The accuracy of GPR was evaluated using laboratory (real data collected in controlled environments) and simulation (synthetic profiles generated from a Finite-Difference Time-Domain, FDTD, electromagnetic wave model) experiments as analogues for water leaks in pipelines. Previous studies suggest that GPR can accurately locate leakages and provide detailed information about their extent and severity, surpassing conventional methods (Tavera, 2008; Lai et al., 2015; Liu et al., 2022).

Moreover, these findings highlight the need for more empirical evidence and case studies to corroborate the effectiveness of GPR under various conditions (Gamal et al., 2023). The outcomes of this research underscore the potential of GPR to significantly enhance early leak detection, suggesting a promising direction for more efficient water management and conservation in both urban and rural areas. At the same time, it seeks to delineate the challenges and limitations of the method in environments affected by water infiltration, which may serve as a reference for future research.

Gamal M. et al. (2023) - Utilizing Ground-Penetrating Radar for Water Leak Detection and Pipe Material Characterization in Environmental Studies: A Case Study. Remote Sens., Remote Sens., 15(20), 4924, https://doi.org/10.3390/rs15204924.

Lai W. et al. (2016) - Perturbation mapping of water leak in buried water pipes via laboratory validation experiments with high-frequency ground penetrating radar (GPR). Tunnelling and Underground Space Technology, 52(2016), 157-167. http://dx.doi.org/10.1016/j.tust.2015.10.017.

Liu Y. & Shi Z. (2022) - Mapping water pipeline leakage by ground-penetrating radar diffraction imaging. Geophysics, 87(4), WB1-WB7, https://doi.org/10.1190/geo2021-0230.1.

Tavera M. (2008) - Aplicación del georadar para la mejora del rendimiento de una red hídrica. Universitat Politècnica de València. http://hdl.handle.net/10251/12248.

Integrated experimental approach for supporting the planning of a Managed Aquifer Recharge (MAR) plantIntegrated experimental approach for supporting the planning of a Managed Aquifer Recharge (MAR) plant

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Keywords: Managed Aquifer Recharge (MAR), geophysical techniques, hydraulic characterization.

In coastal areas, saltwater intrusion due to overexploitation of the groundwater and sea level rise induced by climate change effects, causes a reduction of drinking and irrigation freshwater supplies. Mitigation and adaptation strategies are strongly encouraged in order to preserve water quality and quantity. Among these, Managed Aquifer Recharge (MAR) is an increasingly used water management strategy to protect and enhance stressed groundwater resources. Severe EU regulations control the implementation of MAR plants in order to avoid negative impact on the resource by ensuring the protection of the groundwater. Conversely, technical aspects concerning the planning of a MAR scheme, require the integration of several experimental approaches at different scales.

At this regard, an accurate definition of the geo-hydrogeologic model of the area of interest and, at the same time, the description of hydraulic parameters is crucial for modeling water flow and transport processes in the critical zone of the study area.

An integrated approach that combines traditional hydrogeological measurements and innovative unconventional techniques, has been applied in the Pwales Valley of Malta Island, where a MAR scheme is being planned.

A field-scale geophysical survey based on Electromagnetic Induction (EMI) technique allowed to define the geological setting and the spatial extension of the saltwater intrusion (De Carlo et al., 2024). At the same time, infiltration test performed on the outcropped filtering medium, provided information on the main hydraulic properties (the field saturated hydraulic conductivity, Kfs, and the average infiltration rate).

In addition, laboratory tests, performed on rock samples constituting the studied aquifer, provided water retention and hydraulic conductivity functions crucial to develop a local groundwater-flow numerical model to predict different environmental scenarios and visualize potential effects of the MAR scheme in the Pwales Coastal Aquifer (Caputo et al., 2024).

Caputo M.C. et al. (2024) - Hydraulic characterization of Pwales aquifer in Malta Island preparatory for planning managed aquifer recharge (MAR) pilot plant. Italian Journal of Groundwater, 13(1), 17-26, https://doi.org/10.7343/as-2024-742.

De Carlo L. et al. (2024) - Mapping saltwater intrusion via Electromagnetic Induction (EMI) for planning a Managed Aquifer Recharge (MAR) facility in Maltese Island. Italian Journal of Groundwater, 13(1), 7-15, https://doi.org/10.7343/as-2024-743.

Predictive dynamics of microbiological contamination of groundwater in the earth critical zone and impact on human health: the DY.MI.CR.ON Project

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Keywords: porous aquifer, microbial transport, groundwater contamination.

Groundwater is one of the main sources of water supply for human, agricultural and livestock needs. It becomes essential in areas where surface water is limited or insufficient to meet all needs. However, over-exploitation, due to increasing water demand and climate change impacts, is causing groundwater depletion. In addition, groundwater quality worsening, due to the infiltration of contaminated water from anthropic activities, can impact human health causing epidemics. The geological characteristics of aquifers, especially when the unsaturated zone consists of highly permeable or karst or fissured rocks that activate preferential flows, can influence pollutant transport increasing the risk of groundwater contamination. In these cases, a better understanding of the transport and fate of microorganisms through the unsaturated zone is essential to safeguard groundwater and prevent aquifer contamination. The irrigation of horticultural crops with poor quality water, coming from contaminated groundwater or low-quality treated wastewater, could pose a health problem due to the presence of pathogenic microorganisms, especially in case of consumption of raw or undercooked foods. The aim of this project, financed by European Union - Next Generation EU, is to improve knowledge on groundwater contamination through a novel interdisciplinary approach based on the integration of microbiological, geological and agronomic skills. Two sites in Puglia and Sicily have been chosen for a total of 5 sampling points, of which the chemical-physical characteristics of soil and water such as pH, temperature, electrical conductivity, dissolved oxygen, solids, have been well determined. The collected samples are filtered by membranes and specific bacteria are detected by culture methods. An additional volume of water is concentrated for the detection of human pathogenic viruses by molecular methods. Coliphages are also quantified, and the presence of protozoa is determined. Moreover, in the Sicilian sampling points, to test any virus adsorption on vegetables, samples of plants irrigated by target water sources are collected to identify and quantify the above-mentioned viruses. To study the transport of microorganisms in unsaturated porous media, laboratory experiments will be carried out on selected rock samples and used to validate a transport model to predict at large scale the migration of pathogens under different environmental conditions. In particular, the project provides methodological tools which, applied in different fields, can help to evaluate anthropic pressures and their impact on environmental matrices like plants, soils, rocks and groundwater. The results of the project permit to modulate anthropic activities, by considering the geological and hydraulic characteristics of the territory, in order to minimize the impacts of microbiological contamination on the environment and on agri-food activities and, consequently, the risk for human health.

Groundwater - lake interaction in a mediterranean coastal aquifer: the Alimini lake case study (Southern Italy)

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Keywords: coastal aquifer, hydrogeochemical indicators, saline intrusion.

The current study is focused on the characterisation of a coastal water system located in the Apulia Region, Southern Italy. The study site lies in the context of a semi-arid region, and comprises a freshwater lake fed by a multi-layer shallow porous aquifer. Groundwater is the main freshwater resource of the area, and suffers from an intensive exploitation that rises dramatically during summer, due to the increase of both population, caused by the massive presence of tourists, and the demand by agriculture. This study is intended to provide insight into the interactions between groundwater and lake water, in view of the potential lake water exploitation for drinking purposes, in order to help efficient and sustainable water management by local authorities.

Four monitoring campaigns were carried out throughout one hydrological year to collect a set of water samples both from the lake and wells in its nearby surroundings. Geochemical interpretation of water quality data was performed by comparing a set of hydrochemical indicators that can suggest the processes controlling the chemical composition of groundwater, with special attention to the potential seawater intrusion. The applied indicators included a number of correlations involving major ions concentrations and a few physico-chemical parameters relating thereto, e.g., total dissolved solids, and seawater fraction. Groundwater and lake water quality were then compared, particularly considering the standard values for drinking water. Data processing was aimed at bringing out potential seasonal variations of groundwater quality, due to the increased withdrawal from wells in the summer season, and the consequent potential impact on lake water quality.

Results suggested that groundwater chemistry was mainly controlled by the dissolution of carbonate minerals, with almost no contribution of cation exchange mechanisms, and a minimal impact of saltwater intrusion only into the wells closer to the coastline. The extent of intrusion showed no significant variation throughout the year. Lake water quality closely mirrored that of the feeding groundwater. Data analysis suggested that either biological and chemical processes occurring in the lake ecosystem, or anthropic activities in the area, did not have an impact on drinking water quality standards.

S44.

New concepts and applications in exploration, sustainable exploitation, storage and modelling of georesources

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What we learned from geodetic monitoring of subsurface industrial activities

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Keywords: geodetic monitoring, hydrocarbon exploitation activity, GNSS & InSAR.

In 2014 the Italian Ministry of Economic Development (MiSE) established a Working Group that drafted a document (Dialuce et al., 2014) providing indications and guidelines (ILG) for the monitoring of subsurface hydrocarbon exploitation activities with high safety standards in seismically active zones and in areas where they can produce ground deformations. The ILG describes the main technical aspects for implementing the monitoring, and the guidelines for its management and control as well as the actions to be undertaken under different scenarios of variation of the monitored parameters. In the following years, the ILG was tested on some pilot sites for which the National Institute of Geophysics and Volcanology (INGV) was involved as the Monitoring Responsible Structure (SPM).

As regards ground deformations, the ILG recommends the joint use of the main satellite techniques (GNSS and InSAR) to measure and analyze the spatio-temporal variations of these signals with respect to the background conditions, in turn identifying any surface deformation phenomena possibly linked to the anthropic activities.

With reference to different case studies embedding hydrocarbon production and storage, in this contribution we illustrate:

– the presentation of the data available at each test site;
– a synthesis of the observations and outcome of the measurements ;
– the critical issues and potentials of individual projects;
– possible future studies.

The high variability in the quantity and quality of data available for each site has made it very difficult to evaluate the impact of hydrocarbon cultivation activities on ground surface deformations, highlighting the need to standardize the planning and implementation strategies of the monitoring. Nonetheless, in some specific cases the available measurements have allowed us to identify specific signals due to the exploitation activity, thus underlining the importance of high-quality GNSS networks for characterizing deformation signals along the three displacement components.

The results thus far obtained evidence several critical issues, which make the monitoring of ground deformations, according to the indications of the ILG, a challenging goal. Nonetheless, we confirm that a rigorous conduction of deformation measurements may provide useful information on both the impact of the industrial activities, and the movements related to ongoing natural phenomena such as hydrological and tectonic processes, or sediment compaction.

Dialuce G. et al. (2014) - Guidelines For Monitoring Seismicity, Ground Deformation And Pore Pressure In Subsurface Industrial Activities. Available at: https://unmig.mase.gov.it/wp-content/uploads/2018/07/151_238.pdf.

Lithosphere heat flow and subsidence of the Tyrrhenian back-arc basin

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Keywords: marine heat flow data, ocean lithosphere, marginal basins.

The presence of active seafloor spreading in some marginal and back-arc basins formed the basis for the hypothesis that their geodynamic evolution and lithosphere thermal structure are similar to oceanic plates. Since the 1980s, it was argued that the heat flow with age in back-arc basins, including the Tyrrhenian Sea, followed the same relation for the oceanic lithosphere created at midocean ridges. It was also argued that the seafloor depth increases with age but differently to major oceans a subsidence excess of about 1 km was generally observed in back-arc basins. In the Tyrrhenian Sea, determining the conductive heat flow has been particularly challenging due to buried, high-conductivity salt structures and localized hydrothermal activity linked to the seafloor reliefs. Although the heat-flow data showed a large scatter, an increase from the Magnaghi–Vavilov Basin towards the younger Marsili Basin was generally recognised. This paper reviews the whole heat-flow database of the Tyrrhenian Sea. We critically assess the thermal measurements and correct heat-flow data for sedimentation and climatic changes to infer the purely conductive terrestrial heat flow. Finally, we discuss the thermal pattern and the seafloor depth compared to the modern oceanic cooling models obtained from the analysis of global heat flow and bathymetry data from oceanic, marginal and back-arc basins.

Geological modelling and CO_2 flow simulation: an integrated approach for basin scale storage in a saline aquifer

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Keywords: geological CO_2 storage, regional flow simulation, saline aquifer.

Theoretical studies and successful industrial projects have emphasise the significant role played by Carbon Capture and Storage (CCS) in tackling global climate change; however, such projects have mainly been limited to field-scale operations (e.g. Eiken et al., 2011).

The regional saline aquifer of the Triassic Bunter Sandstone Formation (BSF) in the UK Southern North Sea has been identified as a promising area for multiple large-scale CCS activities (Noy et al., 2012; Williams et al., 2013). Understanding the fate of the CO_2 plume during and after injection in such a large interconnected system (extending to about 9000 km2) is crucial for both risk assessment and regulatory compliance, and is also relevant should there be the economic opportunity to increase storage capacity (Patruno et al., 2024).

A comprehensive study has been conducted to analyse features that could impact the overall storage, such as plume migration, seabed connectivity of the reservoir, and petrophysical heterogeneities. Composite and wireline logs, core measurements, and 2D and 3D seismic data were analysed, interpreted, and converted to the depth domain, to create the reference geological models subsequently used to generate various flow scenarios using reservoir simulation. Injection of 1 Mt/yr/well for 50 years via 14 injection wells distributed throughout the BSF has been simulated. Results indicate that plume migration may continue for centuries after Cessation of Injection (CoI) and that existing pressure gradients affect its evolution. Poro-perm heterogeneities enhance the residual trapping mechanism by allowing plume spreading beneath low permeability baffles imposed by low local Kv/Kh ratios. During the injection phase, the plumes are mainly driven by viscous forces and exhibit a circular spreading pattern around the wells. After CoI, the plumes are displaced by gravity forces and tend to migrate following the shape of the top reservoir structure. However, differing migration paths have been observed by varying model boundary conditions. In the open scenario (i.e. with flow connection at the reservoir seabed outcrop), a persistent viscous gradient between surrounding traps and the reservoir outcrop displaces the CO_2 plume toward the outcrop; this effect is also observable to a lesser extent in faraway closures. Conversely, in the closed boundary case there is a reduction in plume migration across the whole model, allowing traps to be completely filled. This investigation underlines the complex interactions between geological settings and heterogeneities, boundary conditions and pressure connectivity, hydrogeological fluxes, and force dynamics. This understanding is crucial not only during the expected operational timeframe but also on a long-term scale during carbon storage in large-scale saline aquifers. Understanding the impact of long-term plume migration will lead to new approaches in optimising geological carbon storage at the basin scale.

Eiken O. et al. (2011) - Lessons learned from 14 years of CCS operations: Sleipner, In Salah and Snøhvit. Energy Procedia, 4, 5541-5548, https://doi.org/10. 1016/j.egypro.2011.02.541.

Noy D.J. et al. (2012) - Modelling large-scale carbon dioxide injection into the Bunter Sandstone in the UK Southern North Sea. International Journal of Greenhouse Gas Control, 9, 220-233, https://doi.org/10.1016/j.ijggc.2012.03.011.

Patruno S. et al. (2024) - A Conceptual CO_2 Fill-and-Spill Mega-Fairway in the UK Southern North Sea: A New Approach to Identify and Optimise Large-Scale Underground Carbon Storage (CCS). International Journal of Greenhouse Gas Control, **133**, https://doi.org/10.1016/j.ijggc.2024.104092.

Williams J.D.O. et al. (2013) - Modelling carbon dioxide storage within closed structures in the UK Bunter Sandstone Formation. International Journal of Greenhouse Gas Control, 18, 38-50, https://doi.org/10.1016/j.ijggc.2013.06.015.

Carbon sequestration potential of abandoned fractured reservoirs in Northwest Zagros, Iran

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Keywords: carbon sequestration, carbonate reservoir, Zagros.

Achieving NetZero by 2050 will be possible if contributors to CO_2 emissions take action. In this context, providing an atlas of CO_2 storage in countries that contribute to carbon dioxide emissions is necessary. Evaluating the potential of reservoirs in the Zagros area, a main foreland basin hosting oil and gas and consequently contributing to CO_2 emissions, could be a significant step toward creating a database for future storage plans. Specifically, the presence of carbonate reservoirs in various geological provinces worldwide necessitates their evaluation.

In this study, we conducted an in-depth analysis of the potential of a Late Cretaceous carbonate reservoir situated in the Lurestan area in Iran by formulating the geological model of the Ilam Formation (top of the Bangestan Group). Our target formation for storage is the Bangestan Group, mainly comprised of the Ilam and Sarvak formations, separated by the Surgah Formation in the middle. The study area covers approximately 52 km by 45 km and is located in the northeastern part of Lurestan. For further analysis in the site characterization process, we focus on the Ilam reservoir within the specific structure in the studied area.

The first step in constructing the geological model involved seismic interpretation, utilizing data from well logs and existing geological maps of the area. The target formation is predominantly limestone, with dolomitic limestone present at the top of the reservoir, as determined by interpretation of sonic, Gamma, and Neutron logs. Another reason for considering this structure for carbon sequestration is the presence of a thick layer of the Gurpi Formation serving as a caprock. Composed mainly of marls from the Campanian to Maastrichtian age, this caprock varies in thickness from 900 to 1100 meters and increases from southeast to northwest, providing a barrier for CO_2 migration.

Since[PS1] our structure is laterally bounded by two reverse faults, we formulated two different geological models for this site. Firstly, we considered ‘safe storage,’ focusing only on the top of the reservoir as the exploitable part. Secondly, we considered the volume of the reservoir bounded by these faults. The base case model has dimensions of 48 km × 7 km × 300 m and was discretized into 220×126×15 cells. We present a detailed outline of static estimation, utilizing the proposed equation of USDOE for the Ilam reservoir, followed by the Monte Carlo simulation method to generate multiple realizations of the reservoir performance by randomly sampling input parameters according to their probability distributions.

Carbonate reservoirs, such as the Ilam Formation, are well-known for their consistently low porosity levels. In our reservoir, this characteristic is confirmed by forecasted porosity values, indicating a maximum porosity of 15%. Natural fractures likely play a significant role in the tight carbonate effective permeability due to their low matrix porosity/permeability. Therefore, in this study, Electromagnetic Imaging (EMI) data were utilized to construct a stochastic discrete fracture network (DFN) using Petrel. Subsequently, we upscaled the DFN using the Oda method to assign grid porosity/permeability values to the model.

National energy policy: a focus on georesources targets at 2050

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Keywords: natural gas production, CCS, hydrogen.

International energy policies, such as Paris Agreement (COP 21) and Regulation (EU) 2021/1119, already integrated into the national regulatory framework, boost decarbonization efforts through energy transition with the aim to achieving climate neutrality by 2050.

The targets of the national energy policy are described in the Integrated National Energy and Climate Plan - NECP (art.14 Regulation (EU) 2018/1999) updated on 2023 (PNIEC_2023.pdf (mase.gov.it).

Therefore, Italy is equipping itself with various planning tools to enhance environmental sustainability, safety and energy costs accessibility, while promoting a just transition.

Among these initiatives, transition to renewables is fundamental and passes through the central role of natural gas, while encouraging a new development of the geothermal sector, the possible exploitation of solid minerals in the sea, with particular reference to critical minerals, considering the Regulation (EU) 2024/1252 establishing a framework for ensuring a secure and sustainable supply of critical raw materials, and adoption of new technologies such as, for example, CO_2 capture and storage as well as the promotion of hydrogen as an energy carrier.

An example of an innovative project is the experimental CO_2 storage program in Porto Corsini field. The project, approved by Ministerial Decree of 26th of January 2023, aims to initially store 1 Mt of CO_2 starting from 2024, with plans to scale up to 50 Mt by 2050, potentially making the field as a possible CO_2 storage hub in the Mediterranean level (proposal relating to the PCI project).

In recent years, numerous provisions have been issued to maintain and optimize natural gas production and storage, such as the approval of the so-called Energy Decree, as a tool for revitalizing the sector.

In the geothermal sector, reference is made to the forecasts of the Ministerial Decree of 30th September 2022 which describes the methods for installing closed-circuit geothermal probes, providing simplified authorization procedures to speed up the administrative process, where possible.

For all the different sectors mentioned, the maintenance of high safety standards is fundamental, which is guaranteed at a national level also through specific and advanced integrated monitoring techniques (e.g. Dialuce et al., 2014). In particular, to face up to the growing technical specialization of the sector, scientific partnerships have been carried out with highly qualified research bodies, universities, and government institutions in order to address the main scientific open questions in the context of safety with the energy industy (e.g. Antoncecchi et al., 2023).

Antoncecchi I. et al. (2023) - Buone Pratiche per lo studio della potenziale interazione tra attività produttive in una piattaforma offshore e sorgenti sismogeniche e tsunamigeniche (quali faglie e frane) presenti nelle vicinanze, nonché degli impatti e delle perdite causate da una loro eventuale attività. ISBN: 9788894366914.

Dialuce G. et al. (2014) - Indirizzi e linee guida per il monitoraggio della sismicità, delle deformazioni del suolo e delle pressioni di poro nell'ambito delle attività antropiche. 38 pp. Published on line on 24th november 2014 at the link: http://unmig.sviluppoeconomico.gov.it/unmig/agenda/dettaglionotizia.asp?id=238.

Enhancing the Italian geothermal data infrastructure: integrating geothermal data and potential assessment tools

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Keywords: geothermal database, underground data management, potential assessment.

Geothermal energy is a sustainable and renewable energy, offering significant potential in mitigating climate change and reducing dependence on fossil fuels. Identifying geothermal resources involves the acquisition, processing and analysis of a large quantity of data. Geothopica1, the Italian Geothermal Data Infrastructure (https://geothopica.igg.cnr.it), through a web portal created in 2007 and renewed in 2023 by the Institute of Geosciences and Earth Resources of the National Research Council (CNR-IGG), provides a rich portfolio of geothermal information whose beating heart is represented by the updated National Geothermal Data Base (Banca Dati Nazionale Geotermici, BDNG) (Trumpy et al., 2017).

Geothopica, developed in compliance with national (RNDT 2.0) and international (INSPIRE) regulations, provides data, documents and web services (OGC) to guarantee access, interoperability and re-use of the available information. CNR-IGG maintains and upgrades the infrastructure, updating its contents thanks to different assessment projects. Recently, two main national geothermal projects coordinated by CNR, "VIGOR" and "ATLANTE Geotermico", gave the opportunity to update geothermal information for nine regions in central-southern Italy, however now CNR-IGG has enriched the database also in other regions. The new collected data were obtained by the boreholes masterlog made available by the VIDEPI2 project (funded by the Ministry of Economic development)(https://www.videpi.com), which provided data referred to Marche, Veneto, Friuli Venezia Giulia, Trentino Alto Adige regions and a few locations in the Po Plain. A second new dataset stems from historical data gathered during the geothermal exploration that took place in the 1990s in Larderello and Monte Amiata: about 50 folders with paper documents related to geothermal wells were analysed, and digitalized. The collected data include stratigraphic logs, chemical analyses of geothermal fluids and gases, drilling mud density and temperature data. For some wells, drilling reports were also attached to the boreholes when available.

Geothopica has also been empowered with a web application for computing the geothermal potential in an area of interest. This tool, called ThermoGIS, uses the volume method and geological reservoir information as input to elaborate maps of geothermal potential suitable for several applications, including power generation, district heating, district heating and cooling. The ThermoGIS code was initially developed by the Dutch Geological Survey (TNO) (Van Wees et al., 2013) and then adapted to the Italian geothermal conditions in a collaboration between CNR and TNO.

GeoThopica, the largest and most comprehensive repository of geothermal data in Italy, is useful not only for research and development in the geothermal energy sector but also for thermal and CO_2 storage projects or for the exploration of economically strategic minerals (e.g. lithium, rare earths) favouring the energy transition.

Trumpy E. & Manzella A. (2017) - Geothopica and the interactive analysis and visualization of the updated Italian National Geothermal Database. International journal of applied earth observation and geoinformation, 54, 28-37.

Van Wees J.D. et al. (2013) - A Methodology for Resource assessment and application to core countries. Geothermal Electricity (GEOELEC): Brussels, Belgium, 1995-2013.

Evolution of hydromechanical coupling from quartz to shale rich faults and implications for fault parallel vs. fault perpendicular permeability

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Keywords: permeability, CO_2 storage, friction.

Underground CO_2 storage involves injecting fluids into a reservoir aquifer, leading to artificial changes in the subsurface stress field. The implications for fault-seal and caprock integrity need to be understood to establish safe operational pressures and monitoring / mitigation procedures in case of leakages along faults and induced seismicity during fluid-assisted fault reactivation. For faults cutting across sedimentary rocks, clay concentration into the fault core can significantly alter the fault frictional properties and reduce or create strong anisotropy in permeability. Here we show that the increase in shale content within a quartz-rich experimental fault promotes a fabric evolution from a load-bearing granular framework to an interconnected foliated and clay-rich network causing a significant reduction in strength, enhanced frictional stability, and a marked decrease in permeability. Fault stability is favored by fault dilation associated to a reduction in pore fluid pressure within the low permeability, clay-rich faults. For a shale content > 30% we also observe that the permeability parallel to the foliated fault fabric is 1.5-2 order of magnitude higher than permeability parallel to the foliation. Our data suggest that while the enhanced stability within pressurized clay-rich faults matches well with observations of aseismic slip during hydraulic stimulations of shales, the documented increase of permeability in the fault parallel direction demands a more comprehensive characterization to better predict possible up-fault leakage during CO_2 injection for storage.

A potential site to store Hydrogen in the subsurface in Northeast Italy

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Keywords: energy transition, hydrogen, underground hydrogen storage.

The ongoing transition to a low-carbon economy is pushing the development of renewable energy sources. These latter, however, are characterized by intermittent energy production that causes energy excesses or deficits, thus requiring long-term storage, which poses significant challenges. Increasing emphasis has recently been put on hydrogen as an energy carrier, and Underground Hydrogen Storage (UHS) has emerged as one of the most promising storage solutions.

Preliminary analysis of potential UHS in northeast Italy (Mattera et al., 2023) identified a perspective reservoir-and-caprock system in the Miocene Cavanella Formation (reservoir) and Marne di San Donà Formation (caprock) in the subsurface of the Treviso area.

We used well and seismic data on the Cavanella and Marne di San Donà formations to reconstruct a three-dimensional static model of a buried anticline (Arcade Nervesa anticline) that represents a well-promising structural trap. Then, we computed the volume of the reservoir, to verify its potential as a storage site. The structural trap has a volume of around 1 billion cubic meters, and the reservoir is around 200-300 million cubic meters.

The feasibility of hydrogen storage in this site is then evaluated by computing a storage feasibility index, assigned through a dedicated scoring matrix based on the characteristics that literature identifies as required for hydrogen storage. Results suggest that the Arcade Nervesa anticline area could be considered a potential UHS site

Sealing potential of the messiniaN SALT from IODP Expedition 402

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Keywords: physical properties, Messinian salt, Tyrrhenian.

During the International Ocean Discovery Program Expedition 402, which took place from February to April 2024 in the Tyrrhenian Sea, six deep sites were drilled along two orthogonal transects. The expedition targeted the transition between the continental crust of Cornaglia and Campania terraces and the oceanic domain of the Vavilov Basin. Two of these sites are located on the conjugate margins of the basin, two terraces, where the Messinian Salinity Crisis (MSC) deposits are present. The drilling at sites U1613 and U1617, located at the Cornaglia and Campania terraces respectively, allowed us to recover the evaporitic sequence from gypsum-enriched terrigenous sediments through anhydrite to halite layer. We performed a series of physical property measurements of the recovered cores on board of the JOIDES Resolution drillship that included P-wave velocity, density, magnetic susceptibility, and natural gamma ray. In addition, we analyzed representative discrete samples to measure the P-wave velocity measurements in different directions, as well as bulk density, grain density and porosity. These physical properties allowed us to define with high accuracy the sealing properties of sediments deposited during the MSC. In fact, MSC deposits become the best seal for gas or oil when halite which has zero porosity is present. This capacity can be modified by salt tectonics, typical of these sediments, which decreases the thickness of the salt layers and impacts their lateral continuity by introducing a secondary porosity represented by faults and fractures. Thanks to the great opportunity offered by the IODP program Exp. 402, the physical properties of the entire MSC sequence will be analyzed in detail and correlated with seismic and sedimentological data.

Linking an outcrop analogue to a deep potential CO_2 storage site with 3D geological model: an example from southwestern Sicily

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Keywords: carbon capture and storage, outcrop analogue, seismostratigraphy.

The southern Sicilian sector is notoriously rich in geological traps explored since ’70 by oil and gas companies. Taking also into account the presence of numerous industrial emitters in the near Gela, this area is configured as potentially suitable for CCS (Carbon Capture and Storage) projects.In the area near Sciacca thick carbonate successions outcrop and it is characterized by a sequence of shallow water limestone covered by condensed pelagic limestones, all Jurassic in time. Seismostratigraphic, structural and sedimentological analysis carried out in the Sciacca area through 2D seismic reflection profiles and borehole data collected from public databases, confirmed the presence of potential reservoir and seal for CO_2 storage in correspondence of the Jurassic carbonates. The reservoir is represented by the Lower Jurassic peritidal limestones belonging to the Inici Formation consisting of grainstone-packstone with bivalves and benthic foraminifera with primary porosity. Analysis of facies and terrain analogs identified also a high secondary porosity in the upper part of the Inici Formation due to the fracturing, dolomitization, and paleokarstic processes. The seal is, instead, represented by the Middle-Upper Jurassic condensed pelagic deposits referable to the Buccheri Fm. known as Rosso Ammonitico. These condensed pelagic deposits consist of mudstone-wackestone with ammonites showing low porosity, due to the fine grain texture. The new collected data confirmed that in the area the outermost deformed portion of the western Sicilian chain outcrops composed of a double verging compressional structure delimited by NNE-SSW-trending left-lateral transpressive faults. In the offshore sector the seismic profiles interpretation highlighted the presence of a NE-SW-oriented ramp-anticline, bounded by high-angle deformation with transpressive kinematics. By combining seismostratigraphic and structural results with those derived from geological survey and samples analysis, we generated a 3D geological model defining thickness, lateral extension and fault boundaries (with their leakage potential) for reservoir and seal. This interpretation of the regional structure suggests a potential structural traps within buried antiformal stacks. This study, therefore, presents new data at the regional scale regarding the presence of reservoirs and seals (both onshore and offshore) potentially suitable for CCS purposes. By retrieving the parameters defined by the European Geocapacity Project, the CO_2 storage suitability for the area investigated has been estimated.

Caprock genesis in hydrothermal systems via alteration-controlled fault weakening and impermeabilization

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Keywords: hydrothermal systems, caprock, permeability, friction.

The mechanical and hydraulic behavior of faults in geothermal systems is strongly impacted by circulation of aggressive fluids. This, in turn, affects our ability to model the properties of subsurface structures in both reservoirs and caprocks to assess reservoir behavior and potential hazard during geothermal exploitation. However, the effect of alteration on the mechanical properties of faults in geothermal systems is severely under documented. To fill this gap, we studied the rocks from the caprock of a fossil hydrothermal system in the Apennines, developed in acid volcanic effusive rocks during the Upper Pliocene extensional stage and associated magmatism. We combined field structural observations, XRD analyses, friction experiments, and permeability tests. We document fault weakening induced by the combined effect of mechanical comminution and hydrolytic alteration resulting to strong enrichment in clay minerals (70-80 wt%) along fault cores. Argillic rocks (kaolinite-alunite-quartz-rich), are much weaker (friction coefficient $0.26 < \mu < 0.45$) than the unaltered protolith (trachyte $\mu = 0.55$), favoring strain localization. The enrichment of clays along fault cores induces a local decrease in permeability of three orders of magnitude respect the protolith, promoting an evolution of fault behavior from initial conduit into barrier. The efficiency of this process is demonstrated by the cyclic development of fluid overpressure in the altered volcanic rocks, as highlighted by distinct explosive breccias and hydrofracture networks. Permeability barriers also enhance the lateral flow of hydrothermal fluids, promoting the lateral growth of the caprock. As highlighted by the velocity-strengthening frictional behavior of the studied rocks, hydrolytic alteration promotes stable slip of faults with crucial consequences on the evaluation of the risk of induced seismicity during the exploitation of geothermal reservoirs.

Alteration-controlled repeated breakage of hydrothermally altered marly-limestones seals, Fenice-Capanne mining area (Tuscany, Italy)

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Keywords: hydrothermal alteration, fluid-rock interaction, caprock; fluid inclusions.

Hydrothermal alteration may promote formation of efficient caprocks above reservoirs, limiting the upward movements of hot convective fluxes and thus granting, below it, the high-pressure and -temperature conditions required for exploitation of the geothermal energy. Characterization of the secondary (structurally-controlled) evolution of caprocks is thus crucial to evaluate their seal efficiency. The hydrothermally altered marly-limestones of Ligurian affinity exposed in the Neogene mining area of Fenice-Capanne in the hinterland of the Northern Apennine chain provide an exhumed analogue of the caprocks sealing the geothermal systems of the Tuscan Latium region. In this regard, our study is aimed at assessing the paleo-thermal and paleo-hydraulic conductivity properties of the Ligurian caprocks through an integrated approach that combined field, mineralogical and geochemical studies with fluid inclusion analysis (i.e., microthermometry, micro-Raman and analysis of noble gases). The increase in volume (up to 98%) due to massive silicification of marly limestones favored the initial embrittlement of the calcsilicates-rich rocks, enhancing circulation of hydrothermal fluids along a complex pattern of faults and fractures. Repeated injections of hot hydrothermal fluids (T = 180°C -350°C) caused element remobilization and vein sealing reducing secondary permeability. Cycles of breakage and sealing of the cap rocks are documented by textural relationship between calcium-pyroxenes (solid solution between diopside and hedenbergite), Fe-actinolite, epidotes, sulphides (e.g., pyrite, chalcopyrite, covellite), sulphates and Fe-oxides, which are mutually substituting each other. We interpret this alteration pattern as evidence of cyclic reducing and oxidizing conditions in the system.

Why it is important to perform a fully integrated basin-scale modeling of CO_2 storage in saline aquifers? Insights from the Paris Basin (France)

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Keywords: geological storage, basin modelling, energy transition.

Successful CO_2 storage in deep saline aquifers rely on functional 3D numerical models of the storage complex with the real geometry and conditions. Most of the research performed in recent years on CO_2 storage has focused on a reservoir scale, with the aim to put more light on the migration and trapping of CO_2 in storage formations, and on potential leakage into shallow aquifers. However, much less effort has been put on studying transport and migration of CO_2 at a scale of sedimentary basins and on the impact of CO_2 injection on the geomechanical properties of the target reservoir and its caprock. Nevertheless, basin-scale phenomena may become particularly important when we are dealing with large-scale objects like saline aquifers. O&G industry has a large experience on 3D basin modelling techniques. Basin models are widely used in exploration and development to simulate the history of sedimentary basins through time.

In this context, the question that has driven our work was: how can we use traditional 3D Basin modeling techniques to help assess current and future carbon storage sites? Having in mind this, we developed an efficient workflow for constructing an accurate geological basin model for the evaluation of CO_2 storage capacity and simulate the injection of CO_2 and its long-term effects on the pressure field.

This study presents an efficient workflow for constructing an accurate geological basin model for the evaluation of CO_2 storage capacity in saline aquifers. This workflow has been developed in the general framework of a jointed IFPEN-TotalEnergies collaboration on a CCUS project focused in the Paris Basin (France). The Paris Basin is one of the most mature areas in the Western Europe in terms of the oil and gas exploration, with approximately 100 producing oil fields and more than 850 exploration wells, which can be used nowadays for other disciplines such as CO_2 storage. For this reason, we selected the Paris Basin as an ideal case study, the aim being not to use it to inject CO_2, but rather to test and validate our approach.

Our multidisciplinary and integrated workflow covers three main steps. Firstly, we built a 3D basin model simulating the evolution of the Paris Basin through time, by integrating diverse geological, geochemical and reservoir engineering data. The 3D basin model was then coupled with a comprehensive 4D forward stratigraphic model, which gives greater insight into the facies architecture and the distribution of potential reservoir rocks of the Bathonian reservoir through geological time. Finally, we performed an advanced 3D geomechanical analysis in the model, that allowed us to simulate the present-day distribution of fundamental basin parameters such as 3D stress tensor, porosity, pore-pressure and temperature. The resulting 3D basin model was then used for reservoir modelling purposes, and as input to model the injection of CO_2 and its long-term effects on the pressure field.

CMS@INGV: An operational monitoring center for risk mitigation related to anthropic underground operations in italy

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Keywords: induced seismicity and subsidence, geophysical monitoring.

In 2014 the Italian Ministry of Economic Development issued the guidelines (*Indirizzi e Linee Guida*, ILG) outlining procedures, responsibilities, and roles for monitoring the effects of subsoil activities — focusing on gas storage, hydrocarbon extraction, wastewater injection and geothermal energy production. The need had arisen to respond to public concern regarding the potential effects of underground anthropic activities on earthquake occurrence, ground deformation, and related phenomena. The guidelines define standards for monitoring microseismicity, ground deformation,and pore pressure, and provide guidance on implementing a 4-level traffic light (TL) protocol as a decision support tool for managing possibly induced seismicity. The TL system uses monitoring information such as location, magnitude, and peak ground motion of recorded seismicity, and it is used to take decisions if seismicity is recorded within the monitoring domains. It may be worth noting that it is automatically applied exclusively for wastewater injection. Following the introduction of this regulatory framework, in 2017 the Italian *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) established the Center for the Monitoring of Subsurface Activities (CMS, http://cms.ingv.it/), entirely devoted to collecting and analyzing data associated with exploitation of georesources. In this contribution we present the structure and operational principles of the CMS, its IT architecture, and the organization of the monitoring procedures. We also present the ongoing monitoring projects, that include (1) The two Italian high-enthalpy geothermal power plants (Larderello-Travale and Monte Amiata); (2) Europe's largest onshore oilfield, in Southern Italy; (3) A gas production plant in the Po-plain; and (4) Italy's first off-shore Carbon Capture and Storage plant (Northern Adriatic Sea). These case studies are discussed with reference to the main pending challenges, which concern (i) the distinction between natural and triggered seismicity, that is particularly relevant in a tectonically-active country like Italy; (ii) the comprehensive estimate of uncertainties on parameters derived from monitoring; (iii) the unbiased assessment of background seismicity when exploitation activities are already operational; and (iv) the establishment of reliable and physics-based thresholds for defining the transition between alert levels.

Stochastic and thermophysical modelling for geothermal resource assessment: the case of the Po Basin

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Keywords: stochastic modelling, transient thermal modelling, geothermal resources.

Few studies have explored the geothermal potential of the Po Basin. This work aims to contribute to the knowledge of the thermal state of the western sector of the basin. A new thermal database was compiled, and the underground thermal structure was modelled to identify areas with potential geothermal resources. Initially, available thermal data from various sources were collected and new data were added. The data included bottom hole temperatures (BHT), temperatures from drill stem tests (DST) and thermophysical properties measured in the laboratory on cores extracted from wells. The temperature data were interpolated with an original algorithm to obtain a 3D stochastic distribution model, temperature maps at different depths and the 2D thermal field along selected geological cross-sections with strata mainly characterized by a homoclinal structure. Subsequently, temperature-depth profiles and the basal heat flow were calculated employing transient 1D geothermal models for the deeper boreholes located along the cross-sections. The 1D models were based not only on BHTs and DSTs but also on the measured thermophysical properties. A sensitivity analysis indicates that thermal conductivity and porosity mostly control the modelling results. The 1D thermal calculations and the temperatures inferred from the stochastic model are in good agreement in the 1000-5000 m depth range. Thus, in the case of a relatively simple structural setting, as it occurs for the selected cross-sections, the stochastic model can provide a reliable picture of subsurface temperature distribution, since thermal refraction effects are likely negligible. The geothermal gradient inferred from the stochastic model between 1000 and 5000 m varies from 20 to 27 mK/m. The geothermal gradient calculated with the 1D thermal models confirms such values (21-26 mK/m) and the basal heat flow ranges from 55 to 64 mW/m^2. The stochastic modelling highlights that the highest geothermal potential occurs W of Milan with the highest temperatures (about 180°C) at about 6 km depth.

A mineralogical and geochemical approach to evaluate the redox capacity of basaltic glass and crystals via experiments

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Keywords: water-rock interaction, CCS, supercritical CO_2.

The levels of greenhouse gases, particularly CO_2, rise globally. To tackle this problem, scientists and engineers have been exploring carbon capture and storage (CCS) technology to reduce CO_2 concentrations in the atmosphere. Mineral carbonation is a promising CCS technique that involves CO2 reacting with Ca-Mg-Fe bearing basaltic rocks to store it in the rocks as carbonate minerals. The CarbFix project in Iceland is an excellent demonstration of this approach. However, much remains to be discovered about the intricate physicochemical connections between water, dissolved ions, and crystal growth in complex multicomponent systems at the atomic and nanoscale. These factors are vital for the successful deployment of CCS in basaltic reservoirs.

This research explores the use of supercritical CO_2, which is achieved by exceeding the critical temperature and pressure of 30.97°C and 73.773 bar, respectively. In this state, CO_2 exhibits the properties of both a gas and a liquid. The study presents the results of an experiment conducted on basaltic crystals and glasses under varying temperatures (between 100 and 200ºC) and pressures (64 to 79 bar) to investigate the reaction between CO_2 (sc), water, crystals (mainly forsterite) and basaltic glass. The results highlight the partial dissolution of mineralogical phases and the formation of new alteration phases, in addition to the precipitation of carbonates containing Ca, Mg, and Fe. Furthermore, the composition of the post-reaction gases will be analyzed to evaluate the redox conditions occurring in water-CO_2-basaltic glass and water-CO_2-basaltic crystal reactions.

Development of a site-screening method for hydrogen storage purposes and its application to an industrial dataset of Italian reservoirs

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Keywords: underground hydrogen storage (UHS), site-screening method, multi-criteria decision-making (MCDM).

The use of hydrogen as an energy carrier will require effective storage solutions, and depleted hydrocarbon reservoirs offer a safer and cheaper large-scale option compared to other possibilities. The selection of a site for underground hydrogen storage (UHS) entails considerable responsibilities and expenses, and specific tools should be employed to facilitate and optimize the decision process. Thus, a site-screening method was developed to rank depleted and almost depleted hydrocarbon reservoirs for UHS, with subsequent testing on a confidential dataset of 48 production sites from Italy provided by Eni. A set of 27 screening parameters was selected from a wider dataset and a weight for each one was defined by reproducing the Analytic Hierarchy Process (AHP) (Saaty, 1987, 2008) and gathering expert judgements from both academic and industry following the Delphi technique (Dalkey & Helmer, 1963; Hsu & Sandford, 2007). This was performed from the points of view of HSE (health, safety, and environment), geotechnical performance (GP) and economic performance (EP), dividing the individual parameters among these three supergroups and normalizing the diverse kinds of dataset records to be used in the calculation procedure. The method resulted in three preliminary rankings based on the sites' HSE, GP and EP scores and a comprehensive ranking obtained through the aggregation of these three scores for each site, with penalties applied if specific, adverse features exist for UHS purposes. For sites with incomplete data, an estimation of the potential score was derived based on average values calculated from the dataset and attached as additional information to the screening scores without affecting the ranking. The AHP results highlighted a major role for Faulting Description, Mineralization Type, Onshore/Offshore, Wells Number, Reservoir Architecture, Datum Depth and Initial Pressure at Datum, even though other factors made significant contributions. The result consists of a set of scores ranging from 29 to 72 out of 100. To assess the reliability of the method, two blind tests were conducted on a minor proprietary dataset containing well-known sites from North Africa, the first involving a subset of the sites and the second using all sites. The results yielded a good match with the existing ranking performed by Eni. The developed method can be adjusted for a variety of decision-making scenarios, to accommodate changes in the screening purposes or advancements in research. In this configuration, it consists of a highly effective tool for an objective and transparent screening of sites for UHS purposes.

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Seismic and geodetic monitoring of two underground gas storages in Northern Italy

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Keywords: UGS, Collalto seismic network, Cornegliano Laudense seismic network.

Underground gas storage - UGS is a facility strategically designed to follow the fluctuations in supply and demand of methane gas, by storing it in the summer when demand and price are low, and withdrawing it in the winter when demand is high. UGS is also among the human activities that produce ground deformation in response to the stress changes around the reservoir when the gas is injected or extracted, therefore it can trigger seismicity.

OGS is responsible for the monitoring of two UGS plants in northern Italy, namely Collalto Stoccaggio and Cornegliano Stoccaggio, both of which are operated without exceeding the original reservoir pressure.

The Collalto UGS has been in operation since 1994 and has been monitored by the Collalto Seismic Network – RSC (Priolo et al., 2015) since 2012. This network consists of 10 boreholes seismic stations installed near the reservoir and a GNSS station installed directly above it. The data collected by the RSC is integrated with seismological and geodetic data from other stations existing in the area, the former to distinguish between local and regional events and to constrain earthquake locations, the latter to compare local deformation rates with those of the surrounding area. In about 12 years, the RSC seismic catalog has recorded >3,500 earthquakes (-0.9 The Cornegliano UGS has been operational since 12/12/2018, but has been monitored by the Cornegliano Laudense Seismic Network – RSCL (Priolo et al., 2019) since 1/1/2017, 2 years before the start of storage operations. We have opted for such a monitoring strategy because the company managing the UGS has chosen to follow the Ministerial Guidelines for the monitoring of underground industrial activities (MiSE, 2014), which recommend the measurement of background levels of seismicity and ground deformation as references to show the impact of human activities. The RSCL was designed according to the same criteria as the RSC (10 seismic stations, 1 GNSS station, seismological and geodetic data integrated with those of other stations), but unlike the RSC, ground deformation is also monitored by satellite radar interferometry. After 7 years, the RSCL seismic catalog contains 33 events (0.7

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Syn-tectonic emplacement of late-magmatic granitic dyke swarms in the Capo Focardo area (Exhumed geothermal system of eastern Elba island, Italy)

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Keywords: geothermal, syn-tectonic, granitic.

Elba Island is in the northern Tyrrhenian Sea and represents a crustal section of the inner zone of the northern Apennines exhumed during the Miocene extensional tectonics that opened the Tyrrhenian Basin. The island hosts two magmatic complexes, mainly represented by monzogranite intrusions and related sills and dikes swarms, exposed on the western and eastern sides of the island: the Monte Capanne (8.5-6.9 Ma) and Porto Azzurro (6.4-5.9 Ma) plutonic complexes, respectively. For this reason, Elba represents a natural laboratory for investigating the relationships between structures related to extensional tectonics and the emplacement of magmatic bodies. This presentation deals with the structural setting of an area east of Monte Calamita, where the Porto Azzurro monzogranite metamorphic aureole formed by micaschists and quartzites, it is widely exposed. It is also intruded by peraluminous leucogranite dykes dated at 6.2 Ma and veins, both showing strike roughly N-S and dip steeply to the east. After emplacement, the dykes were deformed by top-to-east HT shear zones associated with low-angle normal faults. The deformation occurred during the cooling of the magmatic system, as indicated by a ultramilonite texture, which is overlain by ultracataclastic domains testifying the change in the rheological behavior of the fault zones. This deformation occurred in the footwall of the regional normal fault known as the Zuccale Fault. Preliminary fluid inclusion analyses carried out in quartz from veins and leucogranite dykes highlighted homogenization temperatures spanning from 250 to 350°C with high salinity values. To conclude, the study area contributes to a better understanding of tectonic vs. magmatism in the inner Northern Apennines, and on a wider scale to improve our knowledge on the strict connection between faulting and dyke intrusion and cooling in upper crust domains.

Potential sources of Li-rich fluids in Northern Apennines (Italy): first results on lithium distribution in pelitic rocks

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Keywords: lithium enrichment, unconventional resource, isotope geochemistry.

Global lithium demand related to the ongoing energy transition has grown exponentially in the last decade and is estimated to increase up to 20-folds by 2050 (Xu et al., 2020). Production from conventional deposits, as well as recycling, need to be increased and development of new unconventional resources considered. Conventional deposits (e.g., pegmatites, salars) are not represented in Italy, while some promising sources of lithium have been identified in low-enthalpy Li-rich fluids (up to 370 mg/L) issued from sedimentary sequences along the Apennine compressional front (Dini et al., 2022). The high concentration of lithium in these waters (up to 164 mg/L in Salsomaggiore Terme area; Boschetti et al., 2011) is possibly controlled either by fluids expelled by sediments during diagenesis or by later water-rock interactions. The advantage of Li-rich fluids is represented by the possibility to exploit lithium using Direct Lithium Extraction techniques (Li et al., 2019). Despite the high scientific and economic potential, the knowledge on these systems in terms of chemical and isotopic data and genetic processes is limited. This study is part of a PhD project funded by ITINERIS (Italian Integrated Environmental Research Infrastructures System project) and aims to fill this data shortage to understand the source(s) and processes controlling the lithium occurrence, both in rocks and fluids. For this purpose, an extensive sampling of the main sedimentary formations of the Apennine chain in Emilia Romagna region has been conducted, with particular interest for argillite-clay sequences. Mud from sedimentary volcanoes, widespread along the Apennine margin, has also been sampled as representative material of the deep sedimentary formations and waters. Samples have been characterized for major and trace elements. Lithium concentration ranges from 13 to 194 mg/kg, with the higher values observed in argillites and clayey formations. Boron and strontium isotope ratios (as δ11B and 87Sr/86Sr) have been also determined for the most Li-enriched samples. XRD analyses have provided the main mineralogical composition and SEM-EDS imaging and chemical maps have been used to unravel mineralogical-chemical zonation. Zoned samples have been further investigated with LA-ICP-MS to quantitatively trace lithium variability and identify the most enriched mineral phases. A leaching experiment, conducted with different solutions (deionised water, NaCl, CaCl2, HCl), has been also done to quantify the release of Li from rocks over time. To trace the water-rock interaction a lithium isotopes analytical procedure and purification method have been developed for MC-ICP-MS in Neptune-TIMS lab at IGG-CNR. The data on rock and sediment samples will be integrated with analogous chemical and isotopic data from the ongoing water sampling to develop a conceptual model of lithium cycle and enrichment processes in this complex geological context. These findings could provide the basis for a sustainable lithium resource exploitation in the Northern Apennines and in other similar environments, supporting the targets that EU sets with the Critical Raw Materials Act (CRMA 2023).

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Inverse modelling for estimating gas flow emission rate on stationary vents

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Keywords: inverse modelling, shallow hydrothermal vent, passive hydroacoustics.

Submarine hydrothermal systems emit huge amounts of both elements and energy, in terms of gas, thermal water and solid deposition. The interest of the scientific community on these extreme environment is increasing, especially in the last few years. Moreover, direct measurements can be challenging due to the extreme environmental conditions (e.g. high temperature, low pH) (Longo et al., 2021).

In this framework, passive hydroacoustics may represent a sustainable and safe method for both short- and long-term monitoring, since the typical source mechanisms present in the hydrothermal fields radiate sound pressure following different acoustic modes directly related to ascending fluids release (Dziak et al., 2012).

Here we present preliminary results obtained by applying a spectral method [Roche et al. 2022] for estimating the gas flow emission rate starting from the acoustic dataset collected on a stationary flux vent (Leifer, 2010) located at ~1.8 metres depth, inside the shallow hydrothermal field at Baia di Levante in Vulcano Island (Aeolian Islands, Italy).

To carry out the estimation of the gas volume emitted by the hydrothermal vent we implemented an inverse modelling algorithm based on the formulation of a forward model for the sound radiated by the bubbles plume, then the path is backward analysed to obtain an estimation of the flow emission rate.

High-resolution audio frames were recorded by using an autonomous smart hydrophone, able to collect and store digitised audio frames in the frequency band [1 - 12800] Hz.

The hydrophone was moored close to the investigated hydrothermal vents, collecting 4 bursts of ~10 hours each at the maximum sampling frequency, between 1 and 2 September 2022.

The collected dataset was preliminarily analysed by employing various techniques of both spectral and waveform analyses, in order to obtain a characterization of the source, thus defining the vent spectral signature. Power Spectral Density (PSD), Power Spectrum and Spectrogram show different persistent energetic frequency peaks which are compatible with the typical mechanisms connected to the dynamics of the hydrothermal field. Among these, the most energetic one is centred around a frequency of ~100 Hz.

Direct optical observations confirmed the presence of bubble radii up to 0.03 m, generating the main energetic peak at ~100 Hz, along with smaller bubbles producing less energetic peaks up to 2000 Hz. Therefore, the inversion algorithm was applied to the dataset, considering the frequency range from 60 to 2060 Hz.

The estimated flow emission rate, which assumes a mean value of 4.51 liters per minute, is in good agreement with the direct observations. This confirms that passive acoustic methods represent a valid and robust tool for both monitoring and research activity in submarine hydrothermal fields, providing to be also a long-lasting instrument for the sustainable management of georesources, as it can detect the fluctuations connected to such natural systems.

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Gorno and Piani Resinelli: genesis and correlations of two Alpine-type Pb-Zn districts

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Keywords: Gorno district, Alpine-type deposits.

The strata-bound, carbonate-hosted Pb-Zn-Ag (± fluorite ± baryte) districts of Gorno and Piani Resinelli belong to the Alpine metallogenic province located between Italy, Austria and Slovenia. The orebodies are hosted in the lower Carnian stratigraphic succession of the Lombardian Basin (Southalpine Domain, N Italy), mainly composed of peritidal limestones. The aim of this study is to constrain the ore-forming conditions using petrography, geochemistry, fluid inclusion microthermometry, and radiometric datings on both ore minerals and associated diagenetic products.

Petrographic studies reveal that the mineralization was preceded by dolomitization, silicification, and brecciation events. Thermometric data from primary fluid inclusions in dolomite, sphalerite, and fluorite indicate the involvement of moderately hot (T between 70 and 150 °C) and high-salinity fluids (up to ~20 wt % eq NaCl) during ore precipitation. Radiometric dating performed on associated diagenetic minerals which pre- and postdate the sulfide mineralization reveals that the precipitation of the ore minerals occurred during the LateTriassic. Moreover, *in situ* analyses (EPMA, LA-ICP-MS) of trace elements on sphalerite will be presented here, including their implications for ore-forming conditions.

Several similarities between Gorno and Piani Resinelli in terms of diagenetic evolution of the host rock, temperature and composition of the fluids, and timing of the ore precipitation highlight the possibility that both districts could be related to a unique, widespread Late Triassic hydrothermal system, in which metal-rich fluids flowed upward through faults and associated fractures. This circulation in the Upper Triassic stratigraphic succession caused major modifications in the host rocks such as multiphase dolomitization, silicification, dissolution, and brecciation, as well as the precipitation of ore minerals in a shallow burial setting.

Characterization of dual porosity in bioturbated carbonates: A case study of Cenomanian-Turonian platform carbonates from the Southern Apennines (Italy)

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Keywords: bioturbated carbonates, Thalassinoides, petrophysical analysis.

Bioturbated carbonate sequences present considerable challenges in characterizing reservoirs for hydrocarbon exploration and exploitation, and for CO_2 storage. Bioturbation strongly influences the petrophysical properties of hosting rocks, creating sedimentary heterogeneities and often enhancing porosity-permeability properties. This study focuses on a detailed investigation of Upper Cenomanian-Lower Turonian bioturbated carbonate succession (75m thick) from the Apennine Carbonate Platform (Southern Italy).

A multidisciplinary approach has been applied, integrating facies, ichnological, and petrophysical analyses using non-invasive techniques such as Computed Tomography scanning (CT, Micro-CT), and Nuclear Magnetic Resonance (NMR). The objective was to explore and characterize the abundance of burrows, their connections, and describe pore-size distribution. Furthermore, geochemical (trace elements), mineralogical, and petrographic analyses (Scanning Electron Microscopy) were integrated to understand the correlation between bioturbation, poro/perm characteristics, and diagenetic processes.

The investigated sequence displays a boxwork pattern of burrows organized with a preferential horizontal network featuring vertical shafts exhibiting Y- or T-shaped branching morphology in a firmground substrate, indicating the dominance of *Thalassinoides* ichnotaxa. *Thalassinoides* traces and porosity increase upwards in the section. CT images reveal low tortuosity of burrow conduits, characterized by preferential vertical and oblique straight paths with circular to elliptical cross-sections. In the most bioturbated strata, approximately 39% of the total rock volume consists of burrows, predominantly filled with dolomite, exhibiting substantially higher porosity than the muddy matrix. Porosity estimated within bioturbation traces ranges from 1.8 to 17.7%, while matrix porosity ranges from 1 to 4.8%. Pore Size Distribution, estimated via Hg-porosimetry coupled with NMR, indicates larger pore sizes (up to 50 μm) in more dolomitized samples, while the smallest pores (0,01-1 μm) are found in the calcitic matrix. Micro CT images offer detailed visualization of pore sizes and pore network in both traces and matrix, facilitating the future fluid flow modelling. Finally, isotopic signatures of C and O in the burrows differ from those in the matrix.

The multidisciplinary dataset we present highlight the relevance of the combination of several methodologies to characterize heterogeneous carbonates to predict fluid flow, fluid-rock interaction and diagenetic evolution. Understanding these processes is fundamental for any subsurface storage project.

New paradigms for an energetic independence and sustainable development of minor volcanic islands in Sicily: opportunities from the geothermal resources

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Keywords: geothermal energy, sustainability, volcanic islands.

This study delves into the possibility of geothermal exploration to attain energy autonomy on small volcanic islands. Our case study is centered on the minor volcanic islands pertaining to Sicily (Southern Italy), i.e. those of the Aeolian Arc and Pantelleria, located respectively in the Tyrrhenian Sea and Sicily Channel. Importance of this issue relies on the energy challenges in the context of global energy demands and the imperative shift towards sustainable resources. This research strives to provide a comprehensive examination of the potential, benefits and potential drawbacks in adopting geothermal energy as the primary resource to establish self-sufficiency within ecosystems of small volcanic islands.

Foundation of this research is based on the present energy landscape on Aeolian Islands and Pantelleria, predominantly reliant on fossil fuels and only sporadically renewable resources. To address these challenges, a polyhedric research approach is adopted, encompassing resource assessment to identify and quantify geothermal potential (Floridia et al., 2022; PRIN 2022 PNRR P2022ZN4XP and CUP E53D23022050001), evaluation of existing infrastructure's compatibility with geothermal integration, environmental impact analysis. Investigation is aimed at assessing the environmental, social and economic implications, the technological feasibility evaluation for identifying the most suitable condition for the geothermal energy exploitation, and the analysis of legal and regulatory frameworks necessary to support and incentivize geothermal energy development.

The study finally endeavors to deliver a holistic view of opportunities and challenges associated with implementing geothermal energy solutions in the distinct context of small volcanic islands. The research underscores the critical importance of understanding economic feasibility and social impact of transitioning to geothermal energy captured in volcanic areas.

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3D lithospheric thermal model of the Calabria region (Southern Italy): a supporting tool for new exploration campaigns for geothermal resources

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Keywords: geothermal resources, Calabria Region, thermal model.

The assessment of the geothermal potential of the subsurface is mainly based on the evaluation of the thermal and mechanical conditions of the lithosphere. Investigating thermal regimes demands a comprehensive understanding of geological features and their operational mechanisms (Floridia et al., 2022). This approach is particularly pertinent in complex and active geodynamic contexts such as the Calabria region (Italy, central-western Mediterranean), serving as a critical case study due to its largely unexplored geothermal potential. In the framework of the PNRR 2023-2026 projects (Tech4You), an effort was made to reconstruct the lithospheric state of Calabria to quantify its shallow and medium-depth thermal regime. Beginning with modelling including the entire Calabrian territory, the main geological units and their lithology-dependent properties were defined to create a 3D geological model consistent with available geological and geophysical datasets. This geological model served as the basis to compute the current thermal conductive field in a steady state. By incorporating physical properties like thermal conductivity and radiogenic heat production for individual lithological units (*e.g.*, Di Sipio et al., 2014), the temperature at each point in the study domain was modelled. Finally, the results obtained from the thermal modelling were validated by comparing them with measured temperatures derived from historical datasets from hydrocarbon exploration (VIDEPI Project). While strong assumptions were made for high-enthalpy resources, the identification of favourable areas for exploiting medium-to-low temperature gradients has been achieved. Maximum temperatures of 90°C at a depth of 3 km along the Ionian sedimentary basins and orogenic domains have been observed, with differences of about 20°C for the Carbonate units (~70 °C) in the northern sector. According to various studies on the geothermal potential in Calabria, Carbonate units represent the main geothermal reservoir (Vespasiano et al., 2023). The model suggests that other units hosted in the sedimentary covers and the crystalline basement may also represent important geothermal systems that require further studies. Future research will focus on transient thermal numerical simulations in a regional context and rheological models coupled with convective heat transport to achieve a more realistic approach to thermal response.

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Geothermal potential of the Tertiary Piedmont Basin: structural and lithological controls

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Keywords: Tertiary Piedmont Basin, geothermal reservoir, basin structure.

Geothermal energy, as a renewable and green source for energy production and heating/cooling activities, has a great development potential in many European countries. The dynamic tectonic history of Italy provides a favorable geologic framework for geothermal resources to be formed. Besides some volcanic regions, characterized by significantly hot manifestations, there are many low enthalpy geothermal fields. Only a few of them have been addressed and are mainly exploited directly as heat. Within this context, less evident and more complex systems suitable for developing new geothermal projects, become key areas for the energetic transition. Nevertheless, their exploration and future exploitation can only occur through the implementation of multidisciplinary methodologies, leading to a detailed characterization of the reservoirs.

Our main goal is to determine the geothermal potential of the Tertiary Piedmont Basin (TPB, north-western Italy) by revealing the thermal structure of the region, as well as the heating mechanisms and heat flow controls in the basin. The TPB records the dynamic evolution of the Alps-Apennines junction. It accommodates on average 3 km of sedimentary units (Eocene to Pliocene in age), which show marked lateral facies variations and tectonically-controlled depositional architectures (Di Giulio et al., 2024 and reference therein). These units and the underlying Alpine basement experienced multiple pulses of deformation, developing kilometric structures over a stretched lithosphere, which likely had a key role in increasing the geothermal gradient of the area (Amadori et al., 2023). Several hot springs up to 70°C (e.g., Acqui Terme) and moderately high surface heat flux, between 62 and 84 mW m-2 (Pasquale et al., 2014) have been observed in the TPB, evidencing its potential as a new geothermal resource. The location of the hot springs, north to the metamorphic basement outcrops, identify the last one as the recharge area of the meteoric water. Furthermore, the presence of a thin crust (30-35 km), revealed by recent seismic tomography studies (e.g., Nouibat et al., 2023), enhances the role of the deep structures in the formation of the geothermal reservoir.

In this study, we display the results of the first field campaign, carried out in the TPB, and the analyses of the available geological/geophysical data. These include the recognition of key lateral and vertical facies variations of the stratigraphic units and of first order structures present in the basin. These outcomes, together with the measurements of petrophysical parameters and fluid inclusion micro-thermometry from the sampled rocks, will be the main input for the implementation of the initial geological model. This workflow based on stratigraphic and structural analyses, as well as diagenesis, will be crucial for the evaluation of the geothermal potential of the TPB and could be applied on similar basins.

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Laboratory experiments and geochemical models for CO_2 mineralization in basalts

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Keywords: basalt, CO_2, mineralization,

Carbon Capture and Storage technologies can help reaching Paris Agreement's temperature increase of no more than 1.5-2 °*C* from pre-industrial level. To meet this target, 10 Gt of CO_2 should be sequestered every year starting today and until mid-century. Most of the research is focus on sedimentary basins for their large storage capacity but CO_2 mineralization (which proved to be the safest process to sequester CO_2) in sedimentary basins can take thousands of years. On the contrary, basalts, due to mafic minerals (olivine, pyroxenes) presence, can provide faster reaction rates thanks to release divalent cations release (Fe^{2+}, Mg^{2+}, and Ca^{2+}) promoting carbonate precipitation.

CO2 injection in basalts has big prospect since it has been demonstrated that CO_2 carbonation occurs in less than 2 years (Iceland, Matter et al., 2016). Success of this pilot project encouraged researchers to focus more and more on injection in basalts. Despite the large interest of these last years, several aspects are still under investigation given especially the high variability of this kind of rocks. "Ageing tests" carried out in reactors to mimic reservoir conditions (high temperature and pressure) are valuable tools to understand the main processes driven by CO_2 injection.

In this research, we focused on basaltic rocks coming from Al-Birk and Harrat-Lunayyir regions in Saudi Arabia. We conducted a series of ageing experiments in a micro-reactor for different durations (2h, 16h, 48h) with Milli-Q water and powdered basalt (120- 250 μm- 2mm) at 110°*C* and 40- 50 bar CO2 pressure to understand the effectiveness of carbonation reactions in these short times. Mineralogic characterization (SEM and XRD) of solid samples and water chemical analysis were conducted before and after experiments to quantify mineral and liquid changes. Preliminary results confirm that CO_2 strongly promoted olivine dissolution; furthermore, pyroxene and plagioclase altered with consequent Ca release and calcite precipitation.

Mass balances calculations/estimates were performed to point out the main reactive processes occurred in the micro-reactor. Existing geochemical database will be enhanced with new site-specific mineral phases for olivine, pyroxene and plagioclases and geochemical model were done using PhreeQC (USGS, 1999). Geochemical models are used to predict long-term behaviour of injected CO_2 and together with Reactive Transport Model (RTM) are used to investigate the dynamics of CO_2 migration and mineralization pattern in reservoir. The results of this study can provide a quantitative indication of the potential efficiency of large-scale subsurface carbonation in basaltic rocks.

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Tracing the palaeo-circulation of geothermal fluids in the shallow crust exposed in the eastern Elba Island (Tuscany, Italy)

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Keywords: exhumed geothermal system, hydrothermal mineralisation, Elba Island.

Migration and storage of geothermal fluids in the upper crust are mostly controlled by permeable rock volumes corresponding to crustal sectors affected by brittle deformation. Understanding how hot (250°-350°C) to super-hot (>350°C) fluids circulate and interact with host rocks in fault-controlled upper continental crust is a challenging task. The results from structural, fluid inclusion, Sr isotope, petrographic and mineralogical studies of the Terranera Fe-hydrothermal mineralisation, considered an exhumed palaeo-geothermal system, describe how hot to super-hot fluids were controlled by the increased permeability resulting from the interplay between low-angle normal faults and high-angle oblique-slip faults, the latter being part of a regional transfer zone (Zucchi et al., 2024). The study area is located in the eastern Elba Island (northern Tyrrhenian Sea, Italy), where the emplacement of a Messinian felsic intrusion has allowed hydrothermal fluids to circulate in relation to a fault-related permeability of the order of 10-15 to 10-13 m2. Magmatic fluids reacted with the host rocks (carbonate and phyllite) to form Fe-ore deposits hosted within the fault zones that controlled the fluid flow. Fluid inclusions trapped in quartz crystals indicate that the fluids consisted of saline solutions (salinity from 18.0 to 26.6 wt.% NaCl eq.), which later mixed with low salinity waters of probable meteoric origin. The fluid temperature during the main hydrothermal stage ranged between about 300° and 360°C under an estimated maximum hydrostatic pressure of 28–30 MPa. In contrast, the maximum possible temperature was about 400°C at a lithostatic pressure of 89 MPa. The hydraulic breccias formed as a result of the transient fluid pressurisation up to lithostatic values, due to the self-sealing process and the subsequent pressure drop, down to hydrostatic values, as framed in the hydrofracturing processes. The results provide useful input for the identification of geothermal and ore body targets in those geological settings where fluids of magmatic and meteoric origin are controlled by active faults in an extensional tectonic regime.

Zucchi M. et al. (2024) - Migration of hot to super-hot palaeo-fluids in an extensional setting (eastern Elba Island, Italy). Tectonophysics, 874, 230210, https://doi.org/10.1016/j.tecto.2024.230210.

S45.

Recent advances in karst research, with particular focus on underground waters

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Desertification risk assessment using the modified MEDALUS model in the Alta Murgia karst plateau (Apulia, Southern Italy)

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Keywords: desertification risk assessment, GIS, karst environments.

Desertification is nowadays among the most severe environmental problems in many countries, and threatens the integrity of natural environments and the sustainability of related natural resources. This work aims to assess the proneness to desertification in the Alta Murgia karst plateau (Apulia, Southern Italy) through the integration of the modified Mediterranean Desertification and Land Use model (MEDALUS, Kosmas et al., 1999) within a GIS-based approach. The model includes among its indexes: climate, vegetation, soil and management, all combined for assessing environmentally sensitive areas (ESAs) to desertification. Considering the karst features of the study area, the management index has been modified in order to evaluate the degree of disturbance in such a fragile environment. This was made by adding the Karst Disturbance Index (North et al.., 2009), consisting of many environmental indicators contained within five broad categories: geomorphology, hydrology, atmosphere, biota, and cultural. According to the model, preliminary results indicated that the whole area falls within a range from "Fragile" to "Critical" ESAs type, with no area that results "Non affected" or "Potential". This could be justified, more than by climatic or ecological factors, by a series of anthropogenic activities carried out over the years that strongly modified and disturbed the original karst landscape, causing a high negative impact on the Alta Murgia karst.

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A global overview of desertification in karstlands

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Keywords: desertification, karst, human impacts, climate change.

Desertification in karst is an effect of climate change and not sustainable anthropogenic activities, the combination of which, however, causes the gradual loss of karst natural resources, such as soil, vegetation, and groundwater. A considerable percentage of global karst areas is found in drylands, characterized by negative water balance and scarce presence of soils. High fragility of the karst environment, and its vulnerability to land degradation and pollution because of the peculiar anisotropic setting, environmental dynamics, and of the direct connection between the surface and the subsurface, are at the origin of the severe problems deriving from desertification processes in karst. In addition to natural drivers, such as geology and topography, karst desertification is generally due to four main factors, mostly or partly related to human activity: deforestation, improper land use, groundwater overexploitation, and climate changes. Through the analysis of a collection of studies conducted in several karst territories around the world, the present work aims to provide an overview of the processes leading to desertification risks in karst areas. Emphasizing the need to preserve these fragile environments, characterized by peculiar features and precious freshwater resources, this review summarizes the main situations at the global scale of rocky desertification in karst, at the same time providing indications for developing innovative and multi-disciplinary approaches addressed toward mitigation of the risk related to desertification in karst.

D'Ettorre U.S. et al. (2024) - Desertification in karst areas: A review. Earth-Science Reviews, 104786, https://doi.org/10.1016/j.earscirev.2024.104786.

Mineralization of the Kozan-8 thermal well (Kruja Province, central Albania): a mineralogical and water geochemical study

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Keywords: mineralization, thermal water, mineralogy, geochemistry.

In Albania, the presence of high mountain chains and active fault systems favors the ascent of deep waters producing several thermo-mineral springs. The most important springs are located in the Kruja Province and rise from deep karst aquifers. The Kruja tectonic zone (central Albania) consists of elongated anticline structures of Cretaceous–Eocene limestones and dolomites covered by Oligocene flysch deposits. It is affected by longitudinal NW-SE faults intersected by some transversal faults. The carbonate rocks have been buried up to ca. 10 km depth, and are underlain by Triassic-Permian evaporites. In the Kruja Zone, the geothermal gradient ranges from 7 to 11 mK/m. Five deep wells are present in the area (depth range 2000-3000 m) tapping thermal waters of carbonate aquifer. Three of these wells, namely Ishmi-1b, Kozan-8 and Galigat-2, are the most important as concerns water quality, temperature and curative values. Thermal waters in the central area of the Kruja province are of the Cl–SO4–Na–Ca type, with temperatures up to 56 °C for springs and 65 °C for wells, and high H2S concentrations (Eftimi & Frashëri, 2016).

Recent scientific activities carried out at the Kruja Province focused on Kozan-8 well (1837 m depth) at Elbasan locality, including water and deposited minerals sampling. Thermal waters discharge exhibits EC = 6400 microS/cm, temperature of 55.4 °C, pH = 6.73, and reducing Eh. Water composition shows similar high Na and Ca contents among cations, and high Cl and SO_4 among anions. According to previous studies (Eftimi, 1998; Reimann & Birke, 2010), this water composition can be related to the presence of deep fluids with long/deep circulation in the local anticline structures, involving Mesozoic carbonates (which contain also pyrite) and the underlying Triassic evaporites. Together with H2S (Eftimi & Frashëri, 2016), enrichment in CO_2, CH_4 and He has been also detected. At the emergence, the water results oversaturated with respect to Ca-Mg carbonates, and slightly undersaturated with respect to sulphates. Around the water discharge abundant mineral deposits are present, consisting of banded encrustations of different colours (white, grey, black, pale yellow, orange-yellow) formed from the outgoing hot fluids. Such mineralization was never analysed before. Combined optical microscopy and X-ray powder diffraction analyses evidenced that the studied encrustations mainly consist of micrometric-sized crystals of Ca- and Mg-sulphates (gypsum, $CaSO_4 \cdot 2H_2O$; bassanite, $CaSO_4 \cdot 0.5H_2O$; anhydrite, $CaSO_4$; epsomite, $MgSO_4 \cdot 7H_2O$), calcium carbonates (aragonite and calcite $CaCO_3$), and sulphur (S_8). Furthermore, Na-, K-, and Fe-sulphates (metavoltine, $K_2Na_6Fe_{2+}Fe_6^{3+}O_2(SO_4)_{12} \cdot 18H_2O$; sideronatrite, $Na_2Fe_{3+}(SO_4)2(OH) \cdot 3H_2O$) were sporadically found.

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Terzaghi's effective stress principle and hydrological deformation of karst aquifers detected by GNSS and inSAR measurements

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Keywords: Terzaghi's principle, hydrological deformation, coefficient of earth pressure at rest.

Studies have shown a strong correlation between spring discharge variations and horizontal ground displacements measured by GNSS (Global Navigation Satellite Systems) stations located in karst areas of the Apennine chain (Italy), revealing that karst massifs undergo deformation in response to groundwater level variations (Silverii et al. 2019; Leone et al. 2023b). We investigated the relationship between the hydrological stage of karst aquifers and crustal deformation in the area of Matese massif (southern Italy). To this scope, we analyzed spring discharge, GNSS, and InSAR (Interferometric Synthetic Aperture Radar) time series. Unlike GNSS, which provides a local measurement of the ground motion, InSAR allows for monitoring more or less extensive areas, making it more effective in detecting vertical crustal deformation due to hydrological processes. Our analyses highlighted that contraction and dilatation phases of the karst massif are associated with decreasing and increasing phases of the spring discharge occurring at annual and multi-annual time scales. Various authors have explained this phenomenon by the widening and closing of sub-vertical water-filled fractures dissecting the rock mass due to varying hydraulic heads within these discontinuities, neglecting the role of the pore water pressure acting in the aquifer's saturated zone. In particular, given Terzaghi's effective stress principle, pore fluid pressure is a fundamental component of the in-situ stress field (Zoback, 2007). In the specific case of karst aquifers, pore water pressure variations up to thousands of KPa are expected to occur at depth primarily in response to water table fluctuations, inducing variations in the state of stress acting in a vast rock volume. We present new equations derived by Leone et al. (2023a), relating strain to pore water pressure variations due to water table fluctuations. These equations explain the observed deformational phenomenon in its generality and are based on Terzaghi's effective stress principle (Skempton's generalization) and linear elasticity. The proposed equations were derived assuming unconstrained and constrained conditions of the karst aquifer. In the first case, the karst aquifer is free to expand laterally, and the hydrological strain depends on the overall elastic properties of the karst rock mass and the coefficient of earth pressure at rest, $K0$. In the second case, an elastic aquitard laterally constrains the karst aquifer, and the strain induced by the change in pore water pressure also depends on the elastic properties and dimensions of the aquitard. The resulting strain is thus a fraction of the unconstrained hydrological strain. We show that karst aquifer hydrological deformation can be compared to the thermal expansion of solids. In particular, the hydrological deformation is due to changes in the pore water pressure that occur at depth and affect the aquifer's saturated zone, primarily, and the epiphreatic zone.

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Leone G. et al. (2023b) - Hydrological deformation of karst aquifers detected by GPS measurements, Matese massif. Italy Environ. Earth Sci., 82(9), https://doi.org/10.1007/s12665-023-10905-3.

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Short- and long-term changes in the discharge of the Caposele karst spring (Southern Apennines, Italy): statistics and modeling to understand their causes

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Keywords: karst spring discharge, atmospheric warming, snow processes.

Decreasing trends have been detected in the time series of the Caposele karst spring (Cervialto massif, southern Apennine, Italy) since 1920. On the other hand, annual precipitation appears stationary over a long period in the area (Fiorillo et al., 2021). Considering this premise, we applied statistical analysis and hydrological modeling to investigate climate change in the karst area of the Cervialto massif and its possible impact on the groundwater resource. Statistical methods were employed to analyze short- and long-term trends in secular time series of climate and hydrological variables and correlations. As observed in other Mediterranean areas, the NAO (North Atlantic Oscillation) and NAM (Northern Annular Mode) large-scale atmospheric circulation patterns affect local precipitation and the occurrence of meteorological dry (drought) and wet periods. Statistical analyses also highlighted that annual spring discharge can be described by an autoregressive-cross-regressive linear model (Kresic, 2010), where the discharge in a given year is affected by precipitation and the discharge of the previous year. Although precipitation and memory effect explain most of the spring discharge variance, they do not explain the observed hydrological trend, suggesting that it must depend on other factors and complex processes. To investigate these aspects, we employed a lumped parameter reservoir model (KarstMod; Mazzilli et al., 2019) to simulate the recharge-discharge process of the Cervialto aquifer on a daily scale and to predict the response of the Caposele spring to various climate scenarios by simulation experiments. Given the topographic features of the spring catchment, the hydrological model was coupled with a snow routine, whose calibration and validation involved the analysis of climate data and Sentinel 2A satellite images. The hydro-meteorological model showed high performance in both calibration and validation periods and reliably simulated the overall hydrodynamic behavior of the Caposele spring catchment. Using the model, we investigated the specific impact of atmospheric warming on the recharge-discharge processes. Simulation experiments suggested a key role of temperature in the karst spring discharge regime. In particular, the 1.5°C atmospheric warming observed since 1999 would contribute to the decreasing spring discharge in the last decades. The analyses highlighted that the groundwater resource depletion observed since 1920 can be mainly explained by the combined effects of recent droughts (last three decades), the aquifer memory effect, and atmospheric warming. This work provides a comprehensive analysis of hydro-meteorological processes affecting the Caposele spring catchment and attempts to clarify the impact of atmospheric warming on karst groundwater resources in southern Apennine. In this region, karst aquifers are widely extended and are a primary source of drinking water.

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Karst hydrology and geomorphology of the Matese and Alburni Massifs, (Southern Italy), focusing on dolines and endorheic areas

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Keywords: karst geomorphology, hydrological features, karst landform mapping.

Karst environments are peculiar settings characterized by a deep interaction between groundwater circulation and surface hydrology and landforms. Small- to large-scale morphological features typified karst terrains, such as ponors, shafts, dolines, poljes, caves, endorheic basins, etc. All these features play an important role in hydrological processes, as they control meteoric water runoff/infiltration, the transferring of water into the underground, and thus groundwater recharge. In this context, mapping the karst landforms and understanding their hydrological role represent the starting point for many investigations, including hydrological modelling of the surface runoff and groundwater recharge, delineation of protection zones for wells and springs, simulation of point source contamination, and artificial test planning. This contribution presents the results obtained from mapping studies that focused on the karst hydrological features of the Matese and Alburni massif (Southern Italy), illustrating landforms of typical karst environments from the hydrological perspective. The hydrological analysis of high-resolution Digital Elevation Models (DEMs) in a GIS (Geographic Information System) environment has represented the primary method used in map making, which has driven the identification of the dolines and poljes, first, and has allowed for the delineation of small- and large-scale endorheic areas, then. From the point of view of surface hydrology, an endorheic area constitutes a closed watershed with internal runoff, which conveys meteoric water toward ponors, dolines, and poljes, representing the most depressed points or areas of the watershed. Therefore, endorheic areas are peculiar parts of a spring catchment from which meteoric water cannot escape (Fiorillo et al., 2015, 2022). Using specific GIS-tools, all the closed depression in DEMs were automatically identified (Leone et al., 2022). The comparisons between morphometric features of mapped depressions and known dolines allowed a first distinction between real karst landforms and false sinks. Then, a visual inspection of various informative layers, including Google Earth images and DEM-derived contour maps and hill-shade, was carried out to support dolines delineations. Based on mapped doline location, endorheic areas were automatically delineated using the well-known Watershed GIS-tool. This contribution provides new insight into the hydrological karst features of Matese and Alburni carbonate reliefs controlling the infiltration and, thus, groundwater recharge. These aspects are of extreme interest for water resources management and protection.

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Open window on water table: examples from Apulia Region

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Keywords: caves, karst, hydrogeology.

Underground water are precious freshwater resources especially in karst settings where often it represents the only available for local communities in many countries of the world (Stevanovic, 2015). Given the high vulnerability to pollution (Goldscheider & Drew, 2007; Ford & Williams, 2007) and fragility of such a resource, karst groundwater has to be protected and properly managed. To reach the goal, a deep knowledge of the geological and hydrogeological features can be considered the starting point to develop best practices and to plan good actions toward protection of underground water resources.

In karst, the integration of traditional geological approaches at the surface with direct exploration and surveying within the caves, by means of speleological techniques (Liso et al., 2020) guarantee a proper characterization of the environment.

In Apulia Region, the biggest karst areas in southern Italy, the freshwater resource flows within the fractured and karstified limestones. Among the over 2000 caves registered in the Regional Inventory, only two directly reach the water table far from the coastline. They have therefore begun open windows to the water table, ideal sites to perform in situ investigations and hydrogeological research. Moreover, close to the coastline, another cave reaching the water table is monitored, since it is located at the transition between fresh and marine water. In this contribution we present our efforts, performed through direct explorations in cooperation with cavers, to combine surface/subsurface data to enrich the available information about hydrogeology of Apulian karst systems, and to contribute to a better understanding of its main features.

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A flank margin cave along the Adriatic side of Apulia, Southern Italy

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Keywords: karst, coastal caves, flank margin.

Flank margin caves are caves developed in typical coastal mixing zones, following the model initially proposed by Mylroie & Carew (1990) for young eogenetic limestone rocks in the Bahamas and other carbonate islands in the Caribbean and the Pacific. Later on, the model has been proved effective also as concerns speleogenesis in coastal areas with hard carbonates. Among the main features of flank margin caves, the following may be mentioned: lack of fluvial sediments, and of evidence of running waters, such as scallops along the rock walls and vaults; typically rounded and smoothed cave morphology, with a spongework pattern in plan view; presence of many dissolutional notches along the walls. Overall, the caves result in interconnected passages and rooms at intersections about parallel to the coastline, with passages tapering out inland, moving progressively away from the mixing zone.

Apulia Region, in southern Italy, with about 900 km of coastlines, is certainly a sector of great interest for the analysis of ancient flank margin caves, produced in the past along the mixing zone and nowadays present at different altitudes above sea level, thus becoming markers of past highstands, and gaining importance in sea level change studies.

The Murge plateau is dissected by the Murgian Escarpment, a NW-SE striking direct fault bounding it toward the Adriatic Sea, and with significant morphological expression. The local bedrock, consisting of the Upper Cretaceous Altamura limestones, is overlain by the fossiliferous Ostuni limestones (upper Campanian-Maastrichtian), forming a stepwise morphology of a set of terraces lowering to the coast (Delle Rose & Parise 2003; Parise 2011). At the foot of one of such cliffs, the Sant'Angelo cave system opens at altitude of 150 m asl. The cave system has an overall length of 1.5 km, with main NW-SE striking passages developed along a fault-line; to this, anastomosing wide and low passages showing the typical mixing-corrosion morphologies are present, marked by rounded walls and swiss-cheese morphologies, and with absence of stream sediments or scallops; due to its present elevation, age of the system may be hypothesized as Lower Pleistocene (Arriolabengoa et al., 2017).

Observing evidence of coastal mixing-corrosion, that includes rounded wall morphologies, notches, anastomosing passages, and the lack of signs of sediments within cave systems, may demonstrate their origin as flank margin caves. In cases where these are found in areas rather far from the present coastline and at much higher altitudes, they are good indicators of past sea level, and quite often are better preserved than any other marker at the surface. Determination of their age can therefore provide new clues on Pleistocene sea level changes and/or in understanding coastal uplift along the western Mediterranean coast.

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Integrating fracture analysis and X-ray tomography with permeability tests for rock fracture hydraulic conductivity assessment at laboratory-scale

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Keywords: hydraulic conductivity; fracture analysis; x.ray tomography.

Discontinuities in rock formations play a crucial role in various subsurface engineering and environmental scenarios, influencing groundwater movement, contaminant transport, as well as slope instability and strength reduction. This impact is particularly significant in heterogeneous and anisotropic fractured media. To accurately assess hydraulic conductivity, various laboratory permeability tests are commonly employed, such as head permeameter tests, falling head permeability tests, radial flow tests, and pulse tests. However, despite advancements in these methods, challenges persist due to limited understanding of the characteristics of rock discontinuities. These characteristics, including fracture aperture, roughness, orientation, and mineral coatings, can vary considerably and have a significant impact on hydraulic conductivity and groundwater movement. In this study, geo-structural and geo-mechanical analyses at the laboratory scale are coupled with 3D x-ray tomography and flexible wall permeameter to assess sample hydraulic conductivity variation among different samples of the Scaglia Rossa geological formation (central Apennines, Italy), one of the principal aquifers in the Umbria-Marche domain. The fracture analysis encompassed the microstructural classification of various tectonic features such as stylolites, veins, joints, and filling materials, along with the measurement of fracture roughness and aperture. Our proposed methodology provides a promising approach to assess fracture conductivity within individual rock samples, thereby enabling the development of mathematical models for water flow in fractured rock formations. These models can subsequently be validated against field measurements, offering valuable insights into subsurface hydrology and aiding in the sustainable management of groundwater resources of similar carbonate aquifers.

Estimation of recharge to the karst Scirca spring (Central Italy) by using conventional and modified APLIS methods: a comparison

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Keywords: karst spring, effective infiltration, recharge.

Mean annual recharge to the karst Scirca spring, in the Umbria Marche Apennines, was evaluated for the 2010-2022 period, both by traditional methods based on the estimation of actual evapotranspiration on a monthly (Thornthwaite-Mather) and on an annual (Turc) scale, and by the multiparametric APLIS method (Andreo et al., 2008). This last determines the recharge to carbonate aquifers by combining five parameters: altitude, slope, lithology, soil type and infiltration landforms. Based on these parameters, a coefficient is calculated which is independent on the climatic conditions and represents the percentage of rainfall contributing to recharge.

All methods were used in a GIS environment. This allowed to spatialize both input data and results over the spring recharge area. As we dealt with a mountainous region, the contribution of snow was considered in the precipitation data. The limits of the recharge area were revised with respect to former studies (Valigi et al., 2012; Tamburini & Menichetti, 2020) by carefully updating the geological information and by using as a base five newly drawn geological cross sections intersecting with each other. Since a highly developed karst system and numerous normal faults are present in the Scirca spring recharge area, the modified version of APLIS (Errahmouni et al., 2022) was used, in which the parameter related to infiltration landforms is determined as a function of three factors, one of which is the distance from faults. A further factor influencing this parameter was here considered the presence of surface karst landforms.

Results obtained by the Thornthwaite-Mather and the Turc methods were similar to each other and indicated that the mean annual water surplus over the spring recharge area is slightly higher than 60% of mean annual precipitation. Such amount corresponds to the average annual discharge of the spring. This indicates that the water surplus contributes entirely to the aquifer recharge and that the runoff is negligible, which is consistent with the geological characteristics of the area.

The modified APLIS method shows results which are coherent with those obtained by the traditional methods and indicate that recharge to the aquifer feeding the spring corresponds to 62% of mean annual rainfall.

The findings of this study update and partially modify those or former investigations on the same area (Valigi et al., 2012) and indicate that the whole water surplus contributes to the aquifer recharge, unlike previously assumed by using climatic and discharge data less reliable than those now available.

It can be noticed that the APLIS method indirectly estimates the water amount not contributing to recharge but, unlike the traditional methods, does not give any information on the way this amount is split in runoff and ETR. Besides, APLIS represents a viable alternative to traditional methods when reliable temperature data are not available, which is often the case of karst mountains areas.

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On the hydraulic role of dolines

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Keywords: doline, karst, hydraulics.

In karst environments, dolines (sinkholes) represent one of the most typical landforms. Beside their genesis, and the mechanisms at the origin of their formation (Gutierrez et al., 2014), an interesting aspect to explore is that dolines play a very important role as concerns the possibility of subsoil infiltration for surface water, and therefore for the recharge of karst aquifers (Stevanovic, 2015). Starting from these considerations, this contribution is intended to deal with the hydraulic role of dolines in different karst settings. To this aim, we will describe some situations in karst environments of Apulia, southern Italy (Pisano et al., 2020, 2022), where dolines have been mapped and classified according to the main sinkhole classification by Gutierrez et al. (2014). In detail, the dolines mapped in the main polje of central-southern Apulia, Canale di Pirro, are of remarkable importance for allowing the slow infiltration of water underground, given that the majority of dolines belong to the suffusion and solution categories (Pisano et al., 2020). On the other hand, in another sector of Apulia, the Salento peninsula, most of the dolines belong to the category of collapse sinkholes (including both cover-collapse and caprock collapse sinkholes; Pisano et al., 2022), with a quite different behaviour as regards the hydraulic functioning.

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Seawater intrusion and coastal karst aquifers in Apulia: status, challenges and future scenarios

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Keywords: seawater intrusion (SWI), karst, modeling, Apulia and, climate change.

One of the most difficult and pervasive environmental issues threatening the sustainable use and quality of fresh groundwater supplies in coastal aquifers is seawater intrusion (SWI). Karst aquifers present a significant challenge due to their unique and complicated properties that set them apart from other types of aquifers. Large voids, leading to high flow rates, and water velocities up to several hundred meters per hour, are expressions of the great heterogeneity controlling karst groundwater movement. Therefore, the hydrogeological approach tools, like piezometric measurements, pumping tests, potentiometric maps, and hydraulic data tests, derived from well observations are largely ineffective in proper evaluating the hydrodynamics in karst terrains. Apulia Region, with over 800km of coastline and a semi-arid Mediterranean climate, represents the most remarkable karst regions in southern Italy. It hosts the amount of freshwater within the karstified carbonate aquifer, representing the main water resource for locals and tourist communities. This study focuses on the evaluation of the seawater intrusion effects on coastal karst aquifers through hydro-chemical data analyses and the realization of hydro-geomorphological maps. Moreover, the scientific activities aim to develop a unique procedure to assess future scenarios in terms of groundwater vulnerability and saline intrusion extension, taking into account climate change effects and rising freshwater demand for human, industrial and agricultural purposes. Using multiple ion plots, the hydrochemical results demonstrate a moderate to somewhat high degree of mixing between fresh and saline water, particularly in samples with higher Na+ and Cl- concentrations. Meanwhile, in the samples that have higher concentrations of HCO- and Mg+2, their salinity can be attributed to mineral exchange. Nevertheless, it may be inferred from the combination of hydrogeological and geomorphological maps that regions with a high degree of karst landform development are also likely to have substantial salinity intrusion. since doline and sinkholes play a fundamental role in terms of increasing the seawater flux into karst aquifers. As a result, the assessment of groundwater vulnerability to salinization will allow us to define the areas highly susceptible to seawater intrusion. Furthermore, taking into account the effects of climate change and the growing demand for groundwater freshwater resources, modeling approaches will be used to estimate the aquifer's quality and quantity over time. Multi-approach studies like this are useful tools for developing further and more detailed research, and might contribute to improving groundwater management plans in the Karst region.

Palude del Capitano (Apulia, Italy): a natural coastal laboratory to monitor biological diversity and dynamics of karst hydrogeology

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Keywords: karst hydrogeology, coastal sinkhole, biodiversity

Coastal karst is characterized by fast evolution due to the simultaneous action of marine and terrestrial processes. Being a peninsula with mostly low-land topography, Salento (Apulia, S Italy) shows complex hydrogeological features related to the groundwater circulation and its interaction with seawater (Liso & Parise, 2023), including the rising of sulphureous deep water (D'Angeli et al., 2021).

The site of Palude del Capitano, along the Ionian side of Salento, represents a natural coastal laboratory for monitoring the high level of biodiversity and to comprehend the dynamics of karst hydrogeology in coastal settings. This wetland area, consisting of collapse sinkholes (Gutierrez et al., 2014) of different size, is flooded by brackish water and characterized by hypothermal waters (T about 19°C) of deep origin, with constant flow throughout the year. It is therefore important to explore the likely correlations between these mixing waters and the high rate of biodiversity.

The aim of this research is to study and analyze the influence of the dynamic equilibrium among the sulphureous, fresh, and marine waters on both rock dissolution process and biodiversity. To reach this goal, Palude del Capitano will be instrumented to become a natural laboratory. Multiparametric probes will be installed to measure physical water parameters like pH, conductivity, temperature and level; further, flow meters will be placed in correspondence of the main freshwater springs and in the narrow channels connecting the sinkholes to the sea, to assess the spring flow rate and the equilibrium between fresh and marine waters, in function of both tides and sea-storms, as well as the migratory flow of euryhaline species.

Moreover, limestone and calcarenite stone tablets will be positioned in transects within the flooded zone of the main sinkhole to assess the dissolution power of such complex mixing water on different rock types. The rock tablets will be placed at different depth of the lagoon to evaluate the dissolution power of sulphur water on rocks, and at different distance from the sea, in order to evaluate the effect of brackish water fluctuation. The role of scuba divers, operating to contribute to the success of the monitoring through actions of Citizen Science, will be crucial to properly install the instrumentation and during the hydrogeological and biological sampling campaigns.

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New groundwater chemistry and isotope evidence on the La Spezia karst aquifer (western promontory, Gulf of La Spezia)

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Keywords: karst aquifer, isotope, hydrogeology.

Karst aquifers are among the most complex water storage and circulation systems. La Spezia karst aquifer is composed of Mesozoic formations with a main limestone component that belongs to the Tuscan nappe. Hydrochemical and structural geology studies carried out in recent years in this area made it possible to reconstruct the hydrogeological flow of the karst system, which consists of separate underground circuits, mainly controlled by tectonic lines. New water sampling was conducted in the time interval February-April 2022, to carry out new chemical and isotope analysis.

Previous research has highlighted fast shallow karst conduits with a high variation in terms of water turbidity among the main springs of the town of La Spezia (Brozzo et al., 2013).

According to similar research in karst aquifer (Ronchetti et al., 2023), knowing the values of the isotopes of hydrogen (δD) and oxygen ($\delta^{18}O$) allows us: to define the origin of the groundwater; to confirm the mixing between fresh groundwater and seawater; to assume the altitude of the groundwater recharge area.

The results of the isotopic analyses have shown that for most of the groundwater samples the δ18O/altitude linear correlation is respected (Tazioli et al., 2019; Deiana et al., 2020). Nonetheless, some samples taken from water springs in alluvial deposits in the town of La Spezia show more negative isotopic values, highlighting a groundwater recharge area at higher altitudes. This implies the existence of deep and buried below alluvial deposits karst conduits, which connect the outflow area with recharge areas at higher altitudes, which are located in the main reliefs at north-west from the La Spezia city. The geometry of these conduits is mainly controlled by the geological structures (faults and folds) and the dissolution degree of the different limestone formations of the area.

Hydrochemistry analyses confirmed the presence of different groundwater flow paths, characterized by different lengths and different water transit times, and by the presence of seawater intrusion phenomena along the seacoast.

Nevertheless, the new results of the research, to be able to exploit the water of this aquifer for drinkable purposes it is necessary to continue the groundwater monitoring and to improve knowledge about the hydrogeological behavior of the deepest karst conduits.

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Preliminary insights on hydrogeology of Mount Toc from 3D modeling

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Keywords: Vajont landslide, karst hydrogeology, fractured Aquifer.

The Vajont Landslide is one of the major man-triggered disasters of the XX century. A vast and detailed knowledge about the geology, geomorphology, geomechanics and modelling of the landslide, results in more than two hundred publications on these topics. However, groundwater conditions of the south slope of the Vajont Valley are poorly known, even if they are a major conditioning factor for slope stability. The existence of two aquifers in carbonate rocks on the north slope of Mt Toc, was hypothesized by Hendron and Patton (1987), supported only by measured piezometric levels before 1963. In their hydrogeological model the water table in the highly fractured and permeable older landslide mass was influenced by the reservoir; the lower aquifer in the Vajont Limestone (OOV) was fed by both the reservoir and precipitation in the Mt Toc watershed. This model implies that high water pressures may have developed in the slope due to rainfall and snowmelt infiltration.

A detailed review of existing data, coupled with geological/hydrogeological surveys led us to build a 3D geological model of the Mt Toc, to unravel the hydrogeological structure that contributed to the triggering of the Vajont landslide in addition to anthropic factors.

The main aquifer below the 1963 landslide is hosted in the OOV, confined by two aquicludes/aquitards at the top (Fonzaso Fm) and at the bottom (Igne Fm), depending on their degree of fracturing. The topmost portion of Mt Toc, where the OOV outcrops, is characterized by the abundance of karst features, such as *karren* and dolines, unfortunately without accessible caves. This portion of the slope is partially covered by continental carbonate breccias that in the past were misinterpreted as belonging to the OOV: the discovery of these breccias allowed us to better evaluate the vertical throw of the known reverse faults which bound the landslide to the south.

The preliminary 3D geological-hydrogeological model shows that the E-W faults theoretically deflect towards the west most of the groundwater contained in the OOV. This imply that a decreasing of the groundwater inflow and pressures at the top of OOV, suggesting further structural/hydrogeological complexity has to be taken in account.

The 3D hydrogeological model, however, is not completely able to predict the location the few water springs from the karst/fractured carbonates aquifer. A rough hydrological balance indicates an average discharge of about 100 l/s from the main aquifer, but the observed outputs are only a fraction. These discrepancies pose a question regarding the faith of the groundwater which flows into the OOV. A modern hydrogeological survey, never been carried out, may clarify the role played by groundwater in conditioning the slope stability.

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Springs water geochemistry in central-southern Albania

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Keywords: karst springs, water geochemistry, Albania.

The complex geological and geomorphological features of Albania allowed the formation of highly heterogeneous hydrogeological structures, resulting in different types of groundwaters, in function of aquifer physical characters, discharge and its variability, hydrodynamics, and hydro-chemistry. Karst springs drain huge amounts of water, as at the Blue Eye, Vjroi and Black Eye springs, representing important sources for human purposes, and at the same time a remarkable tourist attraction for the beauty of the surrounding landscapes.

Recent scientific studies have been performed at several Albania springs belonging to the thermal water provinces of Kruja, the PeriAdriatic Depression Basin, and the South Ionian (Eftimi & Frasheri, 2013; Eftimi et al. 2022, 2023). Thermal water reservoirs of Albania are typically contained within carbonate aquifers associated with evaporites and molasses. The aim of this research is mainly addressed to the assessment of water geochemistry composition of some of the main fresh and thermal springs in central and southern Albania, both along the coastline and inland, up to the border with Greece. Thirty-four samples were collected in December 2023 and January 2024, including 16 samples from large flow rate cold springs, and 12 from 3 thermal systems and several rivers. Chemical-physical parameters were collected on-site, alongside with samples for the determination of major ions, water and carbon stable isotopes and, at some sites, for dissolved gases. Cold waters are characterized by temperatures from 10 to 16°C, pH from ~7.3 to ~8.0 and conductivity from 210 to 550 microS/cm, while thermal waters have temperatures ranging from 23 to 55°C, pH from ~6.7 to ~7.2, and conductivity from 1600 to 6300 microS/cm. Cold groundwaters from the main karst aquifers are characterized by a typical Ca(Mg)-HCO3 composition with, in several cases, a slight enrichment in SO_4. Only one sample along the coastline shows evidence of interaction with seawater. The thermal waters, on the other hand, show two different hydro-types, characterized, respectively, by Na-Cl and Ca-SO_4 facies. Most of the cold groundwaters show dissolved carbon and gases from shallow sources, whilst deeper contributions cannot be ruled for the thermal waters. These latter, therefore, will be further investigated by means of ongoing data analyses that will shed light on their processes and fluids sources.

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The Bossea Karst Hydrogeology Laboratory

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Keywords: carbonate aquifers, monitoring, climate change.

In the Bossea Cave (Southern Piedmont, Ligurian Alps) a laboratory has been active since 1982, mainly dedicated to monitoring the waters of the carbonate aquifer. Generally, the springs fed by karst aquifers are monitored but little is known about how the water resource is generated through a network of karst conduits (transmissive function) and the very extensive network of discontinuities characterized by very limited karstification (capacitive function). In Bossea the main watercourse receives an innumerable series of inputs linked to water circulation in the discontinuities affecting the carbonate mass. The monitoring system installed in the cavity (acquisition, every 15 minutes, of the flow rate, electrical conductivity and water temperature values with real-time data transmission) therefore concerns the main collector and 9 secondary water inputs. Through the monitoring data it was therefore possible to understand the functioning of the aquifer in different hydrodynamic conditions and in the different areas of the system. First of all, the importance of discontinuities in the circulation of groundwater is evident: near the surface (up to a distance of over 100 m) pistoning phenomena dominate, highlighted by increases in the values of the discharge, temperature and electrical conductivity of the water following significant infiltration. Deeper in the rock mass these values tend to become more constant over time with little relationship with the surface meteorological situation. The karst collector, fed by the different portions of the carbonate aquifer and partly also by the waters flowing on the impermeable rocks that limit the karst structure, has flow speeds that are strongly conditioned by the hydrodynamic situation. During flood periods the speeds even exceed 2400 m/d while in low water they are less than 600 m/d. The circulation in the discontinuities (always inferred with dye tracers) is completely different with values between 10 and 60 m/d. Very interesting are the monitoring data over time (42 years) heavily influenced by climate changes during which situations of significant periods of drought or flood events occurred. In long low periods the discharge remains at values no lower than 50 L/s supported by the contributions of the circulation in the capacitive network of the system while following exceptional rainfall the discharge reaches values very similar to ordinary floods (1500 L/s) due of the runoff phenomena that occur on the karst surface. The changes in flow in the winter period linked to snow melting processes are very evident: the minimum discharge has gone from 50 L/s in the 1980s to the current 100 L/s due to the increase in temperatures.

A karst area shared between carbonate megabeds and siliciclastic units: the example of Mt. Bernadia (NE Italy)

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Keywords: karst hydrogeology, dye tracer, geochemistry.

A significant portion (28%) of the entire Friuli Venezia Giulia Region (FVG) (NE Italy) comprises carbonate aquifers, many of which are extensively karstified and exploited for drinking purposes. Ensuring water availability and protection remains a critical priority to meet the rising demand driven by population growth. In pursuit of this goal, according to the FVG Regional Law 15/2016, the Department of Mathematics, Informatics and Geosciences of the University of Trieste and the Geological Survey of the Friuli Venezia Giulia Region started a multi-year project aimed at identifying regional and cross-border karst aquifers and assessing their vulnerability. Among the 130 karst areas recognized, one of the most peculiar area is the one of Mt. Bernadia. Sited in the Julian Prealps, it has a particular hydrogeological and karstic context where several megabeds of calcarenites and carbonatic breccias alternate within marls and siliciclastic sandstones of the Flysch formations (Paleocene – Eocene) lies on the limestones of Cretaceous platform. Megabeds are highly karstified, with important sub-horizontal caves draining groundwaters and impressive caprock sinkholes involving siliciclastic materials. The landscape contrast between the characteristic fluvial landforms and karst features is impressive. In order to improve the knowledge of the Mt. Bernadia aquifer, detailed hydrogeological surveys, electrical conductivity, temperature and water level in continuous monitoring were realized. In adjoin geochemical investigations as well as dye-tracers were scheduled. The experiments were realized thanks also to the contribution of the speleological associations, in particular to Circolo Speleologico e Idrologico Friulano and Gruppo Speleologico San Giusto. Data acquired evidenced how carbonate megabeds experience a mature karst where caves and conduits often develop at the contact between carbonates and siliciclastic layers giving rise to peculiar features: caves develop both thanks to solutional and erosional processes. The presence of several sinkholes also in correspondence of a siliciclastic cover, allow anyway a fast and concentrated infiltration of the waters reaching quickly the karst hydrostructure in the megabeds. Here the groundwaters are guided by the dip of the strata and the main tectonic features. Being in a mature karst system, travel times are quite short and as consequence the vulnerability is high.

S46.

Sustainable raw material supply to boost the green and digital transition: the role of mineral waste recovery and recycling

CONVENERS & CHAIRPERSONS

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Giving new life to granite quarrying waste: a case study from Buddusò (Sardinia, Italy)

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Keywords: Sardinia, granite extraction waste, recycling

The large amount of granite quarrying waste scattered on the island of Sardinia (Italy), accumulated during a time when this region was a leader in granite extraction, poses challenges from several perspectives: landscape degradation, potential pollution problems and soil impoverishment. In a context where ecological and digital transition needs lead to a continuous growth in demand for raw materials, reconsidering quarry waste materials not as waste, but as potential resources, becomes imperative. Consequently, the identification of possible solutions for their utilisation could not only mitigate the problems arising from the presence of such waste, as previously highlighted, but also provide a contribution in the context of raw material supply.

This study focuses on a granite quarry located in the municipality of Buddusò, in central-northern Sardinia. Over the decades of granite extraction activity, in this quarry, several hundred thousand cubic meters of extraction waste have accumulated in designated landfill areas. The objective of this study is to identify innovative solutions for the utilization of this waste in the context of raw material supply including quartz and feldspars crucial for the ceramic industry, as well as Rare Earth Elements. By unlocking the latent potential of these granite extraction byproducts, we aim to find solutions to give new life to extraction waste by contributing to a paradigm change in the supply of raw materials.

The waste samples were characterized using cutting-edge analytical techniques such as WD-XRF, ICP-MS, SEM-EDS, and observation under a polarized light optical microscope. Subsequently, a processing method was tested on some samples of this material, including crushing, screening, gravity separation, and magnetic separation, in order to obtain a series of concentrates from the initial waste material. The resulting material was then analyzed using the aforementioned analytical techniques to assess their potential areas of utilization.

Exploring critical and strategical raw materials recovery potential from mining waste: findings from some Italian historical mining districts

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Keywords: mine waste, critical raw materials, recovery.

The growing demand for emerging green technologies, crucial for advancing ecological sustainability and digitalization, presents new challenges to European institutions. The European Union (EU) has conducted assessments and compiled a list of critical raw materials (CRMs) and strategic raw materials (SRMs) necessary for producing these technologies. Consequently, recent policy initiatives have been developed to reduce the EU's dependence on external suppliers and promote circularity and sustainable sourcing practices, focusing on increasing internal production of SRMs and CRMs. This includes taking measures to investigate the potential for recovery of CRMs from extractive waste as a priority action (European Commission, 2023).

Significant amounts of valuable minerals were disregarded during previous mining operations and relegated to waste streams, including tailings or waste rock piles. In Italy, mining wastes are distributed in more than 500 sites within the country, according to the official National Inventory of Mining Waste Facilities (ISPRA, 2022). Moreover, this waste could also create sanitary and visual environmental impacts and contain substantial quantities of waste material that may comprehend valuable amounts of raw materials overlooked in past industrial operations.

The overall objective of this work is to implement a data-driven circular economy approach within the extractive industry, emphasizing the reuse and recovery of end-of-process materials, seeking to establish a zero-waste supply chain for raw materials and rehabilitate abandoned and polluted mining areas. A multi-step approach was designed, integrating publicly available information from governmental sources, scientific literature, and field data. Bibliographical research from modern and historic literature was conducted and data were collected to narrow down the selection of potential abandoned mining sites in Italy for detailed investigation (Baldassarre et al., 2024).

The historical mining districts of Traversella (Piedmont) and Libiola (Liguria) were selected for a detailed investigation. Sampling campaigns were realized by collecting mine waste to characterize them in terms of chemical and mineralogical composition using both on-site portable XRF analyses and laboratory analytical techniques, such as Optical Microscopy (OM), X-ray Powder Diffraction (XRPD), Scanning Electron Microscopy (SEM) and Induced Coupled-Plasma Mass Spectroscopy (ICP-MS). Based on the results obtained, some valuable minerals and elements were identified. Overall, this approach can potentially identify an alternative source of raw materials, utilizing mine waste as a potential source of SRMs and CRMs.

Baldassarre G. et al. (2024) - Recovery of Critical Raw Materials from Abandoned Mine Wastes: Some Potential Case Studies in Northwest Italy. RawMat, 2023, 77, https://doi.org/10.3390/materproc2023015077.

European Commission (2023) - Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committe and the Committee of the Regions. A secure and sustainable supply of critical raw materials in support of the twin transition. European Commission, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A165%3AFIN.

ISPRA (2022) - Inventario nazionale delle strutture di deposito di rifiuti estrattivi, chiuse o abbandonate, di tipo A. Rapporto di aggiornamento 2022. https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/inventario-nazionale-delle-strutture-di-deposito-di-rifiuti-estrattivi-chiuse-o-abbandonate-di-tipo-a-rapporto-di-aggiornamento-2022.

Laboratory-scale reprocessing trials of historical mine waste from the Traversella mining district (Piedmont, Italy)

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Keywords: mine waste, reprocessing, magnetic separation.

Recent European Union policies are aimed at exploring extractive waste and potentially identifying alternative sources of Critical or Strategical Raw Materials. Italy had an active base metals mining industry throughout the 20th century. However, these activities were gradually abandoned starting from the 1970s due to political and economic factors. The Traversella mine district is located about 55km North of Turin, Piedmont, Italy and it is characterized by a polymetallic Fe-Cu-W pyrosomatic "skarn" deposit hosted in the Sesia-Lanzo geological unit. Historically, mining operations can be dated back to the Roman period through the Middle Ages. The modern exploitation of the deposit commenced in the XVIII century producing more than 300,000 metric tons of iron ore in its first century of activity. Due to the implementation of more efficient processing techniques, starting from the XX century Traversella mine also produced scheelite, chalcopyrite and uraninite concentrates. Mining operations ceased in 1971 due to economic reasons (Costa et al., 2019).

The presence of mining waste in the area is documented in the National Registry of Extractive Waste Facilities, particularly in regions proximate to the former processing plant and mine adits (ISPRA, 2022). This study encompasses the characterization and reprocessing trials of waste rock samples sampled from waste sites within the Traversella mining district for assessing the potential recovery of valuable minerals. Laboratory-scale mineral processing trials were conducted to produce mineral concentrates from the waste. Initial chemical and mineralogical characterization involved Optical Microscopy (OM), Scanning Electron Microscopy (SEM), and X-ray Powder Diffraction (XRPD) techniques. The analysis revealed the presence of metallic-bearing minerals in the waste, notably magnetite.

The designed process consisted firstly of a crushing and comminution circuit comprising a jaw crusher and a rod mill. For each stage of the crushing process, sub-samples were obtained to determine the free-grain size using OM and SEM image analyses. Comminution products were divided into two size classes suitable for magnetic separation. The coarser class between 0.250 and 0.125 mm was treated using a dry low-intensity magnetic separator (LIMS), while the finer size class below 0.125mm was treated using a wet high-intensity magnetic separator (WHIMS). Consequently, products with elevated concentrations of Fe and other minor components such as Cu, Mn, and W were obtained.

Costa et al. (2019) - The Traversella Mining Site as Piemonte Geosite. Geoheritage, 11(1), 55-70, https://doi.org/10.1007/s12371-017-0271-y.

ISPRA (2022) - Inventario nazionale delle strutture di deposito di rifiuti estrattivi, chiuse o abbandonate, di tipo A. Rapporto di aggiornamento 2022, https://www.isprambiente.gov.it/it/pubblicazioni/rapporti/inventario-nazionale-delle-strutture-di-deposito-di-rifiuti-estrattivi-chiuse-o-abbandonate-di-tipo-a-rapporto-di-aggiornamento-2022.

Towards a Green transition: tools and protocols to help decision makers and companies to decide if and when applying extractive waste exploitation as an alternative to remediation

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Keywords: decision support tool, extractive waste exploitation, green transition.

Extractive waste (EW) facilities pose serious problems concerning environmental impacts, health safety and slope stability. Their management causes economic and social impacts, which, together with the environmental ones, have to be considered by decision makers and companies to evaluate the best solution for the management of the investigated EW facilities. On the other side, the supply of raw materials (RM), including the critical ones (CRM) is a challenge to face in order to guarantee the EU's high development standards. The huge demand for RM and CRM has therefore prompted Europe to adopt policies to find alternative and integrative sources to exploit.

In the last decades, strong effort has been put to prevent, reduce and minimize the negative environmental impacts from the management of the EW, through the adoption of new management strategies and technologies. The extraction and recovery of RM and CRM from landfills and EW facilities and production cycles, applying respectively landfill mining and circular economy approaches, can offer not only economic but also environmental and social benefits. In order to assess, quickly, whether EW facilities prove to be sufficiently rich to become potentially exploitable, the use of investigation protocols and decision support tools (DST) are here presented.

Tools and protocols help in deciding if an EW facility is worth to be consider as "sustainable exploitable" to improve RM and CRM supply from anthropogenic deposits. In particular, trying to provide, depending on the quality of site-specific data, preliminary or secure assessment of the feasibility of EW exploitation, incorporating the social, environmental and economic factors involved in exploitation processes, a DST for EW has been defined. This tool investigates EW facilities both with quantitative (technical, economic, environmental) and qualitative (social) data. The outputs of the DST are represented by several possible scenarios, useful to decide if and how to approach EW exploitation. The DST uses site-specific information to identify which parameters contribute to make EW viable, the costs and benefits, the social and environmental impacts and the fittest process to mine the EW facility. Thanks to the DST it is possible to study different alternatives for EW exploitation: for example, remediation of the EW facility area; production of filling materials for road construction and infrastructures, SRM for aggregate production in-situ or off-site; exploitation of RM and CRM, etc. It is fundamental to define the type of EW facilities interested by the recovery and to propose different scenarios for EW recovery and associate to each of them the technologies and actions necessary for obtaining specific products.

Protocols for investigation at field and laboratory scales together with DST have been tested and validated using data and processing flow chart of real case studies: one of them will be here presented.

Standardization of innovative construction products as a tool for market up-take

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Keywords: standardization, construction products, secondary raw materials.

To advance the objectives of the European Green Deal and the Circular Economy Action Plan, the use of secondary raw materials in construction is promoted through the development of innovative construction products. However, the introduction of new products in the construction industry requires involvement of the standardization. This often means that relevant standards, such as harmonized standards, need to be identified for the assessment of products under the Construction Products Regulation (CPR). In cases where such standards do not exist, alternative routes, such as European or national assessment procedures, must be considered.

This contribution looks at waste management legislation, the processes for converting waste into products and construction product regulations. The most important aspects of EU legislation on waste (e.g. the Waste Framework Directive and the Landfill Directive) and construction products (in particular the Construction Products Regulation-CPR and REACH) are presented. It also outlines the legal framework for the transformation of residues from waste into products. When waste is classified as such, its use for construction purposes is subject to environmental and health protection requirements laid down in both EU and national waste legislation. However, once ceases to be waste, it is considered a product and falls under product-related legislation. Consequently, the use of waste in construction is regulated under the CPR by harmonized European product standards (hENs) and REACH. In cases where there are no EU-level criteria for waste streams, individual Member States set their own End-of-waste (EoW) criteria. According to EU regulations, CE marking is mandatory for products covered by the CPR if a hEN exists. For novel or innovative products that are not covered by a hEN, manufacturers can obtain the CE marking through the European Technical Assessment and the associated assessment and verification of constancy of performance (AVCP) procedures.

Selected examples from our recent European research projects dealing with the use of various secondary raw materials in construction products and possible EU procedures for the legal market introduction of these products will be presented. These projects envisage the incorporation of construction and demolition waste, steel slag or biomass ash into non-traditional concrete materials. Overall, these examples illustrate the potential benefits of using secondary raw materials in construction products and the need for regulations to support their market introduction, resulting in innovation drive and creation of a more sustainable built environment.

Transforming extractive waste into ceramic innovation: a comprehensive characterization and recycling study

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Keywords: extractive waste, raw materials, ceramic industry.

The recycling of extractive waste (EW) holds the promise of transforming landfills into valuable resources akin to "new mines," benefiting quarrying and recycling industries, as well as the environment and society. Thorough characterization of the selected EW are essential to find the most suitable industrial field of application, as the potential for recovery largely depends on the waste's chemical composition, mineral makeup, and physical properties.

This study focused on EW obtained from a company specializing in producing construction aggregates. These aggregates primarily consist of organogenic limestone and calcarenites. The extraction process involves blasting the ore, followed by transportation to two separate dressing plants for crushing, washing, and sieving. The EW originates from two water clarification systems treating effluents from the aggregate washing plant. These systems collectively generate around 120 tons per day (15-20 thousand tons per year) of waste silts, categorized as non-hazardous special waste under Italian regulations. Typically, these silts are used for restoration within the quarry or deposited in excavation voids or landfills for environmental projects beyond the extraction site. Additionally, this waste was previously utilized in concrete production at a local cement plant until its closure in 2009.

In this project, four batches of waste silts (WS) underwent chemical, mineralogical, and rheological characterization. They were then incorporated into different batches for porcelain stoneware tiles. Subsequently, ceramic tile production was replicated at the laboratory scale, and the final ceramic products were thoroughly characterized.

Qualitative and quantitative analyses of mineralogical compositions was performed by combining thermogravimetric analysis (TGA), calcimetry, elemental analysis (EA), and X-ray powder diffraction (XRPD). XRPD data from randomly oriented samples were refined using the Rietveld-RIR method. All waste silts (WS) showed significant amounts of carbonates (70-80 wt.%), predominantly comprising calcite and ankerite. XRPD analysis of oriented specimens revealed the presence of a minor fraction of clay minerals (also confirmed by TGA), including mica (likely glauconite-illite more than muscovite), illite-smectite (IS) mixed-layer clays, and kaolinite.

From a textural perspective, we examined the particle size distribution of the WS using laser diffraction. All samples exhibited a trimodal distribution, with major components around 30 and 5 μm and a minor component below 1 μm. Overall, the four batches demonstrated high homogeneity, indicating readiness for industrial implementation, particularly where large and uniform volumes are necessary.

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Processing waste of quartzite from Jaipur District (India) as secondary raw materials for cementitious adhesives

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Keywords: Indian quartzite, stone waste recycling, cementitious tile adhesives.

Waste deriving from quarrying operations of heritage stones, which are widely used in social and economic contexts despite the possibility of pollution given by tools' wear and tear, retain almost all the mineralogical and compositional characteristics of the original material. This research aimed to test prototypes of tiles' cementitious adhesives made up recycling quartzite waste used as fine and ultra-fine aggregate (UNI EN 8520-1, 2005). Particle size distribution analysis, along with X-ray diffractometry, X-ray fluorescence and Scanning Electron Microscopy were carried out to characterize the waste. Experimental research involved the mix-designing of three dough formulations tested by using different types of tiles with different grip. Fresh doughs were tested for reology and cured for normative requested time after being stuck on a concrete support as reported in standards (UNI EN 12004-2, 2017). Adhesives' technical performances were evaluated by the Pull-Off test allowing us to acquire results for high initial tensile adhesive strength (UNI EN 12004-1, 2017; UNI EN 12004-2, 2017). Experimental results carried out in this research proved the possibility to use huge amounts of waste coming from Indian stone industry in cementitious adhesives' sector without compromising technical performances, proposing itself as an alternative method to landfill disposal for this waste.

UNI EN 8520-1 (2005) - Concrete aggregates - Supplementary instructions for the application of EN 12620 - Part 1: Designation and conformity criteria.

UNI EN 12004-1 (2017) - UNI EN 12004-1 Adhesives for ceramic tiles - Part 1: Requirements, assessment and verification of constancy of performance, classification and marking.

UNI EN 12004-2 (2017) - UNI EN 12004-2 Adhesives for ceramic tiles - Part 2: Test methods.

The role of secondary prospectivity of mine waste for enhancing critical metals recovery in South Australia

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Keywords: critical minerals, tailings, South Australia.

According to its Critical Minerals Strategy of 2022, Australia aims to turn into the "global critical minerals powerhouse" by 2030 by becoming an integral part of the international critical minerals supply chain (DISER, 2022). The Mine Waste Transormation through Characterization (MIWATCH) group is applying a set of integrated geometallurgical tools to assess the secondary prospectivity of mine waste across Australia to find new sources of critical metals.

The primary focus of these studies is to determine critical metal abundances and their modes of occurrence in tailings, stockpiles and waste dumps of operational and/or abandoned mine sites. This is achieved by a preliminary compilation of the relevant available information from public and confidential sources. A targeted mine waste sampling follows and uses a comprehensive set of analyses, including multi-element geochemical analysis (ICP-MS) and targeted mineralogical and geochemical characterization of selected representative samples (MLA; XRD; LA-ICP-MS).

MIWATCH in conjunction with the Geological Survey of South Australia (GSSA) has identified there is potential to explore for critical metals in mine waste materials across the state forming part of this new supply chain. The initial phase of this research focused on the identification of mine waste with potential to host economic accumulations of critical metals in South Australia. For this desktop study a ranking criteria was created using five key inputs based on data available from the Mines and mineral deposits (MinDep) database, accessed via the South Australian Resources Industry Gateway (SARIG). The criteria included, i) mine status; ii) known commodity; iii) associated commodity; iv) discovery year and, v) mine waste feature/s. The ranking was used to identify abandoned/historic mine sites with a high probability of containing critical metals in the mine waste.

The results of the desktop study indicate that South Australian mine waste is fertile in metals including Co, Cu, Ni, REEs and Au (particularly within the Adelaide Rift Complex, Gawler Craton, Nackara Arc, Kanmantoo Group and Willyama Supergroup). The second phase of this research involves integrated characterisation of the chemistry and mineralogy of mine waste from the sites identified in phase one, including Kanmantoo, a copper mine site (currently under manteinance) located southeast of Adelaide.

Acknowledgements: Department of Industry, Science, Energy and Resources [DISER] (2022) - 2022 critical minerals strategy.

Geochemical and environmental evaluation of trace metals within newly constructed technosols: risks and potentials for large scale applications

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Keywords: mineral waste, technosols, greening and land reclamation.

Mineral wastes coming from demolition activities, including rock and soil from excavations, and extractive industry, represent the first and the second source of waste production at EU level (35.9% and 26.6% respectively). Although some of these waste products can cause environmental and economic problems if not adequately managed and disposed, they represent an alternative resource for civil, building, infrastructure and environmental applications.

This study introduces the state of the art of the research and applications of products arising from mineral waste, with a focus on new potential application of fine fractions for artificial substrate production (namely technosols). The agronomic characteristics of the produced technosols were tested to evaluate their use and the environmental criticalities for land rehabilitation and urban greening. In particular, it is intended to evaluate the different technosol combinations and check for the best yielded results to implement in a large scale mesocosm. A geochemical and agronomical characterization of the produced mixed has been carried out and the results show that total concentrations of trace metals, particularly the potentially toxic metals (e.g., Cd<0.1 mg/kg) of most tested mixes are within permissible limits indicating that the technosols reflect no hazard of metal contamination. The evaluation of the agronomic properties of the soil revealed that the germination rates are higher than expected. Meanwhile, the phytotoxicity rates are relatively low and remained tightly associated to the metal content. All of the results confirmed that, when properly managed and treated the mineral waste fine fraction could be effectively employed for land rehabilitation at large scale.

The application of such materials could largely boost the circular economy by preserving natural soil and recycling the continuous flows of mineral waste, such as extractive waste (in particular residual sludge from dimension stone industry) and construction and demolition waste.

Sustainable and circular management of mineral waste contributes to guarantee raw materials supply, contemporary reducing environmental (including CO_2 production) impacts associated to waste management and landfilling. The potential decrement of environmental impacts and CO_2 production will contribute to enhance the NET-zero greenhouse gas emissions EU strategy.

Sustainability in geo-resource management through shared competence-building projects. The example of GEODES Erasmus Project

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Keywords: sustainable development and georesources, geology and mining engineering high education.

Natural resources, and in particular geo-resources, are a precious and irreplaceable asset, which have always been of primarily economic interest, and only secondarily of environmental and social interest. In recent decades, the concept of sustainability and sustainable development has become increasingly concrete and the social and environmental problems associated with human activities in the management and use (exploitation) of natural resources have been recognised.

Sustainable and responsible management of geo-resources requires rethinking and redesigning our production and consumption patterns through an awareness of the natural environment as a common good to be preserved and knowledge of the close link between the natural environment and the socio-economic system.

The training and education of all actors involved in geo-resource management are necessary tools to activate a profound change in human attitudes at the individual and societal level, to develop critical, ethical and conscious thinking, and to acquire the technical skills needed to solve local problems.

Knowledge of existing innovative technologies, impacts and complex environmental, health and socio-economic dynamics is essential to develop awareness of the need to respect and conserve geo-resources and to adopt sustainable policies and techniques that respect the environment and local society.

In this context the Erasmus project GEODES, which is the continuation of the past Erasmus project SUGERE, aims at standardising and implementing training curricula for teaching mining engineering and geosciences in non-EU countries (focus on Angola and Mozambique).

GEODES project brings together 3 European universities, 2 African universities with advanced structures and extensive teaching experience in geosciences, already present in the SUGERE project, and 4 new African institutions from Angola and Mozambique.

The GEODES project fosters new collaborations at an international level focused on sustainable development in the geomining context. The strengthening of geoscientific skills and the exchange of experiences allows us to develop modern strategies for the responsible and sustainable management of natural resources and acquire the ethical values necessary for solving local problems.

It contributes, together with SUGERE, to achieve this objective through a strong network of sharing, exchange and research activities between European and non-European universities.

The culture of sustainability and education for sustainable development are the basis for the development of critical thinking and the right skills to solve local problems. The path towards environmental and social sustainability of the ‘wise’ use of geological resources leads to a ‘rethinking’ of ‘our’ way of producing and consuming in an intergenerational perspective, through an ever deeper understanding of the ethical value of the interrelationships between factors socio-economic and natural systems.

Toward novel strategies for consolidating earther cultural heritage manufacts

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Keywords: adobe, climate change, consolidation.

The impacts of climate change are evident worldwide, with rising temperatures, rising sea levels and the increasing frequency of extreme weather events. With international initiatives dating back to the first World Climate Conference in 1979, followed by the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and subsequent global conventions such as the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, the world has acknowledged the urgency of addressing this pressing issue (Ford et al., 2016). Although considerable efforts have been made to reduce greenhouse gases emissions, the inevitability of some degree of climate change has prompted the need to focus on adaptation strategies in many aspects of human life.

While the world grapples with the multifaceted challenges of adapting to climate changes, one area that emerges as exceptionally vulnerable is cultural heritage, in particular archeological sites that are typically exposed outdoors and now face an unprecedented threat as climate change disrupts established weather patterns and introduce unpredictability. This problem needs adaptive measures to enhance the resilience of this valuable heritage. In the frame of a PhD project we are addressing possible strategies for consolidating earthen manufacts consisting of adobe bricks, a typology of construction that has been widely used throughout the human history (the oldest structures in earth dating back to 8300 B.C.) and that is still commonly used worldwide. To this purpose, we investigated two strategies including (i) making stronger adobes by adding different reinforcing agents within the starting material and (ii) coating the traditional adobes with potentially erosion resistant materials. The starting bricks for the experiments were prepared from a clayed soil added with straws and ashes, such as to reproduce the original composition of ancient mud bricks (Adorni et al., 2012), and drying the samples at 40°C in a laboratory oven. The used additives include different amounts of nano-idrossiapatite (Capitelli et al., 2020) and a mixture of MgO and MgCl (sorel cement). The latter agents have also been used for the coatings by spraying them to the surface of the adobes. The samples have been subject to artificial weathering in a “rain box” by simulating a wide range of rainy conditions and monitoring the evolution of the sample shape by using both a photogrammetric system and a 3D light scanner. While the project is still ongoing the preliminary results provide the first quantitative data on the response of adobe bricks, treated with the different reinforcing agents, to controlled rain weathering. This information is critical to plan future strategies for the preservation of archeological structures of immense heritage value.

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Capitelli F. et al. (2020) - Functional Nano-Hydroxyapatite for Applications in Conservation of Stony Monuments of Cultural Heritage. Proceedings, 62, 11, https://doi.org/10.3390/proceedings2020062011.

Ford J. et al. (2016) - Adaptation and Indigenous peoples in the United Nations Framework Convention on Climate Change. Climatic Change, 139, 429-443, https://doi.org/10.1007/s10584-016-1820-0.

Physical and petrographic features of CDW rubbles of 2016/2017 earthquakes from Central Italy

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Keywords: CDW, XRF, XRPD.

The European Community (EU) states that each nation by 2020 must recycle ≥ 70 wt.% of CDW (construction and demolition waste) (EU 98/2008/EC), accounting for ~ 40 wt.% of waste in Europe (Eurostat, 2020). The amount of CDW is even more compelling in areas hit by adverse events. Advanced recycling of CDW would help the reconstruction process by reducing downfilling and limiting the exploitation of further raw materials. However, the upcycling recycling of CDW is still a challenge due to the low and heterogeneous physic-mechanical performances of some CDW types (Galderisi et al., 2023). They have to be sorted into homogeneous fractions with defined and constant features. Here, textural, mineralogical, chemical and physical characteristics of highly heterogeneous CDW rubbles produced after the 2016-17 seismic events in Central Italy are investigated. More than 200 cm-sized CDW samples were first visually inspected to determine their mesoscale texture and colour; then, their density was determined (Galderisi et al., 2022). These CDW were grouped into six categories: concretes/mortars, natural stones, tiles, bricks, perforated bricks and roof tiles. 25 representative specimens were analysed with XRPD (X-Ray Powder Diffraction) to identify and quantify crystalline and non-crystalline phases; these XRPD outcomes were corroborated and complemented by XRF (X-Ray Fluorescence) determinations to measure their bulk chemical compositions. Concretes/mortars, natural stones and tiles are whitish to grey coloured with apparent densities > 1900 kg/m3, whereas masonries are coloured with apparent densities usually < 1900 kg/m3. Concretes/mortars and natural stones in this area are rich in calcite (and dolomite) or equivalently in carbonates (CaO- and CO_2-rich) and depleted in silicates; the opposite holds for masonries, while tiles are rich in non-crystalline silicate phases. In parallel, the porosity and water absorption of these CDW categories were quantified; masonries have the largest porosity and water absorption values (≥ 25 % and 15 % respectively), mortars and natural stones the lowest ones (≤ 10 % and 5 %), while concretes plus tile intermediate ones, providing further peculiarities for discriminating these waste. Hence, several mineralogical and chemical aspects correspond to physical features and can be mutually used to identify CDW categories. Only the distinction of ceramic-like CDW categories can be applied to plan effective sorting procedures. Homogeneous, dense, poorly porous and water-absorbing separated CDW can be used to produce RAC (recycled aggregate concretes) with defined and constant performance. By contrast, light, porous and water-absorbing separated CDW can be recycled for downcycling applications or used for unexplored uses considering their chemical attributes. This damaged area of Central Italy could represent a unique opportunity to experiment with innovative selection procedures.

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Sonic drilling: evaluation of the best techniques for tailings and mining waste exploration and valorization

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Keywords: sonic drilling, waste.

Sonic Drilling is an advanced form of drilling that employs the use of high frequency resonant energy to advance a barrel or casing in underground formations. During drilling, the resonant energy is transferred by the drill head to the drill string at various sonic frequencies. The main advantages are: high performance and high recovery rates in poorly consolidated or fractured material such boulders, sand and heterogeneous material; dry drilling or with low water content; minimization of drilling discard: about 70% less discard compared to traditional drilling; straight holes with minimum deviation; up to 4 times faster compared to traditional drilling; big core diameters.

Most of the current applications are related to exploration drilling, for example: titanum exploration in sands; lithiums exploration in salars; bauxite, kaolin, uranium, REE (Rare Earth elements) in clays. Other relevant applications are related to the characterization of heterogeneous material present in tailing dams, stock and waste pile. Actually this technique is mostly used in Australia, USA, Canada, Brazil ,Cile, and in few European countries (Orberger et al., 2018, 2019; González-Díaz et al., 2022, Santos et al., 2022) and it is innovative for mining dumps exploration.

In addition the main goal of Europe Commision highlighted in recent Critical Raw Material Act is to investigate the potential for recovery of critical raw materials not only from extractive waste in current mining activities but also from historical mining waste sites. For all the above mentioned reasons this technique could be a interesting opportunity of exploration with the objective of circular economy in the mining sector.

The research aim to give an overview of the exploration activities by means sonic drilling of Horizonte Mineiro Serviços Geológicos Ltda, in Brazil in order to select the best technologies to be used for the mining tailing storage facilities and waste rock dumps in Europe.

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Orberger B. et al. (2019) - Sonic drilling coupled with on-line-on-mine-analyses: field tests at the Villeveyrac bauxite deposit (Southern France). In 15th SGA Biennial Meeting on Life with Ore Deposits on Earth 2019.

González-Díaz E. et al. (2022) - Geochemical, mineralogical and geostatistical modelling of an IOCG tailings deposit (El Buitre, Chile): Implications for environmental safety and economic potential. Journal of Geochemical Exploration, 239, 106997.

Santos S. et al. (2022) - Technical feasibility study of the exploitation of seabed potassium salts by solution mining. Journal of Materials Research and Technology, 16, 433-441.

Sardinia's mining heritage revaluing: a path to sustainable critical raw materials extraction

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Keywords: mining dumps, circular economy, resource revaluation.

Modern societies rely heavily on critical raw materials (CRMs) for advanced technologies. However, Europe currently imports most CRMs, often from regions with unstable geo-political conditions. To address this, the 2024 CRM Act promotes using Europe's own resources, especially recycled materials from old mines and industrial waste. The success of this plan depends on identifying and analyzing these potential sources across Europe. Sardinia, the most important historical mining region of Italy, must be regarded as a primary target in southern Europe. The past mining activities in the region were oriented to base metals (Pb, Zn, Cu, etc.), baryte, and fluorite. In about 150 years of industrial mining, about 70 Mm3 of mining dumps were produced (Regione Autonoma della Sardegna, 2003).

Our project starts from a regional-scale mapping of the historical mining wastes of Sardinia, to obtain a new database aimed at identifying and hierarchizing the deposits of possible economic interest. Data coming from previous databases were verified and implemented through GIS software. Available ore geology, mineralogy, and geochemistry data from the mined bodies (metallogenic and georesources map of Sardinia: Tocco et al., 2008), together with deposits' volumetric size and with data on minerallurgical processes, allowed a first compositional classification and a preliminary hierarchization of the mining wastes. Over 1200 mining dumps in 109 mine sites of Sardinia have been up to now classified. On selected mine sites, CRMs contents in the wastes are verified with field surveys, sampling, and physical, mineralogical, and geochemical characterization of waste materials by XRF, XRD, ICP-MS and SEM-EDS. First studies were performed in the Montevecchio Pb-Zn mine (SW Sardinia). In the tailings still accumulated in the western plant area, up to 600 ppm of LREE were found, together with up to 1.2% Pb, and 2.6% Zn (Sedda et al., 2024). These metals are related to mineralogical phases – monheimite [(Zn,Fe)CO3], synchysite [Ca(Ce/Nd/Y/REE)(CO3)2F], bästnasite [(Ce/Nd/Y/REE)(CO3)F] and xenotime [Y(PO4)] - once discarded with the quartz-carbonate gangue during ore beneficiation. Similar studies are now ongoing in other mine areas of SW Sardinia where significant contents of CRMs and strategic minerals have been found in Santa Lucia (fluorite, LREE, Ni, Co), Seddas Modditzis (Zn, baryte), and San Leone (fluorite, W, Bi, Sn, Mo). Overall, these preliminary data are indicative of a high secondary raw materials potential of the historical districts of Sardinia and are the necessary premise and a first step in a path for their future sustainable recovery. Reusing these materials brings significant advantages beyond just Europe's resource supply. It can restore polluted areas and ecosystems and improve public health. There's even potential to use leftovers from the recycling process to prevent cave-ins in old mines, like sinkholes (Manca et al., 2014), ensuring safety for the people.

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Sedda L. et al. (2024) - Unlocking Strategic and Critical Raw Materials: Assessment of Zinc and REEs Enrichment in Tailings and Zn-Carbonate in a Historical Mining Area (Montevecchio, SW Sardinia). Minerals, 14(1), 3, https://doi.org/10.3390/min14010003.

Tocco S. et al. (2008) - Carta metallogenica e delle georisorse della Sardegna. LAC, Firenze.

URBES (URBan mining and Extractive waste information Sistem) Project

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Keywords: CRMA, extractive waste, urban mining.

The general objective of the project is to respond to the need expressed by the EC in the art. 27 of the Critical Raw Material Act to re-verify all the potential and availability of critical raw materials from primary (natural) and secondary (anthropogenic: deposits of extractive waste, municipal waste, electronic waste, construction & demolition etc..) deposits, in a context of sustainability and circular economy. To achieve this target, ISPRA has proposed, within the PNNR RePowerEU, the creation of an intelligent knowledge platform on a geographical basis completely dedicated at a national level to the collection, geolocalisation and visualization of all the information available on: 1. Closed or abandoned storage facilities for extractive waste from mining activities and waste deposits from metallurgical plants; mapping and characterization in terms of CRM and SRM contents 2. Storage facilities for extractive waste from quarrying activities, in the case of possible CRM/SRM content, such as in granites and metamorphic rocks 3. Active storage facilities for extractive waste (data provided by managers) 4. Urban Mining, Mapping and characterization of all urban and industrial deposits, potential sources of CRMs/SRMs. The intelligent platform will be implemented by building a geo database that follows the FAIR (Findability, Accessibility, Interoperability, Reusability) principles and a multidimensional document database of all information and unstructured data. The first action for the implementation of the proposal will be the creation of a CTS for the management, coordination, definition of technical actions and dissemination of the entire project. The two-year action will consist of four operational actions, one of which is coordination, one is implementation of the operational platform and two themes as described below Particular attention will be paid to the characterization of the extractive waste deposits of abandoned mining sites and metallurgical plants for the recovery and reuse of critical materials and the mitigation of environmental problems associated with abandoned deposits (acid drainage, diffusion of pollutants by air, contamination in local and vast areas of environmental matrices, possible collapses due to degradation of containment structures, etc.).

EC (2024) - Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework to ensure a secure and sustainable supply of critical raw materials and amending Regulations (EU) No. 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020Text with EEA relevance. Regulation - EU - 2024/1252 - EN - EUR- Lex (europa.eu)

Alkaline-activation of natural and artificial pozzolans as binders for soil treatment

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Keywords: alkaline activation, natural and artificial pozzolans, soil treatment.

The development of soil treatment techniques using alkali-activated binders is a relevant issue since the increasing interest into the use of new sustainable binders as an alternative solution for soil improvement in geotechnical engineering applications.

Alkali activated binders are formed by alkaline activation of an aluminosilicate source, containing precursor materials like pyroclastic soils, fly ash, silica fume, steel sludge, which chemically react with an alkaline solution (i.e. sodium hydroxide, sodium silicate) forming a three-dimensional aluminosilicate gel with cementitious properties (Provis & van Deventer 2014). Recycling of waste materials such as by-product from industrial process and/or valorisation of natural alumino-silica sources (i.e. volcanic pyroclastic deposits) to synthesize a new binders favor a closed loop use of materials, which minimizes the generation of waste and reduces the production costs. Alkali activated binders represent a viable sustainable alternative to the use of ordinary binders for soil improvement (Vitale et al. 2017; Coudert et al. 2021; Miraki et al. 2022).

An insight into the mechanical improvement induced by alkali-activated binders based on the activation of two different pozzolanic materials (i.e. volcanic ash and fly ash) on a clayey soil is presented. An experimental multiscale analysis on chemo-physical evolution of the system and its influence on the microstructural features of treated soil is developed highlighting the link between alkaline activation processes and macroscopic evolution of soil properties. Mechanical tests are performed and interpreted taking into account the chemo-physical evolution of alkali activated binders. Effects of binder content and curing time are also considered. Addition of alkali-activated binders increases shear strength of the treated samples since the very short term. A reduction of compressibility and an increase of yield stress of treated samples are also detected, whose extent depends on the curing time and on the binder content. Macroscopic behaviour of treated soil is linked to the experimental evidences at microscale. Mineralogical and fabric changes induced by alkali-activated binders are monitored over time by means of X ray diffraction (XRD), Scanning Electron Microscopy (SEM) and Mercury Intrusion Porosimetry (MIP). Test results show a high reactivity of alkali activated binders as alumino-silicate source promoting precipitation of new mineralogical phase forming chains and networks with cementitious properties, responsible of the mechanical improvement of the treated soil. The efficiency of treatment is also highlighted by comparing the mechanical performance induced by alkali-activated binders with the one promoted by ordinary Portland cement.

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Miraki H. et al. (2022) - Clayey soil stabilization using alkali-activated volcanic ash and slag. Journal of Rock Mechanics and Geotechnical Engineering, 14(2), 576-591, https://doi.org/10.1016/j.jrmge.2021.08.012.

Provis J.L & van Deventer J.S.J (2014) - eds. Alkali Activated Materials. Vol.13. RILEM State of the Art Reports. Dordrecht: Springer Netherlands.

Vitale E. et al. (2017) - Mechanical behaviour of soil improved by alkali activated binders. Environments, 4, 80, https://doi.org/10.3390/environments4040080.

Critical raw materials supply: challenges and potentialities to exploit REEs f rom siliceous stones and extractive waste

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Keywords: REEs, characterisation, extractive waste.

Critical raw materials (CRMs) supply is a challenge that EU countries have to face, also thinking about domestic procurement from natural ore deposits and anthropogenic deposits (landfills and extractive waste facilities).

The present research focuses on the possibilities linked to the supply of CRM and the potential for exploiting rare earth elements (REEs), investigating a large number of extractive waste and siliceous rocks in the Piedmont Region (Northern Italy). Indeed, the recovery of REEs from the extractive waste (EW) of siliceous quarries and other siliceous ore deposits can be a valuable way to reduce supply chain risks.

Starting with a review of the literature on mining activities in Piedmont, and continuing with the sampling and geochemical, mineralogical, petrographic and environmental characterization of EW facilities connected to siliceous dimension stones, of kaolinitic gneiss ore deposits and of soils present near the investigated areas, this study shows that the degree of REE enrichment differs depending on the sampling area (soil or EW) and lithology.

The concentration of REE in the EW at some sampling sites fulfils the indicators of industrial grade and industrial recovery: the high cumulative production and potential market values of EW, and the positive recovery effects through proven methodologies indicate a viable prospect of REE recovery from EW. However, REE recovery industrialization faces challenges such as the difficulty of achieving an efficient large-scale recovery due to large regional differences in REE abundance, the mismatch between potential market value and waste annual production, etc. Nonetheless, in the future, quarry EW can be differentially studied and reused based on the enrichment and distribution characteristics of trace elements.

The present paper shows investigation procedures, to determine both CRMs potentialities and environmental issues (on the basis of literature data to select the more promising areas and on sampling and characterization activities on the selected areas), together with procedures to determine waste quantities and tentative economic values of REEs present in the investigated areas. This approach, tested on a large area (Piedmont region), is replicable and applicable to other similar case studies (at EU and non-EU levels), and offers decision makers the possibility to have a general overview of the potential available resources, in order to decide whether and where to concentrate efforts (including economic ones) on a more detailed study to evaluate the exploitable anthropogenic deposits.

S47.

Evolution of the Variscan crust

CONVENERS & CHAIRPERSONS

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CRMs prospecting through comparative ore deposit modelling in SW Sardinia

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Keywords: skarn, hydrothermal veins, structural control.

The demand for Critical Raw Materials (CRMs) in the last years brought the need for systematic and large-scale prospecting in fast and efficient ways. Recent studies highlighted the discrete structural control displayed by two types of ore deposits of SW Sardinia: a) mixed sulphides (Cu, Pb, Zn, Fe) skarn deposits with variable contents of W-Sn-Bi, Ni-Co, and F minerals, set along shear zones related to the Variscan Nappe stacking with a low-angle, top-to-the SW transport direction thrusting (Cocco et al., 2022); b) F-Ba (±Pb±Zn) low-temperature hydrothermal veins hosting REEs and subordinate Bi and Ni-Co arsenides-sulfarsenides (Scano et al., 2023) filling high-angle, N-S and E-W striking normal faults with strike-slip components, crosscutting any Variscan structure.

We present two case studies in southwestern Sardinia prospected by comparative modelling: the Rosas Shear Zone (RSZ) and the Santa Lucia-Su Zurfuru (SLZ) areas. In the RSZ, the skarn protoliths are Cambrian limestones sliced within the Ordovician succession by a system of anastomosing NW-SE Variscan thrusts, enhancing the circulation of the mineralizing fluids and the passive structural control on skarn genesis (Cocco et al., 2022). N-S striking F-Ba veins cut the thrusts. In the SLZ, the skarn protoliths and host rocks are analogous to the RSZ: km-sized limestone slices are metasomatised at their peripheries and show a distinct lithological zonation: limestone, marble, and chlorite-skarn. Preliminary field surveys indicate that the limestone slices are cut by later high-angle faults, hosting the F-Ba (Pb-Zn) hydrothermal veins. Decimetre-thick N-S striking veinlets cut across the limestone bodies. The vein system displays a generally good continuity and is distinctly zoned: a) the northern sector is barite-rich, with several generations of fluorite cementing brecciated marble/skarn, rare galena and sphalerite; b) the central zone is constituted by banded fluorite and galena, intercepted by a two kilometres E-W quartz vein that fades into a barite-rich ore at the contact with the limestones; c) the southern part is fluorite-rich and cuts across the skarn ore at depth.

The comparative modelling of RSZ and SLZ helps us to investigate the metallogenic processes that led to skarn and hydrothermal systems emplacements in both areas: a) the RSZ skarn model gave us a key to understanding the general structural setting of SLZ; b) the SLZ hydrothermal veins model suggests some economic potential left in the area and may be used as well as a point of reference for further regional-scale mineral explorations in other related deposits. Globally, skarn and hydrothermal veins are common bearers of CRMs, and the structural-mineralogical comparative modelling we leveraged is an efficient and low-cost way for prospecting and exploring, meeting all the requisites for modern economic needs.

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Scano I. et al. (2023) - From a fluorite vein system to a five-element-type polymetallic vein system? The first evidence of Ni-Co minerals is from the world-class, CRM-bearing Silius deposit (SE Sardinia, Italy). EGU23-7021, http://dx.doi.org/10.5194/egusphere-egu23-7021.

Syn-tectonic plutonism and extensional tectonics in the Variscan orogen: evidence from the Mississippian Reguengos de Monsaraz pluton (Ossa-Morena Zone, SW Iberian Massif)

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Keywords: syn-tectonic porphyroblasts, Mississippian plutonism, Variscan orogen.

In SW Iberian Massif, the evolution of the Variscan belt involved a Mississippian intra-orogenic extensional event, related to the gravity-driven collapse of the thickened continental crust (Pereira et al., 2009). It is consensual that after the continental collision between Laurussia and Gondwana (Late Devonian), continental crust thinning was caused by the rise of a thermal front, associated with plutonism and the formation of gneiss domes. The development of these Variscan gneiss domes at lower structural levels was controlled by tectonic movement along extensional shear zones, formed under low-pressure and medium-to-high-temperature metamorphic conditions (Dias da Silva et al., 2023). Simultaneously, syn-tectonic plutons, like the Reguengos de Monsaraz pluton (Ossa-Morena Zone), were emplaced at upper structural levels composed of metasedimentary rocks deformed by ductile shearing under relatively lower temperatures (Carvalhosa & Zbyszewski, 1991). The emplacement of Mississippian quartz-diorite and granodiorite, and a minor amount of gabbro-diorite and granite (Antunes et al., 2010), was responsible for the genesis of aureole of contact metamorphism in the Ordovician metapelites. The host metasedimentary rocks contain a pervasive S2 foliation that transposes an older fabric/compositional layering (S1 foliation parallel to bedding), suggesting regional, early, tight to isoclinal folding. Many of the early structures probably have been transposed by S2 at least locally, by ductile shearing subparallel to the axial planes of the early folds. The intrusion of hot magma produced a peak assemblage including biotite, andalusite, cordierite and sillimanite rimming the Reguengos de Monsaraz pluton. Close to the contact with the pluton, pelitic hornfels show a pervasive foliation (S2) defined by elongated biotite and andalusite porphyroblasts in a fine-grained matrix composed of quartz, biotite, muscovite, and opaque minerals. Poikiloblastic cordierite and prismatic sillimanite are also present. Moving away from the contact, microlithons lying between S2 foliation that contain a crenulated foliation (S1), are recognized in the lower-grade host metasedimentary rocks. In these spotted metapelites contact metamorphic andalusite (chiastolite) porphyroblasts grew over an older foliation (S1) during the formation of younger foliation (S2) and related intrafolial folds. A rotation of the internal S2 foliation as regards the external S2 foliation is observed. This highlights the synchroneity of magma emplacement of the Reguengos de Monsaraz pluton, the development of S2 foliation, and contact metamorphism.

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New geochronologic and thermochronologic constraints on the Variscan crustal evolution of the Einstein Telescope candidate site of Sardinia (Italy)

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Keywords: Sardinia, exhumation, faults.

Mountain ranges owe their existence to the interplay between tectonics, isostasy, magmatism, and surface processes. To assess their role in the evolution of the Variscan crust of the candidate site for the Einstein Telescope (ET) in Italy, we report preliminary data constraining the regional geochronological and thermochronological evolution. The study area is situated within the high-topography Variscan crystalline basement of northeastern Sardinia. The ET site has been selected for its seismic stability and isolation from significant active faults and hydrothermal activity. To further substantiate this geological stability, we investigate the timing of relief formation.

In this communication, we report the results of U–Pb dating on zircon and apatite (U–Th)/He ages (AHe), to unravel the thermochronological evolution of the studied crystalline area. Our results provide new preliminary constraints on the magmatic and erosive processes as part of our 4D characterization plan for the region. U–Pb analyses on zircon crystals from five samples provide the first age estimate for the magmatism associated with the Bitti intrusion, dated at 320.9 ± 1.0 million years (Ma). Significantly older ages ranging from 479.3 ± 1.3 Ma to 468.5 ± 1.7 Ma have been determined for orthogneisses of the plateau area. To explore the more recent cooling history of the region, samples spaced across an elevation profile have been analyzed and yield AHe ages, ranging from 68 ± 6 Ma on the Mamone plateau to 36 ± 3 Ma in the Rio Mannu Valley near Bitti village.

These preliminary findings indicate that the Bitti intrusive rocks were emplaced during the middle Carboniferous and testify an early magmatic activity that formed the Corsica-Sardinia Batholith. Furthermore, available cooling ages suggest the removal of ~2 km of rocks from the plateau. A first estimate of the exhumation/erosion rates since Paleocene-Eocene time shows very low values (maximum 0.06 mm/yr) compared to a global average of tectonically active regions that are characterized by values between two and four orders of magnitude higher. The geochronological analysis underscores the long-lasting evolution of the Variscan crust while highlighting the limited impact of recent erosion and tectonic activity on its topography. Further U–Pb dating and thermochronological analyses will provide a better understanding of the magmatic and erosive processes shaping the ET candidate area.

Geology of the Asinara Island (Sardinia, Italy)

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Keywords: Asinara Island, Variscan belt, geological map.

The Variscan belt exposed in Sardinia represents an area where it is possible to investigate the inner part of this orogen and a km-scale transpressive shear zone, i.e. the Posada-Asinara shear zone (PASZ), that drove the exhumation of the metamorphic core of the belt (Carosi & Palmeri, 2002). Even though the Asinara island offers very good exposure of main tectonic units building up the Variscan belt of Sardinia, a detailed geological map of the island was lacking, due to a former limitation of access that lasted for many years.

Two juxtaposed complexes have been recognised: the structurally lower Medium Grade Metamorphic Complex (MGMC) and the upper High-Grade Metamorphic Complex (HGMC). The contact in between, i.e. the PASZ, is marked by a km-thick mylonitic zone affecting both complexes. Detailed mapping coupled with multi-scale structural observations allowed the definition of a polyphase evolution consisting of four ductile deformation phases, as recognised in other sectors of the Variscan belt in Sardinia.

The polyphase history recorded in this sector of the Variscan belt in Sardinia emphasises that the Asinara island tectonic evolution started from perpendicular collision (D1 phase) evolving towards an orogen-parallel transpression (D2 phase), continuing with HT/LP metamorphism and magmatic intrusions, then ending with the collapse of the belt. The geological architecture of Asinara island is mainly influenced by the D2 phase linked to the partitioned transpressive activity of the PASZ. The MGMC and the HGMC show strain partitioning in a North-South transect with the development of prevailing folds to the south and non-coaxial deformation with mylonites toward the north. The subsequent granitic intrusions and the prominent HT–LP metamorphism affect this setting, probably related to an HT event during the Permian (Langone et al., 2022).

In conclusion, the new 1:25.000 geological-structural map of the entire Asinara island (Carosi et al,. 2024) is useful to better understand this key sector of the Variscan belt in Sardinia and represents a robust base for other types of investigations.

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Late Variscan age of a metamorphic core complex in the foreland of the Variscan belt: insights from the Mt. Filau Orthogneiss (SW Sardinia, Italy)

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Keywords: Orthogneiss; 40Ar/39Ar mica dating; Variscan Sardinia

The Sulcis Metamorphic Complex (SMC) is a LP-HT metamorphic core complex exposed in the foreland of the Variscan belt in southern Sardinia. It consists of a biotite- and muscovite-bearing orthogneiss (the Mt. Filau Orthogneiss, MFO) together with a pelitic-psammitic host rock (the Settiballas Schist). The SMC is separated from the overlying very low-grade metamorphic units of the foreland by the west-dipping, top-to-the-west, Tuerredda Shear Zone. The MFO crops out with three different facies, a biotite-rich, a leucocratic coarse-grained, and leucocratic fine-grained facies. Two main deformations can be described in the MFO, namely, a high-temperature D1 and a retrograde D2 phase, associated to development of an S1 and an S2 foliation, respectively. In the fine-grained facies, the LP-HT metamorphic peak, coeval with the main S1 foliation, was recorded under conditions of incipient partial melting (<8% of melt produced) in the sillimanite stability field, at ~680–700°C and ~0.32–0.46 GPa (Cruciani et al., 2022). The retrograde P–T path, coeval with the S2 foliation, occurred in the andalusite stability field, and is testified by the growth of andalusite after fibrolitic sillimanite in the fine-grained leucocratic facies. Syn-S1 muscovites of one sample from the leucocratic coarse-grained facies of the MFO have been analysed using laser step-heating and laser *in situ* techniques. The analysed muscovite is a celadonite-poor white mica, with Si within 3.05 - 3.14 a.p.f.u., XNa values between 0.04 and 0.08 and TiO2 contents < 2 wt.%. Preliminary 40Ar/39Ar radio-isotopic data obtained on these syn-kinematic muscovite yielded ages between 290 – 300 Ma. Preliminary 40Ar/39Ar ages of ~285-290 Ma obtained for the white mica in the SMC give evidence of late Variscan deformation under HT/LP metamorphic conditions at depth below the nappe pile in the foreland zone. Syn-S1 partial melting can be linked to a late Variscan, tectonically driven thermal anomaly associated with isothermal decompression of the middle-lower crust, also accompanied to the upward rise of deep hot crust and, possibly, crustal melts. In this scenario, the Tuerredda Shear Zone acted as a preferential channel for upward advection of deep hot melts in the foreland zone of the Sardinia collisional belt.

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Distinct gold mineralisation events in the Variscan mineral system from southern Sardinia (Italy): implications for crustal sources

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Keywords: ore geology, CRMmetallogenesis, mineral deposits.

Sardinia is a transect of southern Variscan Belt characterized by External (SW), Nappe (SE and Central) and Axial Zone (N). From late Carboniferous to early Permian, dextral mega-shears developed in the southern sectors of the Meso-European crust (South Variscan Shear Zone) promoting westwards transport and >90° clockwise rotation of Sardinia. The metamorphic basement was intruded by many post-collisional coalescent igneous complexes forming the Sardinia-Corsica batholith which grew during two main magmatic peaks at about 305 Ma (Old Magmatic Peak, OMP) and 285 Ma (Young Magmatic Peak, YMP). The contribution of crustal melts increased with time along sheared and post-collisional extensional structures. Reworking of crustal material occurred in response to combined deformations, regional metamorphism and extensive magmatism promote the development of two distinct gold metallogenic events in the Sardinian Variscan Mineral System (SVMS: Naitza et al., 2024).

A former amagmatic metallogenic peak consists of As-Au±Sb±W orogenic-type deposits, aligned to mylonitic belts and cataclastic shear zones of SE Sardinia (Baccu Locci Mylonite Zone; Villasalto thrust. A telescoped zonation of deeper Pb-Zn-Cu-Ag(±As±Au±Sb) and shallower As-Au-Sb-W ores is common. The stages of formation of Au-rich ores have been schematized as: earlier sheeted/stockwork veins with arsenopyrite-quartz±scheelite from hot (300-310°C), CO_2-bearing and low-salinity hydrothermal fluids and late Au-stibnite-scheelite-quartz and Zn-Pb-Cu sulfides from cooler (< 270°C), CO_2-poor and low-salinity fluids. Radiometric dating (Dini et al., 2005, and new determinations on scheelite) constraint the mineralisation within a broad range of 307-260 Ma.

A late metallogenic event produced several Sn-W-Mo-Bi(±As±F) granite-related and Au-Bi-Te-W Reduced Intrusion Related Gold Deposits (RIRGD). In SW and SE Sardinia, these deposits are linked to ilmenite-bearing granites (GS1 suite: Conte et al., 2017) belonging to the YMP. The RIRGD consist of hornfels-hosted sheeted quartz veins with ferberite, Bi-tellurides, Bi-Au alloys, Bi-wolframates and native Bi. Fluid inclusions on quartz indicate temperatures of formation in the range of 430-230°C from vapor- and CO_2-rich fluids; U/Pb dating on ferberite indicates an age of 290 Ma. Overall, the SVMS developed from late Devonian to late Permian, with two peaks of activity around 305 and 290 Ma that produced orogenic-type deposits in the SE and RIRGD in SW Sardinia. Metallogenic peaks overlap with post-collisional shearing, uplift and extension and the production of OMP and YMP magmatism. Thus, the differences in metals budgets and types of Au-bearing mineralisation from southern Sardinia were inherited from pre-Variscan crustal sources with distinct geochemical signatures such as Au-Sb-fertile Ordovician continental arc and Silurian black shales, more common in the SE, and an inferred, Mo(-W-Sn)-enriched Precambrian crystalline basement in the SW of the region.

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Mississippian gneiss domes and synorogenic basins: keys to understand the Variscan collisional orogen

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Keywords: gneiss domes, synorogenic basins, Variscan belt.

The relationship of gneiss domes and sedimentary basins is of great interest for understanding an orogen. Gneiss domes (GD) are flat-lying tectono-thermal structures, usually related to the fast thinning of continental crust. They are caused by the high thermal influx that invades the upper crust, related to the rapid exhumation of deeper levels. This phenomenon is responsible for the partial melting of the continental crust and lithospheric mantle, and the resulting magmatism.

As a response to this crustal thinning, extensional shear zones develop in depth in conditions of low pressure (LP) but varying from high (HT) to low temperature (LT). Consequently, topography in the hanging-wall of GD reacts forming horst-graben systems and sedimentary basins. In the Iberian Massif (IM) (Variscan orogen), Mississippian GD and sedimentary basins are described as synorogenic. They were formed as a response to the gravity-driven collapse of the thickened crust after the Late Devonian continental collision between Laurussia (upper plate) and Gondwana (lower plate) (Alcock et al., 2015).

In the IM, Mississippian sedimentation was locally synchronous with volcanic activity, linked in time and space to the syn-tectonic plutonism and the development of GD (Pereira et al., 2012, 2020). Tectono-metamorphic evolution of this orogenic extensional event strongly overprinted the earlier tectonic fabrics.

It seems unlikely that these basins were formed in a foreland, backarc, or forearc setting related to the subduction of the Rheic oceanic lithosphere, given that the Laurussia-Gondwana collision occurred earlier. Their tectonic evolution is believed to be controlled by a notable thermal anomaly beneath the orogen, but the tectonic setting remains under discussion. Recently, two models have been proposed (Dias da Silva et al., 2024): Model A) suggests that following the subduction of the Rheic oceanic lithosphere beneath the upper plate (Laurussia) and the ensuing continental collision, the roll-back of the lower plate was responsible for the formation of an orogenic plateau, the lateral flow of partially molten orogenic roots, and peel-back tectonics; in this case, Mississippian synorogenic basins are considered of peel-back type; and Model B) assumes that the ongoing subduction of the Paleotethys oceanic lithosphere (lower plate), following the Devonian continental collision, provides a reasonable explanation for the onset of a magmatic arc in Gondwana (upper plate); As a consequence, Mississippian synorogenic basins are considered of backarc type.

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Geological investigations at Einstein Telescope site of Sardinia (Italy): preliminary results

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Keywords: structural analysis, Variscan basement, geological modeling.

The Einstein Telescope is a large underground facility designed for gravitational wave detection. One of the candidate sites to host the infrastructure is near the area of the disused Sos Enattos mine (Sardinia). In the framework of the SAR-GRAV and FdS-2021 projects, we performed new geological investigations in the area comprised within the potential vertex (Bitti-Lula-Mamone) limiting the ET triangle, aiming to assess the geological, structural, and hydrogeological conditions. For this purpose, we adopted a multidisciplinary approach involving detailed geological, structural and petrological investigations, and groundwater sampling and analysis (both water chemistry and stable isotopes δD, $\delta^{17}O$ and $\delta^{18}O$). The geological setting of the Sos Enattos area is characterized by metamorphic and magmatic rocks belonging to the Variscan basement. The metamorphic rocks mainly consist of mica-schists, paragneisses and orthogneisses; the magmatic rocks, belonging to the Variscan batholith, are mainly granites and granodiorites, and related dyke complex (Carmignani et al., 2016). Make a comparison with the available published maps, new field data show a more complex geological setting of the study area, characterized by a higher variability of the outcropping lithologies and structures. In particular, a 500 m2 granite intrusion has been detected far from and apparently not in continuity with the other mapped intrusions. Moreover, near to the granite intrusion occur several NE-SW striking aplitic dykes, variable in thickness from a few to tens of meters, never mapped until now. NW-SE striking mafic dyke are also present in the area. The main structural features are the SE-dipping schistosity affecting the metamorphic rocks, and strike-slip faults with a predominantly NE-SW orientation, often paired with dykes. Preliminary petrological data confirm previous works and will be supported by new P-T-t estimates in the near future. Groundwater chemistry varies from Cl-Na compositions to Ca-Mg- bicarbonates in agreement with the lithologies of the area, some samples showed relevant metal concentrations (Al, Fe, Mn). Isotopic composition, close to the South Italian Meteoric Water Line (Giustini et al., 2016) indicates a meteoric origin of water, and does not show evidence fractionation processes.

These preliminary data have been organised in a geodatabase and will be the base to implement a 3D geological model of the area and assess the underground fluid circulation. The new evidence of granite intrusion, dykes and faults suggest that the available geological maps need to be extensively updated to get a 3D geological model as detailed as possible of the area that possibly will host the Einstein Telescope.

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The Variscan basement of Sardinia: state of the art and open questions

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Keywords: tectonics, nappe structures, ore deposits.

The gross structure and evolution of the Variscan basement in Sardinia have been convincingly defined since the 1980s. A Barrovian metamorphic zonation has been recognized, which has allowed the subdivision of the Sardinian basement into three main tectonic zones, separated by regional ductile-brittle shear zones. This tectonic zones show deformation and regional metamorphism increasing from the inner to the external zones (from SW to NE in present -day coordinates), as expected in fold and thrust belt. During the post-collisional stages, an extensional tectonics mainly related to uplift and exhumation occurred and the basement was intruded by a large-scale emplacement of Variscan granitoids.

Nowadays, the main research topics on the Variscan basement of Sardinia concern: a) the pre-Variscan geodynamics, mainly focused on the Ordovician Period; b) the collisional evolution of the nappe stack and tectonic units provenance; c) the kinematics and timing of the late Variscan strike-slip tectonics; d) the mechanism and lithospheric processes leading to the emplacement of the batholiths; e) the metallogenic stages recorded in Sardinia and their relationships with the Variscan orogenic cycle.

The new research on these topics is rising new questions whose answers are essential to better understand not only the structure and evolution of the Variscan Basement in Sardinia, but also the pre-Variscan and the orogenic phases at the scale of the southern Europe Variscan Belt.

The studies on the Ordovician stratigraphic succession and structures of the External and Nappe zones suggest that the Sardinian basement consists of lithospheric blocks that pertained to different geodynamic settings along the northern Gondwana margin. This implies that the Middle Ordovician Sardic and Sarrabese phases are no longer correlatable, and further research is needed to depict the pathway leading to the current structural framework as External and Nappe Variscan zones.

Recent studies suggest a more complex structure of the Nappe stack compared to the previous interpretations. In particular, the occurrence of the Arburese and Bithia Unit directly overthrusting the External Zone, still needs an explanation in the general framework of the belt structure, considering that the Bithia Unit shows a more intense deformation and a higher metamorphic degree than the Arburese Unit, apparently violating the classic ‘nappe rule’.

Studies on the sediment provenance based on detrital zircon will help to shed light on the geological history of the tectonic units now constituting the Nappe structure of the basement, including the role played by the mega-transcurrent faults well known in the European Variscan basement.

Other open questions concern deeper structural levels of the crust, as the batholith emplacement and the related metallogenic processes. It is noteworthy that immediately after the increase in knowledge on the tectonic structuring of the Sardinian Variscan basement, a systematic revision of the metallogenic models in vogue until the 1980s and 1990s began.

Preliminary data from fieldwork in the framework of the CARG Project 546-Guspini (SW Sardinia)

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Keywords: Variscan basement, backthrust, ore deposits.

The new geological and structural data collected in the framework of the CARG Project (Geological Map of Italy 1: 50,000) – sheet no. 546-Guspini highlight some differences compared to the existing geological maps of this area and rises new hints on the structural style of this sector of the Variscan basement.

The Variscan basement outcropping in the study area includes the Arburese Thrust, a first-order shear zone that separates the Variscan External Zone of SW Sardinia from the Variscan Nappe Zone, in this area represented by the Arburese Unit, the shallower tectonic unit of the Variscan Nappe stack in Sardinia. A portion of the late Variscan Arbus Pluton, belonging to the Corsica-Sardinia batholith, is also comprises in the area of the sheet.

The stratigraphic succession of the External Zone of the sheet 546-Guspini spans in age from lower Cambrian to Devonian, with a Middle Ordovician stratigraphic gap related to the Sardic Phase, consistently with that known in the rest of the External Zone. However, in the available geological maps, the different formations are not properly distinguished, giving rise to inconsistencies and/or oversimplification of the structural setting of this area.

In particular, we recognized for the first time a thrust affecting the Cambro-Ordovician succession to the SW of the Fluminimaggiore village. The thrust strikes N-S to NE-SW and dips to W-NW. This structure allows to better explain the geometric relationships between the pre-Sardic lower Cambrian limestones and upper Cambrian-Lower Ordovician siliciclastic succession, and the post-Sardic sequence. Up to now, the limestone outcrops were interpreted as normal fault bounded blocks, whereas they are tectonic slices embedded within the Upper Ordovician succession. The sub-horizontal tectonic foliation developed along the tectonic contacts corroborates this interpretation. Furthermore, the new thrust mapped seems contiguous with the Acquaresi backthrust outcropping further to the south.

Another structural characteristic of this area, previously underestimated, is the relevance of several post-Variscan faults that affect the basement, making the reconstructions of the Variscan deformation harder to unravel. These faults strike NW-SE and are sub-vertical, with slickenlines that suggest oblique to strike-slip kinematics. The NW-SE striking faults host F-Ba (Pb-Zn) hydrothermal veins where they cut across the limestone slices.

To the east of the Fluminimaggiore village, new data suggest that the available maps, showing only an indistinct siliciclastic Upper Ordovician succession, can be improved by distinguishing the 5 Upper Ordovician formations defined for the External Zone. An intriguing feature is the main tectonic foliation that dips to the north, inconsistently with usually observed in the other sectors of the External Zone.

The age of the post-Variscan faults and the understanding of the deformation processes leading to the change in the main foliation attitude are the next tasks we will focus on.

Constraining the deformation in transpressive shear zones: insights from the Monte Grighini Shear Zone in Sardinia and implications for the Southern European Variscan belt

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Keywords: mylonites, East Variscan Shear Zone, petrochronology.

Dome-shaped structures, characterised by a core of high-grade metamorphic or granitic rocks surrounded by low-grade rocks, are important tectonic features in collisional orogens (Cao et al., 2022). Their origin and setting are still debated, and recent studies have highlighted the importance of strike-slip movement, i.e., transcurrent, transtensional or transpressional tectonics in their formation. Thus, unveiling the evolution of shear zones that drove the dome's exhumation requires a multidisciplinary approach combining structures with petrochronology.

This work presents an updated view of the tectono-metamorphic history of the Monte Grighini shear zone (MGSZ) by integrating field observations, meso- and microstructural data, vorticity analysis, pressure-temperature (*P*-*T*) estimates and in-situ U–(Th)–Pb geochronology of monazite. The study area is characterised by a pure shear-dominated dextral transpressive deformation partitioned into low- and high-strain domains. Geothermobarometry of a sillimanite-bearing mylonitic metapelite indicates that the MGSZ developed under H*T* (~ 625 °C) and L*P* (~ 0.4-0.6 GPa) conditions. In-situ U-(Th)-Pb monazite geochronology reveals that the deformation in the shear zone initiated at ca. 315 Ma. While previous studies have interpreted the MGSZ to have formed at ~ 305-295 Ma in a transtensional regime (Musumeci, 1992; Cruciani et al., 2016), our results indicate that the MGSZ shows similarities with other late-Carboniferous dextral ductile transpressive shear zones both in Sardinia (i.e., the Posada Asinara shear zone) and in the Southern European Variscan belt (Simonetti, 2021).

Due to the MGSZ position within the chain (i.e., hinterland-foreland transition zone or Nappe Zone) and the obtained ages, the MGSZ can be considered as one of the youngest and most external transpressive shear zones active in the network of interconnected shear zones related to the East Variscan Shear Zone framework.

Cao S. et al. (2022) - Exhumation processes of continental crustal metamorphic complexes. GeoGeo, 100094, https://doi.org/10.1016/j.geogeo.2022.100094.

Cruciani G. et al. (2016) - Thermomechanical evolution of the highgrade core in the nappe zone of Variscan Sardinia, Italy: the role of shear deformation and granite emplacement. J. Metamorph. Geol., 34, 321-342, https://doi.org/10.1111/jmg.12183.

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Simonetti M. (2021) - The East Variscan Shear Zone: a structural and geochronological review for improving paleogeographic reconstruction of the southern Variscides. Rend. Online Soc. Geol. It., 55, 36-52, https://doi.org/10.3301/ROL.2021.13.

Preliminary results from microstructural investigations of post-collisional granitoid om the Asinara Island (NW Sardinia)

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Keywords: microstructural investigations, late Variscan granitoid, CARG Project.

The geological survey of sheet "424 - Asinara Island" of the CARG Project (NW Sardinia), made it possible to investigate the medium- to high-grade metamorphic basement which formed the inner part of the Sardinian Variscan orogen and the related late- to post-collisional intrusive units (e.g., Carosi et al., 2024).

Three intrusive units were recognized i) Castellaccio Intrusive Unit; ii.) Punta Sabina Intrusive Unit; and finally, iii) sheeted dykes complex. The Castellaccio Intrusive Unit consists of inequigranular granodiorite-monzogranite characterised by large laths of K-feldspar, which often define a magmatic foliation. The Punta Sabina Intrusive Unit consists of peraluminous granitoid with stromatic enclaves, and finally, the sheeted dykes complex consists of peraluminous micro-leucogranite and pegmatite from decimetric to plurimetric thickness.

These granitoid rocks are intruded in medium- to high-grade micaschist and paragneiss, and the migmatitic complex. The field observation shows that they crosscut the main regional foliation (S2). The Castellaccio and Punta Sabina intrusive units have recorded tectonic stresses, which affected the granitoid during the cooling of magmatic bodies, exhibiting a range of deformation microstructures from submagmatic to low-temperature subsolidus conditions, but without developing an evident meso/microstructural fabric, as observed in other sectors on Variscan orogen (e.g., Fazio et al., 2020; Fiannacca et al., 2021).

The main observed microstructures are represented by chessboard patterns in quartz and, especially, sub-magmatic fractures in plagioclase, indicating deformation at high-temperature conditions (T >650°C), in the presence of melt. Solid-state high-temperature deformations (T >450 °C) are provided by feldspar bulging, myrmekites, quartz grain boundary migration and subgrain rotation recrystallization. Finally, low-temperature sub-solidus microstructures (T <450°C) consist of quartz bulging, mica kinks, and feldspar twinning and bending.

This complete sequence of deformation, operating from submagmatic to low-temperature subsolidus conditions is recorded in both granitoid intrusions, suggesting a deformation activity during post-collisional exhumation of the Variscan orogen in northwestern Sardinia (e.g., Casini et al., 2015).

Carosi R. et al. (2024) - Geology of the Asinara Island (Sardinia, Italy). J. Maps, 20(1), 2317136, https://doi.org/10.1080/17445647.2024.2317136.

Casini L. et al. (2015) - Evolution of the Corsica–Sardinia Batholith and late-orogenic shearing of the Variscides. Tectonophysics, 646, 65-78, http://dx.doi.org/10.1016/j.tecto.2015.01.017.

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Fiannacca P. et al. (2021) - Fabric analysis in upper crustal post–collisional granitoids from the Serre Batholith (Southern Italy): Results from microstructural and AMS Investigations. Geosciences, 11, 414, https://doi.org/10.3390/geosciences11100414.

An integrated field, microstructural, AMS and EBSD approach to unveil the architecture and construction mechanisms of post-collisional granitoid complexes: evidence from the late Variscan Serre Batholith (Southern Calabria)

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Keywords: anisotropy of magnetic susceptibility, CPO, shear zones.

This study, based on a multidisciplinary approach integrating field, microstructural, AMS and CPO data, allowed adding new significant constraints on the architecture of the late Variscan Serre Batholith and the link between batholith construction and activation of regional-scale shear zones. As a first step, a robust field mapping, supported by petrographic investigations, revealed both the relationships and the structural features of the main magmatic units making up the batholith. The field survey allowed also to realise the first geological maps of the magmatic units exposed in the north-eastern Serre Batholith and Capo Vaticano Promontory (CVP), at 1:200,000 and 1.140,000 scale, respectively. In particular, in the CVP, where only the deep-intermediate portion of the batholith crops out, field activity and petrographic studies allowed to separate the promontory in a northern sector characterized by a continuous exposure of the deep-intermediate granitoids, and a southern sector with a more chaotic arrangement due to a stronger tectonic reworking. Deformation microstructures, studied in all the magmatic units from both CVP and Serre Massif, together with kinematic indicators, provide evidence of continuous shear-related deformation, though with varying intensity, during cooling of all the magmatic units making up the batholith, from at least submagmatic conditions. AMS revealed an internal fabric in both deformed and apparently isotropic granitoids from all the magmatic units. In the studied granitoids, AMS is dominantly controlled by paramagnetic phases, with values generally lower than 500 x 10-6 SI for all the granitoid types. The AMS ellipsoid shape is dominantly oblate, implying that flattening component of the strain was important during granitoid emplacement, while minor prolate shapes might provide indication of possible feeder zones. Quartz CPO is consistent with a sub-simple shear regime, which, together with shear indicators, supra- to subsolidus deformation microstructures and AMS data, indicate an important shear zone control over batholith construction. In particular, magnetic data are consistent with emplacement of the earliest and deepest granitoid magmas in a transtensional regime. On the other hand, a transpressional regime with a NW-SE shortening axis operated throughout the main build-up history of the batholith, triggering the nucleation of the Lower Mammola Shear Zone (LMSZ), which accommodated the emplacement of the magmatic units at progressively shallower depth. The last emplaced units remained in direct contact with the waning LMSZ, which concluded at high crustal levels its upward journey through the Calabrian crust.

Far-field interplay between the intra-Ordovician compressional tectonics along the northeastern Gondwana active margin and Gondwana interior: insights from the central Lybia Ordovician succession

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Keywords: Intra-Arenigian unconformity, Sardic and Sarrabese Phases, Cenerian Orogeny.

The Variscan basement of southern Europe, the Alps, and the Carpathian-Balkans belt hold clues about the pre-Upper Ordovician tectonics along the northeastern Gondwana margin. The folds mapped at the peripheral south European terrane are vital indicators of the compressional northeastern Gondwana event. In addition, intra-Ordovician events affected the remote parts of widespread Cambrian-Lower Ordovician shelfal siliciclastic succession (Sardic and Sarrabese unconformities). In turn to southern Europe, just a few reports explain the middle Ordovician compressional tectonics that affected Saharan's north Gondwanan interior basins. Several hundred-meter-thick conglomerates, often followed by widespread North African ironstone sequences, rest on the angular unconformity, providing evidence of a critical intra-Ordovician erosional event. The constraints on tectonomagmatic imprints show signals of peripheral magmatic activity, characterized by calk-alkaline mafic intrusive and volcanic rocks Middle-Upper Ordovician in age.

The geodynamic setting is interpreted as a convergent margin leading to a late Lower Ordovician folding event (Sardic and Sarrabese phases), uplift and erosion, and the development of a volcanic arc in a peripheral northeastern Gondwana subduction zone. The Ordovician compressional tectonics, characterized by no crustal thickening, is called Cenerian Orogeny.

In this abstract we present data supporting the idea that the Ordovician geodynamics along the northeastern Gondwana margin had a far-field tectonic effect on the Gondwana interior, now detectable in North Africa. A combination of literature review and field mapping provides first-order constraints between the Cambro-Ordovician features of central Libya and peri-Gondwanan Ordovician geodynamics recorded in south-European and Alpine-Carpathian-Balkan basements.

In North Africa, the so-called "intra-Arenigian" angular unconformity separates the Hasawnah (Cambrian-Lower Ordovician) from the Hawaz (Darriwilian) fms. The stratigraphic position of the "intra-Arenigian" unconformity is consistent with the age of the compressive tectonics related to the Sardic and Sarrabese phases. Interferences between the active margin and Gondwana interior are also testified by the change of detrital zircon sources within the transgressive Middle Ordovician Hawaz Fm., suggesting exhumation and erosion of different portions of older basements. Moreover, the lowermost stratigraphic part of the Hawaz Fm. contains K-bentonites, suggesting a relationship with the coeval volcanic arc along the active margin. The long-lasting far-field interplay is further supported by the basalts interbedded within the Melaz Fm. (Upper Katian-Hirnantian), that are consistent with a short-lived back-arc volcanism induced by the accretionary tectonics related to the Cenerian Orogeny.

Acknowledgements: The field mapping campaign in Libya lasted from 2005 to 2010, cooperating with the Industrial Research Centre (Tripoli, Libya) and the Geological Survey of Serbia. This work was partially financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grant No. 451-03-66/2024-03/200026) and FdS (Fondazione di Sardegna) research program F73C22001210007 (grant to F.C.). The study is dedicated to the loving memory of Prof. Dr. Milun Marović, who was tragically killed in a car accident in 2009 during a field campaign.

Polyphase deformations and transposition cycles in the "Median Dacides" tectonic units

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Keywords: Cenerian Orogeny, Variscan Orogeny, Alpine Orogeny.

The Carpathian-Balkan fold-and-thrust belt formed during the Alpine Orogeny by reworking a metamorphosed Variscan crust whose protoliths span from the late Proterozoic to the late Paleozoic. The structural style is characterized by a thick-skinned nappe stack emplaced onto the rigid Moesian microcraton.

Up to now, attempts to discern the different tectonic phases are only limited to a distinction between Variscan and Alpine deformation.

In this abstract, we delve into the complex tectonic history of the Carpathian-Balkan fold-and-thrust belt, presenting new data from the central "Median Dacides" (eastern Serbia). The "Median Dacides" comprise two gneiss amphibolite-facies basement units, namely Serbo-Macedonian and Getic/Kučaj, intervening by the Supragetic greenschist-facies basement. The investigated gneiss-bearing units are embedded into Southern Carpathians (Romania) and Carpathian-Balkans (Serbia), where the Serbo-Macedonian Unit strikes across North Macedonia, western Bulgaria, and Inner Hellenides (northern Greece). The main regional structural features result from (i) the Variscan suturing of "Median Dacides" with the Danubian unit or 'Marginal Dacides' (amalgamated to western Moesian microplate) and (ii) the superimposed Alpine deformation. However, employing geological mapping and structural and microstructural analysis, previous deformation phases have been detected in both the Serbo-Macedonian and Getic/Kučaj tectonic units, and a polyphase deformation with several transposition cycles has been defined.

The first deformation event (D1) is marked by a metamorphic imprint and a relict tectonic foliation coupled with the evidence of magmatism dated to the Middle-Upper Ordovician. Moreover, an angular unconformity in the Getic/Kučaj tectonic unit has been mapped and ascribed to an Early-Middle Ordovician uplift. This tectonomagmatic phase has been connected to the Cenerian Orogeny.

The second deformation event (D2) is marked by rare folds characterized by axial plane foliation, NE-SW-striking fold axes, and NW-vergence. HP metamorphism showing amphibolite and eclogite facies is mainly related to the Variscan Orogeny. During the Variscan Orogeny, the features that originated from the Cenerian Orogeny were almost entirely obliterated and transposed.

The third deformation event (D3) is marked by a new fold generation characterized by axial plane foliation and NW-SE-striking axes. Several kinematic indicators, such as δ-type and σ-type porphyroclast, indicate a top-to-east transport direction. The axial plane cleavage acted as a transposition surface of the previous structures. The spatial arrangement of the fold axis coupled with the tectonic exhumation of the late Mesozoic-Paleogene age allows us to ascribe this tectonic phase to the Alpine Orogeny.

The fourth deformation event (D4) is marked by the eastward emplacement of the nappe stack, which led to the current structural configuration of the Carpathian-Balkan fold-and-thrust belt.

Special thanks to the Geological Survey of Serbia for support during field seasons.

Carlin Canyon, a key area for the study of the latest Carboniferous deformation in Nevada (USA)

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Keywords: Nevada, unconformity, structural geology.

The debate on the Late Paleozoic deformation identified in Nevada has grown in interest during the last years due to its importance in understanding the geodynamic evolution of the western portion of the North American Plate. One of the key areas for the study of this deformation is the region near Carlin, Nevada, renowned for its gold ores and its historical significance as part of the California Trail used by pioneers in the 19th century. In Carlin Canyon, clear evidence of pre-Pennsylvanian tectonic deformations related to NW-verging fold-and thrust structures has been documented in several papers (Trexler et al., 2004) and recently revised in detail (Beauchamp et al., 2022; Snyder, 2022). Here, the lower member of the Upper Pennsylvanian (Gzhelian) Strathearn Formation unconformably covers the Lower and Middle Pennsylvanian stratigraphic units (Ely Group, including the Tomera and Moleen formations) and the Upper Mississippian Tonka Formation. Paleosoils, followed up-section by fluvial conglomerates, document an impressive angular unconformity, which is well exposed along the Carlin Canyon section and dated to the Gzhelian (Trexler et al., 2004; Beauchamp et al., 2022), and known by geologists since the 19th century. In spite of these clear field relationships, Jansma & Speed (1991) previously interpreted the unconformity as a fault surface, which was defined as an "omissional" fault on the base of young-on-older stratigraphic relationship between the supposed hanging wall and footwall, implying the tectonic erosion of part of the succession. The aim of this contribution is to revise the structural setting of the historical locality at Carlin Canyon, based on structural field analyses carried out at the macro- and mesoscopic scale on folds and faults exposed in the area. Tectonic deformations recorded in the pre-Gzhelian successions of the Ely Group have been compared to those affecting the Strathearn Formation in order to define a relative chronology of the tectonic events. Starting from the paper by Trexler et al. (2004), the pre-Late Pennsylvanian deformations have been analysed in terms of fault and fold analyses, confirming their direct relationships with a NW-SE contractional event (in present coordinates), occurred before the deposition of the Lower Strathearn Member, which unconformably rests on the deformed units of the Carboniferous Ely Group. A subsequent tectonic event is responsible for the folding of the Lower and Upper Strathearn Formation showing NNW-SSE trending tights folds involving the Pennsylvanian unconformity, as also shown in Beauchamp et al. (2022). These structures may belong to the Cretaceous Eastern Nevada W-verging thrust belt directly related to the late Mesozoic Sevier Orogeny. The Permian succession of Carlin Canyon and nearby area has recently attracted considerable interest because a base-Kungurian GSSP candidate has been identified at Rockland section (125 km to the east), and the possibility of Standard Auxiliary Boundary Stratotypes for the base-Sakmarian, base-Artinskian, and base-Kungurian at Carlin Canyon.

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S48.

Multidisciplinary Approaches to 3D Geological Modelling: Uncertainty mitigation for basin analysis and geological applications

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Multidimensional structural analysis of reservoir-scale fault damage zones flanking the eastern side of the High Agri Valley Basin, Southern Italy

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Keywords: Mesozoic shallow-water carbonates, basin-bounding faults, Discrete Fracture Network (DFN).

Faults can have a profound influence on the accumulation and migration of fluids in the shallow crust. Due to their conductive, sealing, and/or combined fluid barrier-conduct behaviour, faults impact the subsurface hydrogeology according to the processes associated with their nucleation and growth, the geometry of the interacting fault segments, the strain rates they evolved under, the tectonic environment in which they formed, and their diagenetic history.

In this study, we carried out a structural survey on cliffs several 100's metres high exposing Jurassic–Cretaceous platform carbonates crosscut by WNW-striking, high-angle trans-tensional faults bounding the High Agri Valley Basin. By combining field and digital outcrop structural analysis techniques, we assessed the variation of geometry, distribution, density, and intensity of both fractures and faults according to the host rock lithology and distance from the main basin-bounding faults. Then, we computed their multiscale length and height attributes to obtain input data for Discrete Fracture Network (DFN) modelling and fluid flow simulation. For the DFN modelling, we built multiple stochastic models of fracture networks at bed package (height: 5m), outcrop (height: 50m) and reservoir scales (height: 500m). Our goal is the assessment of variations of both bulk fracture porosity and permeability, as well as the scaling factors for horizontal permeability ellipses. Finally, we carried out a fluid flow simulation of the whole Monte Viggiano area in order to understand the behaviour of the carbonate aquifer at varying boundary conditions.

Field and digital results show a scale dependency of fracture and fault geometry over 3-orders of magnitude for the Cretaceous carbonates, and, in contrast, a scale independent geometry for the Jurassic carbonates. In terms of fluid storage and migration properties, results from the DFN modelling show the profound contribution provided by both strata-bound and non-strata-bound fractures to the computed porosity, and by faults to the computed permeability. Furthermore, most of the DFN models show near isotropic horizontal permeability ellipses, which is consistent with the fractured and faulted carbonates behaving as a porous medium for horizontal fluid flow. We note that fault-parallel dominated flow is exhibited by geocellular volumes representative of the main basin-bounding fault zones. Results of ongoing fluid flow simulation should shed more light on the optimum reservoir development and production strategy to adopt while modelling the migration of fluid through the assessed pathways. Overall, the results of this study will be useful to hydrogeologists for groundwater management and operations, and to other geoscientists and reservoir engineers in understanding shallow reservoir behaviour, identifying production/injection patterns, and optimizing reservoir management strategies.

Building a 3D model of CARG Ragusa Sheet 648 (Hyblean Plateau, SE Sicily, Italy): evaluating/mitigating uncertainty through the integration of structural data at different scales

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Keywords: 3D geological models, seismic, Hyblean Plateau.

In the frame of CARG Project, a subsurface digital mapping and a 3D geological model of Ragusa Sheet 648 have been performed using both seismic and borehole data.

The CARG Ragusa Sheet 648, 1:50,000 map scale, covers part of the Hyblean Plateau, which is foreland to the Maghrebian thrust belt in SE Sicily. It represents a culmination of the Mesozoic-Cenozoic carbonate sedimentary succession, part of the larger crustal sector known as Pelagian Block, northernmost margin of the African Plate. Since the 1950s, the Hyblean Plateau has been an area of great interest for hydrocarbon exploration due to the first oil field discovered in 1954. Since then, important subsurface research activities have been carried out by several energy companies. For this work, vintage subsurface sections, check shots, and well logs have been made available by ENI S.p.A, plus deep wells and seismic sections from public resources (e.g., ViDEPI database) have been considered. In this work we do show a systematic vectorization of the seismic SEG-Y data through WIGGLE2SEGY script (Sopher, 2018) and then an interpretation of the subsurface data integrated with the structural field maps of the area. The quality and resolution of the SEG-Y vintage seismic lines allow only to infer large scale tectonic structures. Most of the faults recognized on outcrop always have throws that fall below vertical seismic resolution, or often are challenging to identify through the reflection datasets. However, by evaluating/mitigating the uncertainty in the subsurface fault geometry through the integration of structural data at different scales (using some wells), we do propose a first comprehensive 3D subsurface model for the Ragusa sheet, matching outcrop data to seismic scale structures.

Sopher D. (2018) - Converting scanned images of seismic reflection data into SEG-Y format, Earth Sci. Inform., 11, 2, 241-255.

Progetto ViDEPI (2009-2024) - Visibilità dei dati afferenti all'attività di esplorazione petrolifera in Italia, https://www.videpi.com/videpi/videpi.asp.

Unexpected results from 3D geological modelling in already extensively investigated area: the SE termination of the Salsomaggiore Terme tectonic window (Northern Apennines foothills, Parma province, Italy)

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Keywords: 3D geological model, Northern Apennines, Salsomaggiore tectonic window.

The increasing availability of software and the improved calculation capabilities of desktop computers allow to approach the 3D geological modelling. The models provide a valuable tool for describing, analizing and showing the geological features of a specific area of variable extents and depth from the surface. The 3D modelling is extremely useful for: 1) collecting, integrating and comparing all the available geological data (geological maps, wells, subsurface geophysical data, etc..); 2) implementing and updating an existing model with new geological data; 3) analyzing quantitatively areal extent, thickness, geometry and volume of geologic units, faults and folds; 4) interactive visualizing, free hand slicing and 360° perspective of the different geological features; 5) foreseeing the most likely prosecution of the geological features in the modelled area where data are less, poor or absent. Therefore, the 3D geological modelling is a strategic tool for researchers, professionals, companies, organizations as well as administrations dedicated to study, plan and manage the territory and its natural resources; but it is also a useful way for disseminating and communicating with non-expert/specialist in geology. In order to test the benefit of the 3D modelling, we built a model of the SE termination of the NW-SE trending Salsomaggiore Terme tectonic window in the Parma province in between the Taro River and the Recchio River. This area has been investigated since long time for hydrocarbon exploration, stratigraphic and structural analysis, morphotectonics studies, geological mapping at different scales (AA. VV., 2005) and unpublished master thesis. All these available data have been integrated and processed by using the software Leapfrog Geo by Seequent.

In order to refine the model, additional field surveys and new geological cross-section were realized and uncertainties arisen by model building were solved providing an anchor for better constraining the 3D model. The new 3D model contributed to confirm the geological evolution of the Salsomaggiore tectonic window since Serravallian to present, as depicted in previous work (Artoni et al., 2004 and references therein), but it unexpectedly provides interesting results by revealing new geological features such as:

- shale diapirs within the Ligurian allochthonous units;
- Serravallian normal faults affecting unlithified sediments and sealed by the overlaying allochthonous units;
- a NE-SW striking transfer fault which is longer than previously mapped and aligned with cold hydrocarbon seepage likely sourced along the buried thrust whose depth has been estimated at around 800 m depth b.s.l.

The 3D modelling provides an easy-to-visualize geology of the area by processing all available, often disomogeneous, geological and territorial data but, in the study case, it has been also a useful tool for re-interpreting and discovering new features of the geology of an area.

AA.VV. (2005) - Carta Geologica d'Italia alla Scala 1:50.000, Foglio 199 di Parma Sud. Regione Emilia-Romagna. S.EL. CA., Firenze.

Artoni A. et al. (2004) - The Salsomaggiore Structure (Northwestern Apennine foothills, Italy): a Messinian mountain front shaped by mass-wasting products. Geo Acta, 3, 107-127.

From geological map to 3D model: integrating surface and subsurface datasets from Sheet 177 Tortona of the Geological Map of Italy at 1:50.000 scale (CARG Project)

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Keywords: Northern Apennines, 3D modelling, CARG Project.

Integrating geological maps and outcrops stratigraphic-structural data (i.e., surface dataset) with well data and seismic reflection profiles (i.e., subsurface datasets) is a crucial aspect of creating constrained 3D models of sedimentary basins. The main uncertainty in combining these datasets lies in the different scale of observation of the tectono-stratigraphic elements that are typically found in sedimentary basins. Outcrop- and map-scale surface datasets can be used to reconstruct the three-dimensional architecture of stratigraphic units (e.g., lithofacies, members, formations, groups, and synthems), stratigraphic unconformities, and the main structural elements (e.g., faults and folds). In contrast, subsurface datasets mainly resolve the stratigraphic unconformities and the architecture of geological bodies and tectonic structures at the basin-scale seismic resolution, especially in areas with a flat morphology where no outcrop data are available. Sheet 177 Tortona of the Geological Map of Italy at 1:50,000 scale (CARG Project) represents an excellent example to discuss the best practices for integrating surface and subsurface data, as it includes hilly areas where the tectono-sedimentary assemblage of the Northern Apennines is outcropping, and alluvial plain areas where this assemblage is covered by alluvial sediments of the Po Plain, for which subsurface data are available.

We present preliminary 3D models of selected areas of the Sheet 177 Tortona that are built by integrating geological mapping and outcrop stratigraphic-structural data with the interpretation and correlation of well-logs, borehole data, and some deep hydrocarbon well logs available on the ViDEPI database (www.videpi.com). The tectono-stratigraphic assemblages of the Northern Apennines has been subdivided into the Early Cretaceous – early Eocene External Ligurian Units, which are unconformably covered by the late Eocene-Miocene Epiligurian Units and the Pliocene - Quaternary successions of the Po Plain. Different stratigraphic unconformities, and mappable faults and folds are considered in the 3D model using i) intersecting geological sections to describe the geometries of the main structural and stratigraphic elements, and ii) punctual measurements of the attitude of the geological surfaces. These robust surface constraints allow for down-tracing of main stratigraphic boundaries and tectonic structures for surface-log correlations. The integration of the surface and subsurface datasets helps to visualize the 3D architecture of the complex assemblage that characterizes the Tortona sheet and represents a starting point for implementing the 3D model with deep seismic reflection profiles.

3D reconstruction of regional-scale unconformities in the Po Basin: integrating well data and seismic profiles to improve the understanding of Plio-Pleistocene evolution

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Keywords: Po Plain, 3D geomodeling, seismic interpretation.

The tectonic framework of northern Italy is characterized by the complex interaction between the Southern Alps (SA), the Northern Apennines (NA), and their shared foreland basin, the Po Plain (PP). Extensional tectonics dissecting carbonate platforms mainly characterized the Mesozoic evolution of the basin. The structures produced during this phase played an important role in the consequent evolution of the SA since the Late Cretaceous and of the NA since the Lower Miocene. The geometry of the NA and SA fold-and-thrust belt was influenced by inherited structures and consequent basin topography that controlled the evolution of the thrust fronts. In particular, the NA fronts show three different arcs with different amounts of shortening, with the lowest values found in the Monferrato Arc to the west and increasing towards the east with the Emilian Arc and the Ferrara Arc. The particular evolution of each arc controlled the deposition and the architecture of different zones of the Plio-Pleistocene syntectonic successions of the PP (onshore) and northern Adriatic Sea (offshore).

To date, published works on the basin-scale evolution of the Po Basin have primarily focused on the eastern depocenters of the Po-Adriatic Basin (Amadori et al., 2019) This was achieved for specific intervals of the sedimentary infill consisting of siliciclastic units bounded by regional-scale tectono-eustatic unconformities. In a stratigraphic order, these units are defined as Base of Pliocene (PL1), Intra-Zanclean (PL2), and Intra-Piacenzian (PL3) for the Pliocene succession, followed by Early Gelasian (PS1), Early Calabrian (PS2) and Late Pleistocene (PS3) for the Pleistocene succession.

In this work, we present a comprehensive 3D reconstruction of these regional-scale unconformities for the entire Po Basin, using an extensive database of well data and 2D seismic profiles provided by Eni E&P, integrated with previously published studies. Depth conversion was performed using a 3D velocity model based on borehole interval velocities from all over the basin. This allows us to better understand the evolution of the PP by enabling the investigation of relationships between surface development, tectonic activity, and basin-wide changes in sedimentation rate through time. The 3D reconstruction also provides the basis for a better understanding of the degree of interaction between the SA and NA along the basin and its effects on the evolution of the Plio-Pleistocene basin.

Amadori C. et al. (2019) - From cylindrical to non-cylindrical foreland basin: Pliocene-Pleistocene evolution of the Po Plain-Northern Adriatic Basin (Italy). Basin Research, 31, 991-1015, https://doi.org/10.1111/bre.12369.

Examples of multidisciplinary approach as a strategy to reduce uncertainties in geological models

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Keywords: 3D geological modles, field work data, seismic interpretation.

Geological models are used to handle the results of geological processes that create significant heterogeneities at multiple scales below the surface of the earth.

Our observations are always limited for several reasons, including limitation dur to adopted methods, to the observers, to scale, dimension, and time. Uncertainties can also enter at different steps, during acquisition, processing, and model building. These limitations bring to multiple interpretations that can all satisfy the same incomplete dataset. Therefore, the evaluation of uncertainties in geological interpretation and modelling plays an essential role for a wide range of applications, from scientific investigations to geotechnical aspects, hydrogeological investigations, and geo-energy resources exploration.

Reduce uncertainties is very important and there are different approaches, based on different kind of data (surface data, geological sections, geophysical data, borehole data, etc). Statistical methods can be used to quantify and reduce the uncertainty and variability estimating probability distributions and uncertainty propagation.

Geological uncertainties can be considered gaps in the continuity of data observation that can also be fill combining different kind of information from different disciplines. Procedures to provide the evaluation of CO_2 storage capacity can be a good example of the management of uncertainties and of the tools used to improve results and reduce bias.

The volumetric approach is based on the definition of the available volume suitable for storage. As a consequence, the first step is the construction of a "static geological model" which is a geological based model able to provide a volume of reservoir. Here the uncertainties due to the reconstruction of the surfaces is constraint by quality and quantity of data (well logs, seismic lines, surface geology). In fact, 3D models' reconstruction is based on different mathematical algorithm to perform spatial data interpolation. The obtained geological model is than corrected using petrophysical parameters, based on the sedimentological and structural aspects provided by the geological model. Again, multidisciplinary data are needed.

These steps need to be integrated with the application of a statistical evaluation as the Monte Carlo method to reduce bias and to provide a better evaluation of results a statistical evaluation. The fluid flow dynamic approach can than further reduce uncertainties. This latter is, on its turn, based on efficiency factors that integrates geological data and define their dynamic role. An example comes from the role of fractures, where volume availability starts from field data to fluid flow dynamic simulation.

A subsoils model reconstructed integrating geological and geophysical data in the area of the town of Palermo

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Keywords: 3D model, geophysical surveys, boreholes.

The plain of Palermo is a strategic area as it hosts the fifth city of Italy as number of inhabitants and several industrial activities and infrastructure arise in this sector. For these reasons, exploiting a dataset composed of both geological and geophysical data, the University of Palermo is implementing the reconstruction of a 3D model of the subsoil of the plain to detail the geologic features of the area and underling hazards that could affect the city. The database used consists of more than 2000 boreholes and active and passive seismic data. The stratigraphic data were initially analyzed due to be homogenized to make them more usable for the definition of a small-scale 3D model. From the analysis of the bores, it was noticed that mainly the subsoil consists of limestones, flysch, clays, calcarenites and alluvial deposits. For each stratigraphic unit the position of the top of each described layer has been computed. In addition, a geophysical survey campaign was carried out to detail the model in areas where there are not many stratigraphic data. The acquisition of data by MASW surveys (Park et al., 1999) had allowed to associate shear waves velocities (Vs) values to the main lithologies outcropping in the subsoil of Palermo. The shear waves velocities computed range vary from 200 - 300 m/s for alluvial deposits to Vs equal or greater than 800 m/s for limestone and flysch. Moreover, several environmental noise recordings have been carried in the city. These data have been analyzed by means of the HVSR technique (Nakamura, 1989). The HVSR curves produced by seismic noise analysis are characterized by the presence of several peaks that have been linked to the main stratigraphic boundaries that characterize the subsoil of the plain. In particular, the peak present at lower frequencies, between 0.8 and 2.5 Hz, has been connected to the stratigraphic contact between the flysch and the overlying Ficarazzi clays. The velocities derived from MASW have allowed to invert the HVSR curves in seismographic models. These models made it possible to calculate the depth of lithological boundaries and integrate the database for the construction of the 3D model. Subsequently using different interpolation algorithms, depending on the number of available data for the top of each recognized lithology and the reciprocal distance between them, the stratigraphic surfaces that make up the 3D subsurface model have been generated. As a result of this, the thicknesses for the most common lithologies in the plain area have been calculated. The achieved model allows to depict the main lithologies that characterize the Palermo subsoil and their spatial distribution, vertical thickness and lateral extension. Furthermore, this model also describes the former morphology of the area, which is nowadays masked by a dense urban settlement. The outcomes of this study will improve the ability to identify areas subject to geological risks such as seismic and hydraulic hazards.

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Park C.B. et al. (1999) - Multimodal Analysis of High Frequency Surface Waves. Symposium on the Application of Geophysics to Engineering and Environmental Problems 1999. Society of Exploration Geophysicists, 1999, 115-121, https://doi.org/10.3997/2214-4609-pdb.202.1999_013.

Characterization of the sedimentary basins in coastal plain sectors through the integration of geological and geophysical data: the case study of the North-Eastern Sicily

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Keywords: geophysical surveys, groundwater bodies, 2D-3D modeling.

The analysis of the geological setting of alluvial plains, located in coastal sectors, currently represents a topic of great importance. Indeed, over time, several urban areas have concentrated in these plains as well as industrial activities and infrastructures. In the north-western Sicily wide alluvial plains are present; in this sector, overlooking the Tyrrhenian Sea and surrounded by the Nebrodi and Peloritani mountains, coastal plains are connected to the hydrographic network that is characterized by gravel bed rivers and streams, better known as "Fiumare". Numerous urban centers and the related industrial areas are located these plains, such as Milazzo and Capo d'Orlando. Many geological hazards have been highlighted in these areas, including seismic and hydraulic hazards. Furthermore, water resources are heavily affected by human activities which often cause groundwater pollution. For these reasons, within a project of the INGV-DAR (Granata et al., 2018), several studies have been conducted to reconstruct 2D and 3D geological and geophysical models of groundwater bodies of three alluvial plains: Caronia, Sant'Agata-Capo D'Orlando and Barcellona-Milazzo. The construction of these models is based on a large database made up of previous and newly acquired geological and geophysical data; several geological data have been derived from field surveys and boreholes, while the geophysical data have been mainly obtained from the Cassa del Mezzogiorno project (CASMEZ, 1978). These previous geophysical data, consisting in vertical electric soundings (VES) and seismic refraction surveys, have been qualitatively analyzed and partly been reanalyzed; in particular, 3D resistivity models have been obtained by interpolating 1D inverse VES models. Moreover, to detail the underground models, new geophysical surveys campaigns were carried out, relating to active and passive seismic acquisitions. The data computed by several multichannel analysis of surface waves surveys (MASW) allowed to describe different S-wave velocity profiles. Furthermore, the VS values have been used to constrain the inversion of the HVSR curves, obtained from seismic noise recordings. Using all the available data the geological models of the three coastal plains were realized. These models describe the depth reached by the alluvial and other deposits constituting the groundwaters bodies and their anomalies in the thickness: the greater volumes described for the Caronia area (Canzoneri et al., 2023) and for the Sant' Agata - Capo D'Orlando and Barcelona P.G. – Milazzo plain (Capizzi et al., 2024) are not closely related to the nowadays morphology and fluvial environment due to some changes in rivers networks net, but are probably related to the recent tectonic movements and differential uplift rates that affected these costal area. Moreover, the realized models allow to identify areas that may be most susceptible to geological hazards.

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Capizzi P. et al. (2024) - Coastal Groundwater Bodies Modelling Using Geophysical Surveys: The Reconstruction of the Geometry of Alluvial Plains in the North-Eastern Sicily (Italy). Water, 16(7), 1048, https://doi.org/10.3390/w16071048.

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Granata A. et al. (2018) - Studio per la definizione dei modelli concettuali dei corpi idrici sotterranei di Peloritani, Nebrodi e ragusano e indagini geofisiche correlate. Atti del 37° Convegno del Gruppo Nazionale di Geofisica della Terra Solida-GNGTS. OGS, 37, 104-108, https://hdl.handle.net/10447/316230.

Geological reconstruction of the Romagna and Ferrara folds area to evaluate its geothermal potential

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Keywords: geothermal reservoir, geological modelling, InGEO project.

Geothermal energy is recognised as a sustainable and environmentally friendly solution for power generation and district heating/cooling, offering uninterrupted availability throughout the year and day, with significant development prospects worldwide. However, the exploitation of deep geothermal reservoirs requires thorough a detailed reservoir characterisation.

The InGEO project ("*Innovation in GEOthermal resources and reserves potential assessment for the decarbonisation of power/thermal sectors*") aims to develop an innovative exploration workflow that integrates geological/geophysical data and other direct and indirect information, in order to characterize the reservoir rocks and the overlying sedimentary cover.

To this aim, we chose as a target area the Romagna and Ferrara folds, where a thermal anomaly has been identified and attributed to the thermal convection in deep-seated Mesozoic carbonate units (Pasquale et al., 2013; Pasquale et al., 2014). The Romagna and Ferrara folds represent the outer deformation front of the Northern Apennines thrust and fold belt. They are partly buried under thin (about 200 m) Plio-Pleistocene terrigenous deposits of the Po plain. The Ferrara folds are composed of the Mesozoic carbonate sequence, which has been significantly deformed during the Neogene and Quaternary tectonics, while the Romagna folds are composed of the Tertiary clastic formations overlying the Mesozoic limestones (Montone & Mariucci, 1999).

In this study we present the first results of the analyses of the geological data (e.g., seismic lines, stratigraphic columns, well reports and logs, borehole tests and measurements, gravity anomalies) collected from VIDEPI (https://www.videpi.com/videpi/videpi.asp) and GEOTHOPICA (https://geothopica.igg.cnr.it/index.php/it/) database, in terms of the depth of the main geological units. These results will be compared with those already published in previous studies (Livani et al., 2023), in order to implement a consistent geological model of the study area. The last one will be further supplemented with interpretations from thermophysical experiments on rock samples.

The geological model will contribute to the development of an open-source and web-based GIS tool and will be the main input for calculating the area's geothermal potential, improving business planning for the exploitation of deep geothermal resources in Italy.

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Geological 3D modeling is the new geological mapping

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Keywords: 3D geological models, geological maps, CARG Project.

Geological mapping has represented, and largely still is, the most common way to synthesize and communicate the geological history and processes of an area; consequently, geological maps have represented successful and strategic tools not only for geologists. In the last decades, the evolving demands for digital geoscience and the need for up-to-date, high-quality, and public subsurface geoscientific information fixed a new challenge for the geoscientific community.

The Geological Survey Organizations are leading this transition by being able to combine their long-established mapping activities with advanced technologies in the collection, management, integration, and dissemination of the geological data, introducing also the third- and forth-dimension; therefore, documentation of geology is undergoing a transition from static 2D maps to digital 3D reconstructions. The Servizio Geologico d'Italia (SGdI) faced this transition by promoting the systematic production of 3D geological models, now also as part of the CARG Project.

The concurrent realization of the geological map and 3D model of an area allows for a holistic approach, with strong integration of new collected and vintage data, both surface and subsurface, aiming to provide richer, reliable, harmonized, and multi-resolution depictions of the geological architecture and parameters.

The 3D geology paradigm requires i) a clear fit-for-purpose conceptual model, ii) input data from geological field surveys, boreholes, and various geophysical investigations, iii) a well-established harmonization process, iv) a robust, replicable, and iterative modeling workflow. In addition, according to the final use, the geological 3D modeling requires geochronological constraints and physical and geochemical parameters.

The experiences in European (GeoMol, GeoERA, GO-PEG, GSEU) and national 3D geomodeling (RETRACE-3D) projects focusing on the description and analysis of the geological architecture of both shallow and deep subsurface and the cutting-edge technological aspects, allowed to design and refine these steps, emphasizing the need for integration and maximization of different types of available datasets and for finding and testing open-source tools and algorithms for data analysis and modeling. As part of this process, the 3D geological models production in the CARG Project will represent a significant step forward for the national geological community which is asked for a greater effort in reconciling all the available conceptual and physical constraints, and to provide accuracy evaluation.

The production of robust 3D geological models is one part of the challenge, the institutional mandate of the SGdI is also the FAIRness of geological information: through ISO standard metadata and DOI, OGC standard download services, using INSPIRE Geology-based extended data model, and adopting CC-BY open license. The access point of 3D geological models will be the GeoIT-3D viewer https://geo-it3d.isprambiente.it.

Fluid flow history and paragenesis along a syn-rift basin bounding fault: the Helmsdale Fault (NE Scotland)

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Keywords: fluid flow, calcite vein, rift basin.

Within syn-rift basinal settings, the juxtaposition of rift-related clastic deposits in the hanging wall of basin-bounding normal faults against a footwall of crystalline basement is a recurrent structural setting where plays for hydrocarbon exploration or carbon storage can be found. Here, fault-controlled fluid flow can significantly influence and change the petrophysical properties of the fault zone and host rocks over time by means of mineralization and cementation, ultimately controlling fluid pathways. Investigating the timing and extent of fluid flow along major faults permits us to better understand the host rock properties and if these can potentially be favourable for subsurface extraction and storage.

Here, we present a detailed investigation of the timing and paragenesis of fluid flow along the well exposed Helmsdale Fault in NE Scotland. The Helmsdale Fault is a major tectonic feature that bounds the western side of the Inner Moray Firth Basin, which developed during rifting in the Late Jurassic. The hanging wall consists of the Late Jurassic (Kimmeridgian-Tithonian) Helmsdale Boulder Beds that are made of alternating debris flow and mudstone/siltone deposits, whereas the footwall is composed of the Helmsdale Granite (Silurian-Devonian). There is ample evidence of paleo-fluid flow along the Helmsdale Fault in the form of calcite cementation and widespread calcite veining in both the hanging wall and in the footwall, locally making up to 5 m thick fault cores of stacked crack-seal veins. U-Pb calcite dating of fossils, veins and cements shows an initial fluid flow event that quickly follows diagenesis in the hanging wall and spans from 147 to 113 Ma, followed by a later reactivation of the fault system between 86-60 Ma. The spatial distribution of the dated calcite veins shows a clear localization over time of fluid flow along the main faults within the footwall.

Carbonate stable isotope analysis, combined with the salinity of the fluid inclusions in the calcite veins, has revealed a marine fluid composition of the calcite vein network over time, irrespective of the structural domain within the fault zone. Furthermore, clumped isotope thermometry shows a gradual temperature increase towards the footwall (35 to 65 °C), but fluid inclusion microthermometry on secondary fluid inclusions also reveals that these fluids could originally have been much hotter (up to c. 80 °C). These data suggest that fluids percolated upwards along the main faults within the Helmsdale Granite. Occurrence of calcite veins derived from meteoric fluids is documented in the youngest dated vein network (60 Ma) and likely related to the later stages of regional uplift.

Our results suggest that the evolution over time of the petrophysical properties of the hanging wall with progressive mineralization and cementation exert a critical control on future fluid pathways as well as localization and style of subsequent fault deformation.

How high-resolution tomographic imaging can provide new information on fault interaction: the case of the 2009 L'Aquila seismic sequence

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Keywords: geometric-kinematic fault interaction, L'Aquila 2009 seismic sequence.

The geological and structural complexity of the Central Apennines (Italy) often hinder the identification of which factors control the development of energetic seismic sequences, like those occurred in recent decades.

In this study, we built a new seismotectonic model of the area affected by the Mw 6.1 2009 L'Aquila seismic sequence based on a multidisciplinary approach, combining geological and structural evidence with 3D high-resolution Vp and Vp/Vs velocity models obtained by inverting about 36,000 seismic events to compute Double-Difference seismic tomography.

The tomographic model's high-resolution (2x3x2km cell) has unprecedented details that allow us to isolate velocity anomalies and refer them to geological bodies.

The area is mainly characterized by compressional structures of the Mio-Pliocene belt and pre-existing normal faults, vertically segmented and confined between major thrust sheets. Our results indicate that the complex structural setting due to the compressional stage still controls the evolution of extensional earthquakes. The original lack of continuity of inherited normal faults embedded within different thrust sheets influences the evolution of seismic ruptures during large earthquakes, the dynamic coseismic propagation, and the segment interaction. The chance of long segments to be activated (or reactivated), favored by interaction of vertically juxtaposed segments, relies on their original orientation that is not always favorable with the actual extensional stress field. We infer a consistent geometric and kinematic interaction between a large, mostly NW-SE fault located in the footwall of the Gran Sasso thrust sheet activated by the Mw 6.1 mainshock, and the surface expression of part of the Paganica Fault, even their different orientation, in the area where they are vertically and coincidently continuous.

Regional subsurface 3D model of southern Sicily for potential seismogenic fault characterization and seismic scenarios: the INGV SPIN project

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Keywords: 3D subsurface model, fault kinematics, seismic scenarios.

The monitoring and characterization of potential seismogenic features in the Italian Peninsula have been pivotal goals for the National Institute of Geophysics and Volcanology (INGV) for decades. The development of more advanced tools allowed the investigation of structures which might or actively contribute to the actual and historical seismicity of our territory. In particular, the elaboration of more sophisticated 3D models led to a better understanding of the possible scenarios at different scales – nationally and locally. However, regional scale work relating fault activity, seismic hazard potential, and associated scenarios is a complex task to accomplish.

We here present the ongoing INGV work under the framework of the project "SPIN", which aims at defining seismogenic faults and evaluation of their effective hazard through synthetic scenarios. It tracks down the previous INGV projects to corroborate a solid workflow at different scales. Here, the complex frame of Sicily Island, which is also prone to tsunamis, is introduced. An area of ca. 19'000 km2, both onshore and offshore, covers the three main domains of the Island: Apennine-Maghrebian thrust fold best; Catania-Gela foredeep; Hyblean Plateau foreland. A copious subsurface dataset has been developed in the last 70 years thanks to the interest of Oil and Gas companies and their ongoing productions, in particular in the foreland domain. Thus, this project considers most of the 2D seismic lines and deep wells from exploration surveys, as well as literature geological and structural maps, sections, and reports. The result is a regional 3D model up to ~50 km depth through the integration of available crustal models.

The characterization of the model allows a better constraint of fault activities through time and their associated seismic shaking scenarios. Plus, it represents the starting point for geomechanical modelling.

3D workflows, such as the one here developed and shown, represent a solid practice to lead to a more accurate and realistic characterization of fault activity, contributing to the characterization of local seismicity, thus, risks, at any scale.

A first step toward a 3D geological model of Florence area (CARG Programme, Sheet 275): first approach for the reconstruction of the top substrate surface

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Keywords: 3D geological models, gravimetry, CARG.

The CARG sheet n°275 "FIRENZE", currently under realization, in addition to the surface map includes for the same area a reconstruction of the top bedrock surface, which for the urban area of Florence will constraint a 3D geological model of the Quaternary infill deposits. The methodology followed for reaching this goal is based on the integration of two main datasets. These include a collection of geognostic surveys (boreholes) for which a stratigraphic description is available (Coli, 2022) and gravimetric data provided by ENI under a confidential agreement with ISPRA for the realization of the CARG sheets (ISPRA,ENI, 2020). For the Florence area the database includes more than 2,000 stratigraphic logs coming from different sources (Regional Tuscan Administration, Florence Municipality, ISPRA L.464/84). Borehole data are managed through a three-dimensional geognostic database, the structure of which is set up for use in the reconstruction of the three-dimensional model. The gravimetric data consist into the Bouger Anomaly provided by ENI that was calculated considering a rock density of 2670 kg/m3 and computed over a regular grid of 500x500 m. To estimate the sediment thickness we first computed reginal Bouger Anomaly considering only measurements performed on bedrock and therefore inferred residual Bouger anomaly for the sedimentary basins (Salimi & Motlagh, 2012). This was inverted to sediment thickness by adjusting the unknown sediment density in order to minimise the difference with real bedrock depth that is available for more than 1250 boreholes distributed over the area of analysis (Moretti, 1942; Coli, 2022). The poster addresses the problems of processing and integrating these two different types of data, i.e., direct and indirect and shows the results obtained with different processing levels, integrated using the software Leapfrog® and the basic geological concepts and regional knowledge.

ISPRA, ENI (2020) - Accordo Sfornitura dati Servizio Geologico d'Italia – ENI Progetto CARG.

Coli M. (2022) - Inquadramento geologico e geomorfologico. In "La microzonazione sismica e le analisi delle condizioni limite per l'emergenza del Comune di Firenze, I libri della Giunta Regionale, territori, 27-42. ISBN 0978-88-7040-137-0.

Moretti A. (1943) - . A. Moretti. Il bacino lignitifero di Firenze. Relazione conclusiva sulle ricerche compiute dall'Azienda Carboni Italiani (A.Ca.I.).

Salimi P. & Motlagh A.T. (2012) - Mapping of the Bedrock Topography Using Gravity Data: A Case Study in the South of Hormozgan Province, Iran. J. Geophys. Remote Sensing, 1,105, https://doi.org/.10.4172/2169-0049.1000105.

Seismotectonic characteristics of the 2022/24 Fano seismic sequence (Central Italy)

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Keywords: transversal faults, strike-slip, active tectonic.

On November 9, 2022 a seismic sequence began offshore of Fano town with a MW= 5.5 mainshock. The affected area falls in the external sector of the central Italy (Marche region) structurally characterized by a series of NW-SE high-angle Plio-Quaternary transpressive flower structures. These latter are generally interrupted by left-lateral transversal fault systems ENE/WSW to NNE-SSW trending (Pierantoni et al., 2019). Compressional structures are mostly sealed by undeformed Quaternary deposits in the off-shore, while the transverse structures are active and seismogenic (Costa et al., 2023).

The sequence developed with rapidly decreasing intensity and number of events until the end of 2023 and beginning of 2024 consisting of more than 900 earthquakes with M>1. The main shock is characterized by a compressive or transpressive focal mechanism with NW-SE, low-angle focal planes.

Several steps can be recognized within this sequence, some with epicenters distribution falling along NW-SE compressive structures and others with a prevalent NE-SW alignments of the epicenters in accordance with transversal structures. Furthermore, strike-slip focal mechanism along subvertical planes consistent with the transversal structures occasionally occurred.

According to current literature, the external sector of the Apennine is characterized exclusively by low-angle, NE-vergent thrusts that developed without interruption for tens of km (Structural Model of Italy, 1989). Maesano et al. (2022), Pezzo et al. (2023) believe that the Fano seismic sequence occurred because of the local activation of NW-SE compressive structures buried below thick undeformed Quaternary marine deposits.

Nevertheless, based on available focal mechanisms and epicenter distribution, a different seismotectonic hypothesis can be suggested. It appears that limited segments of NW-SE trending compressive structures have been activated, and this could be connected to movements along a transversal strike-slip structure in the area, the Metauro-Fano Fault System (MFFS, Pierantoni et al., 2019). This is an active fault system marked by recent seismic sequences (Costa et al., 2023). The largest number of events belonging to the 2022-24 seismic sequence is concentrated in a subtriangular area bounded by the offshore branch (NNE-SSW) of MFFS to the W, and by an approximately NE-SW alignment (probably unknown branch of MFFS) to the E. Since MFFS is an active left-slip structure, the subtriangular area between the two branches is affected by a NE oriented compression. Therefore, segments of the NW-SE structures, located only in this area, were reactivated and produced the shallowest earthquakes, while other earthquakes can be associated to the simultaneous activation of the strike-slip transversal structures. In fact, some scattered events also occur near the Metauro valley and indicate the occasional activation of the onshore branch of MFFS.

Costa M. et al. (2023) - Seismotectonic role of transversal structures in the Plio-Quaternary evolution of the external Marche Apennines (Italy). Journal of the Geological Society, 180, https://doi.org/10.1144/jgs2023-002

Maesano F.E. et al. (2023) - Buried Alive: Imaging the 9 November 2022, Mw 5.5 Earthquake Source on the Offshore Adriatic Blind Thrust Front of the Northern Apennines (Italy). Geophysical Research Letters, 50(11),e2022GL102299, https://doi.org/10.1029/2022GL102299.

Pezzo G. (2023) - Seismic source identification of the 9 November 2022 Mw5.5 offshore Adriatic sea (Italy) earthquake from GNSS data and aftershock relocation. Scientific Reports, 13,11474, https://doi.org/10.1038/s41598-023-38150-5.

Pierantoni P.P. et al. (2019) - Plio-Quaternary transpressive tectonics: a key factor in the structural evolution of the outer Apennine–Adriatic system, Italy. Journal of the Geological Society, 176, 1273-1283, https://doi.org/10.1144/jgs2018-199.

Groundwater modelling in faulted siliciclastic-carbonate sequences

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Keywords: fault zones, groundwater modelling.

Fault zones affect to groundwater flow, as the fault volume usually undergoes important petrophysical variations and represent a key zone for trapping, channelling and deviating fluid flows. Through a sensitivity analysis within a groundwater model, we aim to quantify the fault effect on fluid flow conditions within the siliciclastic-carbonate Logudoro basin, in northern Sardinia, Italy. The study is focussed specifically on how groundwater flow may be affected by deformation structures in the fault damage zone, fault rocks in the fault core, and the geometrical effect of juxtaposition along the fault plane. Special attention is given to the role of varying deformation structures such as deformation bands in high-porosity sands and open fractures in low-porosity limestones and marlstones. The groundwater model is completed with MODFLOW6, with 3 orthogonal-to the fault sections in 2D steady-state single-phase, subsurface flow models. Parameters included in the models are: i) the lithostratigraphical framework based on surface control points, lithostratigraphies and the resulting 3D geological model; ii) piezometric heads, measured in March 2021 in wells, and spring locations in the study area; iii) the permeability of the different predefined hydrogeological units, acquired through in-situ air-permeability measurements with TinyPerm3 and converted into hydraulic conductivity for modelling purposes. The model is calibrated with PEST against observations from hydraulic heads in proximity to the fault. Expected outcomes are, (i) the quantification of the individual and combined impact of fluid flow affecting components in the fault-zone on groundwater flow circulation across and along the fault zone and, (ii) the quantification of impact on local and regional fluid flow systems. Hence, with this study we enhance the understanding of the role of fault-zones in groundwater models and quantify the effect, especially in mixed siliciclastic-carbonate basins.

A geology-based 3D velocity model of the Amatrice Basin (Central Italy)

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Keywords: Amatrice Basin, geology-based 3D velocity model, seismic hazard assessment.

The Amatrice area was historically affected by moderate to large earthquakes, which caused extensive damages and many casualties, like the 1639 and the 2016-2017 seismic sequences. For this reason, the area was extensively studied and a large amount of seismological, geological and geophysical data were acquired. However, a detailed 3D geological model of the area subsoil was still missing and, consequently, the local seismic response evaluation of the area could only be based on the geological and geotechnical characteristics of rocks and the available low-resolution and large-scale models.

In this work we present a new methodological approach integrating geological (e.g., maps, cross-sections and core-wells) and geophysical (e.g., down-hole, MASW, refraction, and seismic noise measurements) data applied for reconstructing a detailed 3D geological and geophysical model of the uppermost hundreds of meters of the Amatrice Basin. All the available data were georeferenced and uploaded into 3D geological modeling software where faults and stratigraphic boundaries were digitized, checked, hierarchized, and modelled. The reconstructed 3D geological model was parameterized with the S-wave (Vs) and P-wave (Vp) velocities values, and the resulting 3D geology-based velocity model was verified by comparing the environmental noise (i.e., horizontal-to-vertical spectral ratio analysis, HVSR) recorded at some seismic stations with the seismic responses modelled at some nearby control points.

The proposed model is the first geology-based 3D velocity model of the Amatrice Basin, which may be used for example as input-model for future ground-motion and seismic-wave-propagation simulations aimed at a more precise local seismic response assessment and, consequently, at the development of more realistic seismic hazard scenarios. The methodological approach here presented can also be applied in other areas for reconstructing detailed 3D geological-geophysical models to be applied for the assessment and mitigation of different geological risks.

Early deformations of carbonate platforms driven by differential compaction of the basinal unit: Finite Element Method-based numerical analysis

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Keywords: carbonate platform, basin, differental compaction.

In this study, we use a 2D linear elastic Finite Element Method-based numerical model to investigate the relationship between the differential compaction of a basinal unit and the early deformation of a prograding and/or aggrading carbonate platform. The numerical simulation aims to examine changes in stratal geometry and the stress field resulting from differential compaction. We compare the numerical results with two case studies: Lastoni di Formin and Nuvolau Mountains (Passo Giau, Italy). Both outcrops are remnants of Triassic carbonate platforms located in the Eastern Dolomites of the Italian Southern Alps. Our model explains the modifications in stratal architecture and the fault and fracture patterns observed on these platforms. A key finding from our simulations is that the slope and slope-to-basin transition regions are likely to experience the majority of brittle deformation. Contrary to findings from previous numerical studies (e.g. Resor & Flodin, 2001; Nolting et al., 2018), our simulations suggest that within the same region, platform-ward dipping faults and major fractures may form, with dip angles decreasing towards the basin. Additionally, the inner platform region may exhibit a tensile regime, potentially leading to the formation of nearly vertical syndepositional and/or syndiagenetic fractures. These were not predicted in previous research papers but are observed in our case studies (Inama et al., 2020; Menegoni et al., 2022b). Lastly, in platforms that predominantly prograde, our simulations indicate a general tilting and thickening of the inner platform strata towards the platform break.

Inama R., Menegoni N., & Perotti C. (2020) - Syndepositional fractures and architecture of the lastoni di formin carbonate platform: Insights from virtual outcrop models and field studies. Marine and Petroleum Geology, 121, 104606, https://doi.org/10.1016/j.marpetgeo.2020.104606.

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Nolting A., Zahm C.K., Kerans C. & Nikolinakou M.A. (2018) - Effect of carbonate platform morphology on syndepositional deformation: Insights from numerical modeling. Journal of Structural Geology, 115, 91-102, https://doi.org/10.1016/j.jsg.2018.07.003.

Resor P.G. & Flodin E.A. (2010) - Forward modeling synsedimentary deformation associated with a prograding steep-sloped carbonate margin. Journal of Structural Geology, 32(9), 1187-1200, https://doi.org/10.1016/j.jsg.2009.04.015.

The subsurface geological map of the Torino metropolitan area (Western Po plain): from 3D model to 2D map export

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Keywords: subsurface geological map, sedimentary basins, 3D model.

The 1:100,000 subsurface geological map of the Torino area is the cartographic output of a database-assisted 3D geological model, covering an area of about 890 km2, between the western Alps and the Turin Hill reliefs. This sector is of geologic relevance as it develops above one of the most significant structural elements of the northwestern Apennine - Po plain transition, i.e. the Torino Hill thrust Front and associated folds system, whose late Miocene to early Pleistocene tectonic activity strongly influenced the geologic evolution of this region.

In the recent past, the geologic setting of the northeastern partly outcropping part of this fold-thrust complex was mapped in detail, and its oldest (Late Miocene) tectono-stratigraphic evolution was studied in the Turin Hill. Conversely, the general traits of the architecture of its southwestern, buried counterpart and its Plio-Quaternary tectono-stratigraphic evolution were only partly illustrated by a few seismic reflection profiles. Furthermore, lower detail and scale subsurface maps of the subsurface of the central-eastern and northern portions of the study area have been provided. Therefore, a complete geological subsurface representation of the Pliocene-early Middle Pleistocene tectono-stratigraphic assemblage of the area was still lacking.

In this perspective our map is a more detailed document, providing an updated representation, below the Middle Pleistocene regional unconformity, of the stratigraphic and tectonic relationships characterizing the buried Pliocene-Lower Pleistocene sedimentary pile involved Turin Hill thrust-propagation folds system. The map is grounded on over 500 water-well and borehole logs detailed correlations along shallow triangle meshes (average investigation depth of 200 m below ground surface), managed by the GMS (Groundwater Modeling System) software, and constrained by published seismic transects.

The map provides new elements to discuss late Pliocene-early Middle Pleistocene tectono-stratigraphic evolution of the northwestern termination of the Apennine thrust-and-fold belt (Irace et al., submitted). The map and related 3-D model thus represent a new stratigraphic and structural geological base for various thematic research with application purposes such as groundwater, geothermal and mineral resources management and seismic hazard analysis.

Irace A. et al. (submitted) - Subsurface geology of the Torino metropolitan area (Westernmost Po Plain, NW Italy). Journal of Maps.

In search of a geological signature of slow earthquakes: structural and geochemical characterization of crack-seal veins in metasediments from the Alpine accretionary prism

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Keywords: slow earthquakes, crack-seal veins, subuction.

Metasedimentary rocks exhumed from various depths in subduction accretionary settings are typically infused by systems of mineralized veins, commonly filled by quartz and/or calcite. Their geometric and chronologic relationships with the multiphase deformation history characterizing the host rocks suggest repeated tensile and/or shear hydraulic fracturing at near-lithostatic fluid pressures.

The zones with evidence for high pore-fluid pressures in active subduction plate interfaces are in the same depth ranges where the spectrum of slip behaviors of slow earthquakes (low-frequency earthquakes, tremor, slow slip events) are seismologically or geodetically detected: the transition zones between the locked seismogenic zone and the shallow and deep stably sliding zones. This suggests that hydraulic fracturing of variably lithified sediments during passage along the plate interface and accretion at the prism base, may represent a possible source for slow earthquakes. Unfortunately, the deformation mechanisms responsible for slow earthquake deformation, or their relationships with megathrust earthquakes, are far from being understood, making further studies of fluid-rock interactions of timely importance.

Here we report on a detailed structural and geochemical analysis of crack-seal, composite quartz/calcite vein systems in the trench turbidite deposits, covering the Ligure-Piemontese ocean-derived units ,cropping out in the Internal Ligurian Units (ULI) of Northern Apennines and in the Upper Units (UU) of Alpine Corsica. The two groups of units were structured in the same Late Cretaceous-Early Tertiary Alpine accretionary complex but at different structural levels (200-230 °C and 0.6-0.8 GPa for the studied ULI; 150-200°C and 0.3-0.4 GPa for the studied UU).

The structural analyses show the occurrence of distinct episodes of hydraulic fracturing and mineralization – with Mode I and/or Mode II opening mode - evidence of a complex fluid-rock interaction, accompanied by progressive lithification and diagenesis of the turbidite sequence during subduction, that resulted in a continuous evolution of the rheological properties of the turbiditic multilayer. The vein textures clearly indicate multiple episodes of fracture and sealing associated with cyclic build-up of pore fluid pressure.

Preliminary C and O isotope analyses of the vein sets in the UU and in ULI show quite homogeneous d13C e d18O values for all the different sets of veins, suggesting a common fluid origin for all vein sets, no matter their geometric and chronological relationships with the different deformation steps. Particularly, the d13C e d18O values for either the Corsica or Ligurian samples seem to suggest a fluid origin related to decarbonation of calcareous sediments. Further investigation will be devoted to deeply understand the isotope trend of host rocks, most probably related to the progressive lithification and diagenesis of the turbiditic section moving along the plate interface.

The importance of lithofacies mapping: a case study of Eocene base-of-slope deposits of the Apulia Carbonate Platform (Gargano Promontory, Southern Italy)

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Keywords: lithofacies maps, Apulia Carbonate Platform, Eocene.

Despite their significance in the characterisation of reservoirs, lithofacies heterogeneity, geometry and resulting distribution are often neglected. The Apulia Carbonate Platform (ACP) represents one of the most extensive Meso-Cenozoic isolated carbonate domains of the Tethyan Ocean. During the Eocene, the ACP experienced a generalised uplift and subaerial exposure related to regional unconformity, gravitational collapses and the massive deposition of slope and base-of-slope resedimented carbonates. In the north-eastern area of the Gargano Promontory, the Middle to Upper Eocene Peschici Formation consists of breccias and bioclastic turbidites, alternating with micritic limestones and pelagic marlstone, deposited in a slope to base-of-slope setting that, in this area, are related to a point-source supply mechanism (Calciclastic-Submarine-Fans (CSF) type).

The analysis of the facies distribution of these Eocene deposits reveals significant heterogeneities. The differentiation of eight major lithofacies was achieved through a detailed fieldwork mapping at 1:5000 scale. These include calcarenites (fine, coarse) (CAF-CAC), floatstone and rudstone with nummulitids (NF-NR), breccias with different clast contents such as nummulitids (NB), corals (CB), rudists (RB), alveolinid clasts (APG) and pelagic mudstone (PM) rich in planktonic foraminifera. The resulting detailed map, therefore, allows the reconstruction of the areal distribution and lateral relationships and heterogeneity of the lithofacies.

Consequently, the study of the Eocene Peschici Formation serves as an exemplary case study in demonstrating the necessity for an accurate depositional model deduction and reservoir characterization, to be based on a detailed lithofacies map reflecting the various heterogeneities and geometries. Moreover, the importance of this knowledge also lies in its application to aspects of sustainable energy, such as CO_2 and H_2 storage.

Approach and methodologies for the 3D geological modelling of the CARG 121 Brescia 1:50.000 sheet

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Keywords: 3D geological modelling, Brescia geological sheet, 3D GIS.

The 121 Brescia sheet of the 1:50,000 geological map of Italy covers an area stretching from the southern Alps to the densely populated and seismically active northern Po plain. This area showcases a complex geological landscape, with faulted and folded Mesozoic and Cenozoic carbonate sedimentary formations in the southern Alps, transitioning to a wide sector of the northern Po plain. The plain is composed of Quaternary marine, fluvial, fluvio-glacial, glacial, and loess deposits, some of which have been affected by recent tectonic activity.

The area of this geological sheet has been site of intense subsurface exploration, mainly for hydrocarbon search, groundwater management and scientific studies, producing complex sets of subsurface geological and geophysical data. Thanks to the effort and support provided by ISPRA – Servizio Geologico d'Italia, Regione Lombardia, ENI S.p.A., A2A Ciclo Idrico S.p.A. and AATO - Ufficio d'Ambito di Brescia, among others, many of these data have been made available for the 3D geological modelling of the area. This dataset includes seismic profiles, hydrocarbon well logs, gravimetric data, water well logs, Airborne ElectroMagnetics (AEM) soundings, and in-depth logs and sample analyses from shallow scientific and commercial cores retrieved from the alluvial plain. These subsurface data have been complemented by large amount of surface data from the new detailed geological field survey, especially for the mountain Southern Alps sector comprised within the geological sheet area.

This multifaceted dataset represented both a challenge and an opportunity for the geological modelling of the 121 Brescia sheet, because of the great difference in format, resolution, quality, depth, and 3D spatial distribution of the available data. For some of the data, new approaches have been developed to account for their quality and/or novelty. For example, old seismic data in raster format, imaging the deeper part of the subsurface, required complex processing for their translation in SEGY format, interpretation, and time-depth conversion. Also, AEM data, acquired for the shallower part of both the Po plain sediments and the mountain sector, required the design and implementation of a new (semi)automatic GIS algorithm for the delineation of geological surfaces to be correlated with the surface and subsurface stratigraphy.

These different surface and subsurface datasets have been processed in specialized software and then imported in a 3D GIS to: (1) provide a combined view of the subsurface geology, and (2) support the interpolation of surfaces and volumes representing geological objects that can be correlated with the known stratigraphy and structure of the area (e.g. CARG surface stratigraphy and GEOMOL project).

Here, the full workflow for the construction of 3D geological model is shown, discussing its main features, obtained results, and potential replicability in similar geological contexts.

Interpretation of subsurface data for the 3D static model of the High Agri intermontane basin: inferences for Quaternary tectonic evolution of the Southern Apennines

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Keywords: 3D static model, geological geophisical tools, Southern Apennines.

The study of intermontane basins located in fold and thrust belts is of fundamental importance for assessing the control exerted by tectonic structures on the geometry of the sedimentary infill, thus providing clues on the tectonic evolution of the area. In this context, the High Agri Valley (HAV) is one of the most important NE-trending intermontane basins of tectonic origin located in the axial sector of Southern Apennines. The Quaternary infill of the valley, occurred during the activity of two main systems of high-angle faults exposed along the two sides of the valley. The study of Quaternary deposits in the HAV was realised by using geophysical and well data, which can be interpreted considering the geological structures exposed in the sides of the valley.

Piling of tectonic units in the Southern Apennines took place during the Miocene, following the collision between the African and Eurasian plates, which led to the formation of an allochthonous wedge migrating in a NE direction above the carbonate rocks of the Apulian foreland (Patacca & Scandone, 2007). This older deformation is testified by regional-scale thrusts and folds, that are exposed in both the sides of the HAV. The younger deformation producing normal and transtensive faults that cross-cut the allochtonous units, piled up during the formation of the fold and thrust belt, were responsible for the consequent opening of the HAV basin during Quaternary.

This study focuses on the detailed reconstruction of the geometry of Quaternary lacustrine and alluvial deposits infills of the HAV, through the construction of a 3D static model of the HAV floor area. The proposed model has been created with the MOVE modelling software and it is based on a dataset of subsurface data including a series of DERTs obtained during a recent acquisition campaign, which integrate the previous DERTs collected by Colella et al. (2004) and by Rizzo & Giampaolo (2019). In addition, shallow wells have been used to calibrate the DERTs. Subsurface data allowed the construction of geological cross-sections, used as a starting point for the 3D modelling.

The construction of a 3D static model of a large area presents a degree of uncertainty due to the type and distribution of data. In particular, the DERTs show limitations in the qualitative resolution due to the scale of acquisition, whereas well data are in some cases not sufficient to calibrate entirely the DERTs. During the development of the model, has also been possible to observe how the scarcity of data in some sectors of the area produced a greater degree of approximation in the interpretation.

The 3D static model allowed us to determine the geometries of the allochthonous sedimentary bodies, with particular attention in the location and distribution of the main depocentral areas. Particular attention was paid to the high-angle faults occurring in the HAV area, which allowed us to recognize how some normal faults were involved in the Quaternary clastic deposition during the last tectonic phases.

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3D Subsurface structural-geological modelling at the Central-Southern Apennines boundary: The 379-Capracotta geological sheet

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Keywords: 3D Geological Modelling, CARG Project, Central-Southern Apennines.

In this study, we present the results of an integrated subsurface structural-geological characterization and three-dimensional modelling within the 1:50 000 CARG 379-Capracotta geological sheet. The studied area is located at the transition zone between the Central and the Southern Apennines fold-and-thrust belt. This sector of the Apennines is characterized by the complex superposition of different paleogeographic domains that developed during the Mesozoic along the passive southern margin of Adria. Given the structural complexity, different and strongly contrasting interpretations on the origin of the various stacked units and tectonic style (thin-skinned vs wrench tectonics vs combined thin-/thick-skinned) were proposed by many authors over time.

The subsurface dataset includes legacy wells and 2D seismic data from hydrocarbon exploration that were made available for the first time by ENI exclusively for the CARG project as well as public information retrieved from the ViDEPI database and previous studies. The seismic lines of various vintages, provided in the form of scanned copies of the original plots, were digitised and imported along with the digital logs into an industry-standard interpretation and modelling platform. The available geological maps were draped over the digital elevation model in order to constrain the seismic interpretation to the mapped surface geology. The interpretation and 3D modelling regarded the reconstruction of the top of the autochthonous Apulian Platform *s.l.* sequence, some markers within the Molise allochthonous units as well as the main faults.

The Bouguer gravity anomaly data provided by ENI were also modelled through a constrained inversion of the 3D model retrieved after seismic data interpretation. Volumes pertaining to the main geological units were parametrized according to density values derived from well logs. Several inversion procedures with decreasing constraints on the density allowed for each cell were computed. Driven by a distance weighting function, the inversion procedure minimizes the residual between the observed data and the data predicted by an objective function1. Results predict some lateral density variations within the Apulian Platform sequence and within the allochthonous units, respectively in the central and western area of the geological sheet, which are compatible with the sedimentary and tectonic evolution of the area.

The integrated subsurface structural-geological study provided strong insights for a better understanding of some, among of many lively debated, key open topics at the Central-Southern Apennines transition zone such as: i) definition of the tectonic significance of the Sangro-Volturno transverse lineament; ii) relationships between autochthonous and allochthonous units; iii) definition of the deformation and tectonic styles and iv) hydrocarbon exploration potential within the deep autochthonous positive structures.

A proposal for simple accuracy evaluation of geological surfaces based on spatial autocorrelation

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Keywords: 3D geological models, geological maps, accuracy.

A standardized approach for assessing geological surfaces accuracy remains elusive. Recent studies have proposed methods and standards for error analysis in geological or subsurface maps (e.g., Kint et al., 2020 and references therein). However, these methods are still subject to significant bias due to their reliance on data availability and selection criteria. Quality flagging is a common method used to quantify uncertainty within spatial datasets, typically achieved through assessment of metadata fields. This approach may range from simply indicating data presence or absence to more complex methods yielding a comprehensive array of quantitative error ranges (e.g., Bardossy & Fodor, 2001). In the case of few data or datasets without associated uncertainty these methods are not recommended/feasible, and accuracy is not quantifiable.

We propose a more general simplified method already tested in Livani et al. (2023) based solely on the distribution and quantity of input data to generate maps of spatial accuracy. Spatial autocorrelation through the Inverse Distance Weighting (IDW) explores the similarity between nearby observations in geographic space, weighting feature locations and feature values simultaneously. In our analysis, we implemented a method to assess the accuracy/confidence of geological horizon/fault quantifying: i) the data density contributing to evaluating lateral accuracy and depth variability, ii) the accuracy based on data density and spatial autocorrelation, transformed into a probability reflecting confidence in the data at each point within the study area, and iii) the error associated with the depth of geological surfaces due to discrepancies among data from different sources (boreholes, seismic/geologic sections and subsurface maps) where divergent interpretations exist. Consequently, for each point within the study area, we provided values indicating accuracy and estimated error of the depth of the geological surface.

This method, resulting from the geological 3D modelling activities carried out in the GeoSciences IR and MEET Next Generation EU funded projects, will be proposed as a standard for the accuracy evaluation of 3D geological models produced in the framework of the CARG Project.

Bardossy G. & Fodor J. (2001) - Traditional and new ways to handle uncertainty in geology. Nat. Resour. Res., 10(3), 179-187, https://doi.org/10.1023/A:1012513107364.

Livani M. et al (2023) - Subsurface geological and geophysical data from the Po Plain and the northern Adriatic Sea (north Italy). Earth Syst. Sci. Data, 15, 4261-4293, https://doi.org/10.5194/essd-15-4261-2023.

Kint L. et al. (2020) - Uncertainty assessment applied to marine subsurface datasets. Q. J. Eng. Geol. Hydrogeol., 54(1), https://doi.org/10.1144/qjegh2020-028.

Fluid flow patterns inferred from selective cementation in fluvio-deltaic, sandstone-conglomerate bodies, Crotone forearc Basin

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Keywords: structural diagenesis, carbonate concretions, fluid flow pathways.

The study of selective cementation of high-porosity sandstone bodies is crucial to the understanding of reservoir quality. This has heavy impacts on the efficient exploitation of strategic fossil resources (oil and gas), preservation and management of aquifers and underground storage of anthropogenic CO_2 and H_2. The detailed analysis of selective cementation patterns at the outcrop scale could provide hints to unravel the fluid flow pathways affecting siliciclastic sandstone bodies.

We present the results of a study dealing with the selective cementation affecting fluvio-deltaic, Pliocene age, sandstone to conglomeratic bodies exposed in the Crotone forearc Basin, South Italy. The siliciclastic unit was deposited in a shallow marine setting and reaches a maximum thickness of ~80 m, unconformably overlying the Paleozoic Sila Massif metamorphic basement. The sandstone is almost completely devoid of any primary diagenetic cement thus appearing nearly incohesive. The mild brittle deformation affecting the high porosity sandstone is characterized by sparse deformation bands, small deformation band clusters and a few subsidiary faults. Selective cementation can be traced along the studied outcrops as diagenetic concretions of different shapes and sizes. Concretion types comprise tabular and laterally extensive up to 10's m-wide bodies, elongate blade-shaped objects from 10 cm up to several 10's meter-long, asymmetric drop-shaped concretions and nodular-spherical bodies. The elongation direction of concretions parallels the subtle southeastward dip of bedding surfaces, except in the vicinity of deformation bands and faults, where elongate concretions are vertically oriented. The selective cementation was due to pervasive calcite precipitation, which caused a dramatic porosity loss, leading to a significant increase in sandstone cohesion and stiffness. Tightly cemented bodies enclose deformation bands and host 2-3 sets of joints which abut at the concretion-host rock boundary. Cold cathodoluminescence analysis revealed the extensive presence of yellow-bright calcite cement within concretionary bodies. Calcite cement has granular to poikilitic texture with rare bright-dull zonation rims along coarser crystals. Carbon and Oxygen stable isotopes performed on calcite cement suggest two different cement sources responsible for the selective cementation. The first source can be traced within weaky cemented lens-shaped bodies and along secondary faults and is made of mixed marine-meteoric fluids with contributions from soil percolation. Conversely, the second one can be documented in tightly cemented lens-shaped and nodular to elongate concretions and is given by a mix of marine fluids with contributions from biogenic methane likely related to biological-bacterial activity in a shallow marine setting. The evolution of fluids from meteoric to marine ones can be associated with the sea level rise and marine transgression that occurred after sandstone deposition.

Multidisciplinary approach for 3D geological model reconstruction: the example of Mt. San Calogero (Sciacca, Southwestern Sicily)

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Keywords: 3D geological model, Mt. San Calogero, Sicilian chain

The inability to access continuously and directly to subsurface data forces geologists to use a combination of different methods and a multidisciplinary approach to determine in high detail the possible extents of deep geological geometries. We analysed the carbonate relief of Mt. San Calogero (about 390 m a.s.l.), part of the "geological sheet 628 Sciacca" (CARG project). Field collected data were used for a preliminary 3D geological model reconstruction. The results were integrated with the seismo-stratigraphic and structural interpretation of 2D seismic reflection profiles calibrated with stratigraphic wells, covering the offshore sector of the study area. Mt. San Calogero, which belongs to the outer sector of the western Sicilian Fold and Thrust Belt, represents an outcrop of part of the paleogeographic domain known as the " Saccense". The outcropping succession is characterized by thick shallow-water carbonate platform deposits from the Lower Jurassic overlain by condensed pelagic deposits from the Middle-Upper Jurassic to the Eocene, covered by the Oligo-miocenic syntectonic clastic deposits. The new collected data confirmed that Mt. San Calogero represents the outermost deformed portion of the western Sicilian chain composed of a double verging compressional structure delimited by NNE-SSW-trending left-lateral transpressive faults involving deposits of Calabrian age. In the offshore sector the seismic profiles interpretation highlighted the presence of a NE-SW-oriented ramp-anticline, bounded by high-angle deformation with transpressive kinematics. To establish a structural continuity between Mt. San Calogero structural high and the adjacent offshore compressive structure, additional data were integrated. The gravimetric anomaly map of this sector shows positive values of the Bouguer anomalies, with approximately NE-SW direction. In addition, data regarding heat fluxes show that there is a direct connection between the geothermal field of Sciacca, which reaches a temperature of approximately 76°C at a depth of 2600 m b.s.l., and the offshore sector, where thermal anomalies and fluids evidence are documented. In general, the structure thus identified represents the northward prosecution of a compressive/transpressive structural high with an approximately N-S trend, recognized in different literature data (Catalano et al., 2000; Fedorik et al., 2018). This multidisciplinary approach therefore allowed a more correct and continuous correlation between onshore/offshore structures and the definition of the offshore extent of a structure essential for understanding the tectonic evolution of the Sicilian chain.

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Fedorik J. et al. (2018) - Structural analysis and Miocene-to-Present tectonic evolution of a lithospheric-scale, transcurrent lineament: The Sciacca Fault (Sicilian Channel, Central Mediterranean Sea). Tectonophysics, 722, 342-355.

Stratigraphic constraints for the 3D modeling of the Tevere Alluvial Valley beneath Rome (Italy)

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Keywords: 3D, modelling, Tevere.

Understanding the complex three-dimensional (3D) architecture of Quaternary alluvial deposits beneath modern urbanized alluvial plains is useful for defining the basin evolution and the rock property distribution, and for assessing and mitigating possible geohazards.

This study proposes an integrated methodological approach to reconstruct the complex stratigraphic setting of the Tevere valley in the subsoil of Rome city. We analyzed and elaborated stratigraphic data from 129 boreholes and 24 cone penetration tests. The available data were elaborated applying a kriging geostatistical algorithm in a geological-geophysical modeling software. The model defines the spatial distribution of primary architectural elements within the late Quaternary units of the Tevere River valley, establishing spatio-temporal relationships and evolutionary trends of the alluvial succession.

This modeling approach helps in bridging the gap between the conceptual sedimentary models established for the Holocene Tevere alluvial succession and real-world geological challenges. Moreover, it may serve as a pivotal tool for evaluating and managing subsurface resources and mitigating geohazards in a densely populated area. The methodological approach proposed in this study can improve the 3D representation of sedimentary successions through an efficient and time-saving process.

Preliminary findings from deep 3D electrical resistivity tomography in active faults

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Keywords: deep electrical resistivity tomography, active faults, 3D modelling.

This study presents preliminary outcomes from a deep geoelectrical survey aimed at investigating subsurface resistivity changes associated with active faults in the Central Apennines region. Utilizing a 3D electrical resistivity approach, we conducted comprehensive surveys to overcome limitations posed by traditional arrays and topographical challenges.

We utilised the FullWaver system (Iris instruments), the system consists of 15 wireless dual-channel digital receivers and a 5-kW time-domain induced polarization transmitter (Sapia et al., 2021). Our measurements included induced polarizations, resistivity, and self-potential. The methodological approach mirrored the quadrupole measurement principle (Mazzini et al., 2021; Lajaunie et al., 2019; Carrier et al., 2019), with real-time recording using GPS for data synchronization and combination of transmission and receiver records. The survey design targeted depths of 50 to 200 meters to map the trend of active faults.

Following rigorous quality control processes to ensure data accuracy, we modelled the processed data using ViewLab 3D software, resulting in robust 3D resistivity models. The preliminary results demonstrate the effectiveness of the FullWaver system in deep 3D electrical resistivity tomography for studying active faults. The final 3D volume provides a detailed view of the resistivity distribution, allowing us to relate this variability to the presence of fault ruptures and/or scarps. This research contributes to the analysis of active faults in the region and opens avenues for integration with further geophysical and paleoseismological studies.

Sapia V. et al. (2021) - 3–d deep electrical resistivity tomography of the major basin related to the 2016 mw 6.5 central Italy earthquake fault. Tectonics, 40(4), e2020TC006628.

Mazzini A. et al. (2021) - 3D deep electrical resistivity tomography of the Lusi eruption site in East Java. Geophysical Research Letters, 48(18), e2021GL092632.

Carrier A. et al. (2019) - Deep electrical resistivity tomography for the prospection of low- to medium-enthalpy geothermal resources. Geophysical Journal International, 219(3), 2056-2072, https://doi.org/10.1093/gji/ggz411.

Lajaunie M. et al. (2019) - Structure of the Séchilienne unstable slope from large-scale three-dimensional electrical tomography using a Resistivity Distributed Automated System (R-DAS). Geophysical Journal International, 219(1), 129-147, https://doi.org/10.1093/gji/ggz259.

S49.

Multidisciplinary approaches to the geometric and kinematic definition of seismogenic faults

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Advanced tool for fault plane solution reliability assessment

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Keywords: focal mechanism, earthquake, seismotectonics.

Assessing the quality of fault plane solutions is valuable for numerous activities, including seismotectonic analysis and estimating pore fluid pressures at hypocentral depths. Recently, new techniques have emerged to calculate pore fluid pressures based on focal mechanisms of seismic events and to monitor the temporal variation in the pore pressure field (Terakawa et al., 2014; De Matteis et al., 2024).

In this work, we introduce an updated version of the tool originally developed by Adinolfi et al. (2022), designed to evaluate both the reliability of focal mechanisms and the ability of a seismic network to analyze fault plane solutions and their associated errors. With a specified network configuration, the tool can be utilized to assess the reliability of a focal mechanism solution or to classify the quality of fault plane solutions provided by a seismic bulletin. Additionally, new statistical methods have been developed to more accurately determine the quality of a computed focal mechanism, as well as its associated uncertainties.

The tool is particularly helpful as it enables precise assessments of the reliability of focal mechanism solutions, which is essential when analyzing low-energy earthquakes. Such assessments are crucial for developing seismotectonic models, determining the geometry of seismogenic sources, and understanding regional strain and stress fields.

Adinolfi G.M. et al. (2022) - A functional tool to explore the reliability of micro-earthquake focal mechanism solutions for seismotectonic purposes. Solid Earth, 13, 65-83.

De Matteis R. et al. (2024) - Pore fluid pressure in St. Gallen geothermal field (Switzerland) based on earthquake focal mechanisms. Geophysical Research Letters, 51(6), e2023GL105127.

Terakawa T. (2014) - Evolution of pore fluid pressures in a stimulated geothermal reservoir inferred from earthquake focal mechanisms. Geophysical Research Letters, 41(21), 7468-7476.

The geology of Mt. Vettore area in the Sibillini Mountains, Northern Apennines of Italy

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Keywords: active faults, thrusts systems, Sibillini Mts.

Mt. Vettore (2476 m asl) is the most prominent relief of the Sibillini Mts. and the Umbria-Marche Apennines mountain chain. The area has been affected by at least three main tectonic phases: I) a Meso-Cenozoic extensional phase responsible for the evolution of the basin, filled with more than 3000 m thick sediments. These marine sediments record the thermal and mechanical subsidence history from the Early Jurassic carbonate platforms to the pelagic realm of the Paleogene. In the Sibillini Mts, the basin was dissected into structural highs and deeper basinal areas by a slope-to-basin transitional domain of varying thicknesses and facies, bounded by Jurassic extensional faults. In the Mt. Vettore area, the Calcare Massiccio Fm (Early Jurassic) crops out along the eastern face, characterised by cyclic sedimentation of carbonate banks, with a few hundred meters local thickness. Lithologically, it consists of white, thick-bedded to massive grainstone and packstone, containing several bioclasts and locally dolomitisation lens. The overlying Corniola Fm (Lower Jurassic) outcrop extensively in well-stratified decimetric to metric beds of dark grey-brownish lime mud wackestone with grey chert nodules. It contains abundant clastic deposits, including slumps and large olistoliths, produced by tectonic activity along the margin of the surrounding carbonate platforms.

II) A compressional phase occurred in the Neogene, forming the Umbria-Marche foreland fold-and-thrust belt. Several asymmetric NE verging rootless anticlines constitute the hanging wall of the Mt. Sibillini thrust system, which runs for more than 60 km with an arcuate shape and a total shortening of many km. In the eastern face of Mt.Vettore, the thrust system has a strike about N-S and transpressional kinematics through NE. Right lateral strike-slip fault systems are associated with the thrust splays. Several detachment levels are located in the Upper Cretaceous and Miocene marls, rooted in the deeper Triassic anhydrites. In the eastern region, outcrops more than 2500 m thick of Upper Miocene to Pliocene terrigenous clastic of the Laga Fm belong to the foreland basin and are involved in the thrusts.

III) Finally, from the Pleistocene onward, the area is involved in an extensional tectonic phase. A set of normal faults striking NW to SE crosscut the compressional structures, which were activated during the 2016 earthquakes of the Amatrice-Norcia sequences. These extensional structures control the evolution of the intramountain basins and their filling of the Pleistocene continental deposits. The field observations of the cross-cutting relationships between the compressional thrust structures and the active extensional faults in the Mt. Vettore area show that the normal faults cut and displace the thrust system.

Quaternary stress and strain patterns in the Italian peninsula from QUIN's data

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Keywords: geological stress and strain-field in Italy, intra-Apennine late Pliocene-Quaternary extensional fault system.

Knowledge of the strain and stress field of the Earth's crust is crucial to understanding the structural and seismotectonic contexts. It helps to reconstruct the evolution of geological processes that have affected the Earth's crust and provides information on the orientation and magnitude of tectonic forces controlling seismically active zones. It is also fundamental to constructing predictive models of fault behaviour, thereby improving our evaluation of seismic hazard. Information on tectonic stress can be derived from direct measurements from boreholes, focal mechanisms, or structural-geological data (fault/slip attitude). Information obtained directly from faults provides a long-term view of kinematic and deformation processes. In this study, we exploit the high potential of the QUIN database (Lavecchia et al., 2022, 2024), which collects ~8000 data of Fault Striation Pairs (FSP) distributed over ~800 Structural Sites (SS) and belonging to 74 Fault Systems (FS) along the intra-Apennine late Pliocene-Quaternary extensional belt of Italy. For the strain analysis, we developed a MATLAB code to analyze the kinematic compatibility of the FSP data and to extract the orientation of the strain tensor (P/S1, B/S2, T/S3) axes and the strain ratio R=(S2-S3)/(S1-S3). At the same time, we applied the formal stress inversion to the FSP data using the MSATSI software (Martínez-Garzón et al., 2014) and obtained the stress tensors (σ1, σ2, σ3) and the stress ratio φ=(σ2-σ3)/(σ1-σ3) for the 74 FS. We calculated the horizontal strain/stress (SH) axes using the correction method of Lund & Townend (2007). We compared the data from the latest geodetic velocity models and focal mechanism catalogs with the long-term tectonic trends using QUIN FSPs on a regular grid map. Our results confirm a coherent extensional stress field spanning multiple time scales from the Late Pliocene to the present. The reconstructed geological SHmax directions generally correlate well with observed contemporary stress indicators from earthquake and geodetic data. In general, we reconstruct a multi-wavelength outward arcuate pattern and observe that small-scale SH rotations are detected with increasing resolution of the stress field. The stress field migrates coherently eastwards with time, and generally, temporal stress variations are not observed, except in a few areas corresponding to pre-existing localized W-E to WNW-ESE normal and normal-oblique shear zones. Such discontinuities appear to control regional and local bendings of the strain trajectories. Therefore, we interpret them as tectonic corridors that may act as barriers to along-strike propagation of potentially seismogenic Apennine normal faults. This study demonstrates that a geologically based comprehensive multi-scale strain and stress analysis of active structures over time can significantly enhance and even transform the understanding of local and regional seismotectonics within the broader geodynamic context.

Lund B. & Townend J. (2007) - Calculating horizontal stress orientations with full or partial knowledge of the tectonic stress tensor. Geophys. J. Int. 170(3), https://doi.org/10.1111/j.1365-246X.2007.03468.x.

Martínez–Garzón P. et al. (2014) - MSATSI: A MATLAB Package for Stress Inversion Combining Solid Classic Methodology, a New Simplified User–Handling, and a Visualization Tool. Seismological Research Letters, 85(4), https://doi.org/10.1785/0220130189.

Lavecchia G. et al. (2022) -QUaternary fault strain INdicators database - QUIN 1.0 - first release from the Apennines of central Italy. Sci Data, 9(204), https://doi.org/10.1038/s41597-022-01311-8.

Lavecchia G. et al. (2024) - QUIN 2.0 - new release of the QUaternary fault strain INdicators database from the Southern Apennines of Italy. Sci Data, 11(189), https://doi.org/10.1038/s41597-024-03008-6.

Get to know the QUIN database: applications and potential insights from fault traces and over 8000 structural-geological data points in the Quaternary extensional belt of Italy

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Keywords: structural-geological database, potentially seismogenic faults, Italy.

Extensional tectonics play a crucial role in shaping the morphology and structural characteristics of the Apennine chain in Italy, yet their importance has often been overlooked. Recent advancements in highlighting the significance of Quaternary extensional tectonics have been made possible by developing the QUIN database (QUaternary fault strain INdicators database).

The QUIN database consists of two releases: QUIN 1.0 covering the central-northern Apennines (Lavecchia et al., 2022) and QUIN 2.0 covering the southern Apennines and Calabria (Lavecchia et al., 2024). This database provides the scientific community access to over 8000 georeferenced points related to host fault planes displaying kinematic evidence of prevailing extensional stress.

The QUIN database incorporates data on fault location, attitude, kinematics, and deformation axes, mainly focusing on Fault Striation Pairs (FSPs) along Quaternary faults. Each release includes a comprehensive dataset in .shp and .txt formats and an original .shp file containing fault traces hosting the FSPs.

Key information provided by the QUIN database includes:

- Geographic location and geometric characteristics of fault traces
- Name of fault hosting the structural sites and associated fault system
- Age of the oldest recorded displacement or syn-tectonic deposits
- Evidence of seismogenic or potentially seismogenic activity based on integrated geological and seismological data.

The QUIN database represents a valuable resource due to its extensive coverage across the Italian peninsula, where the regional stress field has remained relatively stable over some millions of years. This stability offers a unique opportunity to analyze long-term structural data, particularly for seismic purposes, extending the investigation timeframe to encompass at least the entire Quaternary period. Such insights are critical for understanding the long-term deformation of the Apennine range, especially in areas that may have exhibited minimal seismic activity in instrumental times but could harbour significant yet unrecognized seismic potential.

The applications of the QUIN database, spanning from northern Tuscany to southern Calabria, are diverse and impactful. Its comprehensive collection of fault traces in a unified database opens avenues for three-dimensional seismotectonics, numerical modeling, forma stress inversion, seismic hazard assessment, and industry and territorial planning applications.

Researchers interested in leveraging the QUIN database for collaborative studies are encouraged to contact us for potential collaboration opportunities.

Lavecchia G. et al. (2022) -QUaternary fault strain INdicators database - QUIN 1.0 - first release from the Apennines of central Italy. Sci Data, 9(204), https://doi.org/10.1038/s41597-022-01311-8.

Lavecchia G. et al. (2024) - QUIN 2.0 - new release of the QUaternary fault strain INdicators database from the Southern Apennines of Italy. Sci Data, 11(189), https://doi.org/10.1038/s41597-024-03008-6.

Probabilistic analysis of slip rates over time of offshore buried thrusts in the Central Adriatic Sea (Italy)

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Keywords: seismogenic faults, Adriatic Sea, slip-rates.

Understanding the seismotectonics of buried and potentially active faults represents a demanding challenge and requires robust approaches. Detecting recent-to-ongoing activity of the active buried frontal thrusts of the Apennines is particularly challenging because sedimentation rates easily exceed the very slow tectonic rates and the foredeep deposits of the northern and central Apennines cover the features that better displays the recent activity.

In this work, we quantitatively analyse the Plio-Pleistocene tectonic activity of the major Apennines buried thrusts in the central Adriatic Sea. Then, we calculate the slip rates of those faults combining seismic reflection profiles interpretation, kinematic restorations and balancing.

The northern and central Apennines foredeep is filled by thick Messinian to Quaternary sediments, unconformably lying on a Meso-Cenozoic carbonatic and siliciclastic passive margin succession, which is in turn involved in the East-Northeast propagation of the fold-and-thrust belt (Adriatic Sea). As highlighted by previous studies, the region is experiencing an overall tectonic activity decrease, but local observations on specific structures show evidence of recent tectonic activity.

The frontal thrusts of the Apennines are active nowadays, as demonstrated by the moderate recent (few past centuries) seismic activity recorded in that region. We interpreted, depth converted, and restored two northeast trending regional seismic reflection profiles, roughly orthogonal to the main strike of the buried thrusts. We used the inverse *trishear* approach to determine the slip necessary to restore the residual tectonic deformation (after decompaction) of five (well age-constrained: Zanclean to Middle Pleistocene) deformed stratigraphic horizons. We then calculated and reported the slip rates using probability density functions, considering the uncertainties associated with both horizon ages and the restoration process. At the end, our results show a gradual reduction of slip rates over time, with a main slowdown around 1.5 Ma. The majority of the deep analysed thrust show evidence of ongoing activity, even though they are characterised by much slower activity rates than in the past. A probabilistic analysis of the slip-rates evolution represents an essential tool for taking over epistemic uncertainty on the total seismic moment release in earthquake hazard analyses.

Do faults play hide-and-seek? New hints on the relationship between active deformation and surface faulting in a seismic gap zone of central-southern Apennines – A multidisciplinary approach

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Keywords: Late-Quaternary normal faults, remote-sensing analysis, central-southern Apennines (Italy).

Finding evidence of recent tectonic activity is not a simple task, particularly in areas characterized by low strain rates. The Late-Quaternary activity of normal faults across the Italian belt is constrained by paleoseismology, historical and instrumental seismicity, field geology, stress and geodetic data-, and highlighted by distinctive geomorphic features on the landscape. However, in the sector between the central- and southern Apennines (Abruzzo-Molise border), this evidence is less clear or even missing. Our area of interest is located between two active fault systems (the SW-dipping Aremogna-Cinquemiglia and NE-dipping Isernia-Bojano, Lavecchia et al., 2022). However, across the latter, the structural continuity of the extensional system breaks down suddenly highlighting a "transition zone" marked out, in addition, by the predominance of siliciclastic and marly-limestone lithologies (Bucci et al., 2022) and an evident seismic gap (Rovida et al., 2020). According to Carafa et al. (2020, and reference therein), post-LGM throw-rate estimates (0.7-1.0 mm/yr) of outcropping faults in neighbouring sectors are consistent with geodetic and stress data, remarking that the area is currently undergoing rather fast permanent bulk deformation not strictly associable to known active structures. To investigate this challenging setting and inspect the disconnection between active deformation and (apparent) absence of surface faulting, we used a multidisciplinary approach combining topographic and relief analysis (to detect possible transients in the topography), photointerpretation (to portray continuous lineaments across the landscape to be traced back to tectonics structures) and field survey to support remote data interpretation. This approach allowed us to focus on new potential tectonic lineaments (in the area between Roccaraso and Forlì del Sannio towns) aligned, in continuity, with neighbouring fault systems and consistent with normal-fault kinematics. In addition, other minor fault segments, located in more external positions (east of Vastogirardi village and Mt. Campo-Mt. San Nicola sectors), suggest a further encroachment of the extensional deformation to the East. In contrast with other sectors of the Apennines, normal fault size and their distribution over a ~ 15 km wide area, are likely coherent with a diffusive deformation pattern, possibly led by the peculiar tectono-stratigraphic setting of the sector. Gravitational movements situated on or near the mapped structures further support the hypothesis that, in the specific context, these phenomena can be enhanced by the presence of active faults. InSAR data analysis across the study area will be used to map and analyse the spatial distribution of gravitational movements, and possibly differentiate tectonic versus gravitational (slope-related) signals, thus providing additional information on the seismic hazard of this understudied region.

Bucci F. et al (2022) - A new digital lithological map of Italy at the 1 : 100 000 scale for geomechanical modelling. Earth Syst. Sci. Data, 14, 4129-4151, https://doi.org/10.5194/essd-14-4129-2022.

Carafa M.M.C. et al. (2020) - Partitioning the Ongoing Extension of the Central Apennines (Italy): Fault Slip Rates and Bulk Deformation Rates From Geodetic and Stress Data. J. Geophys. Res-Sol. Ea., 125, e2019JB018956, https://doi.org/10.1029/2019JB018956.

Lavecchia G. et al. (2022) - QUaternary fault strain INdicators database – QUIN 1.0 – first release from the Apennines of central Italy. Sci. Data, 9(1), 204, https://doi.org/10.1038/s41597-022-01311-8.

Rovida A. et al. (2020) - The Italian earthquake catalogue CPTI15. B. Earthq. Eng., 18(7), 2953-2984, https://doi.org/10.1007/s10518-020-00818-y.

Geometric and kinematic assessment of the seismogenic sources of Northeast Italy

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Keywords: active tectonics, seismogenic sources, Northeast Italy.

The Italian Database of Individual Seismogenic Sources (DISS; DISS Working Group, 2021) describes several individual and composite seismogenic sources in Northeast Italy and neighboring countries, i.e. Veneto and Friuli Venezia Giulia regions and Slovenia, straddling the outer S-verging thrust fronts of the Eastern Southern Alps, and the NW-striking, right-lateral strike slip structures of the Dinaric fault system. In recent years, several new studies have been conducted on the active tectonics of the area that helped better constrain the geometry and kinematics of the active fault systems. We present here an updated seismogenic source model of the area, based on published and unpublished studies and datasets, and original interpretation of new data acquired from field mapping (CARG projects), seismic profile interpretation and subsurface geological models, and terrestrial and space geodesy (InSAR and GPS). The new model includes a reevaluation of the geometry, kinematics, and activity rates of the seismogenic faults in the study area. The results of this study have been used and will be used to reevaluate the seismogenic sources of the DISS database included in the current release and for the next updated versions.

DISS Working Group (2021) - Database of Individual Seismogenic Sources (DISS), Version 3.3.0: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas. Istituto Nazionale di Geofisica e Vulcanologia (INGV), https://doi.org/10.13127/diss3.3.0.

A fresh view of the 1997 Umbria-Marche seismic sequence in light of a fusion of updated seismological and subsurface data

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Keywords: seismotectonics, Central Italy, tectonic inversion.

The high seismic hazard area of the central-northern Apennines has experienced multiple seismic sequences in recent decades, including the 1997 Umbria-Marche, 2009 L'Aquila, and 2016-2017 Amatrice-Visso-Norcia, all linked to post-orogenic extension. Following the Amatrice-Visso-Norcia sequence, advancements in subsurface geological data and seismological networks have improved our understanding of shallow crust structural settings and their relation to seismic activity. Recent studies have focused on the role of inherited structures, such as large thrust faults from Apennines orogeny, in compartmentalizing seismic sequences horizontally and vertically. There's also a discussion about how major compressive structures might contribute to seismogenesis by inverting their kinematics within the current extensional regimes. Similar discussions emerged after the 1997 Umbria-Marche seismic sequence, notable for its six main shocks originating on adjacent NW trending normal faults. Our work reviews data from this event, combining seismic reflection profiles, deep boreholes, geological surveys, and passive seismic data. We've developed a new 3D geological and velocity model for the area and computed a revised relocation catalog based on this data. Comparing the geological model with relocated seismicity reveals vertical and horizontal compartmentation of the shallow crust due to thrust action. Seismicity concentrates within specific structural and stratigraphic levels, often on normal faults or reactivated thrusts. Integrating seismological and geological data helps address questions about interference between Quaternary normal faults and Tertiary thrusts, as well as the geometry of faults causing the 1997 seismic sequence. This holistic approach enhances understanding of seismotectonic behavior and improves seismic hazard assessments for the region.

Reprocessed SEG-Y seismic profiles across the continuation in the Apulia offshore of the onshore seismogenic Mattinata Fault (Adriatic Sea, Southern Italy)

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Keywords: Mattinata Fault, vintage seismic profiles, conversion to SEG-Y.

The Mattinata Fault is one of the most important faults in southern Italy, since it is active and responsible for the most relevant historic seismic events in the northern Apulian Foreland, in Apulia. This fault crops out in southern Gargano Promontory and in map view roughly strikes W-E; its continuation toward the east has been documented by several studies in the adjacent Adriatic Sea area, where it has been named Gondola Line. These studies dealt with the interpretation of both deep and shallow reflection seismic data acquired on the present-day continental platform surrounding Apulia (e.g. Ridente et al., 2008; Argnani et al, 2009). The related seismic data are not freely accessible and, however, can be interpreted in various ways, especially as regards deeper structures associated to the fault. In this respect, it should be noted the recent tendency to interpret halokinetic structures associated to the main faults around the Gargano Promontory area (Festa et al., 2019, and references therein).

The available data possible dealing with the fault on the present-day continental platform are represented only by vintage unmigrated stack seismic profiles, as raster images of poor quality, hence very difficult to interpret. These are parts of the reflection seismic profiles D445, D451 and D452 acquired during the end of the sixties of the last century, and freely available from the ViDEPI database (www.videpi.com/videpi/videpi.asp). Therefore, we wondered: how to improve the quality the existing data, of crucial importance to better constrain the fault in this area?

With the aim to obtain SEG-Y files, namely of increased quality information to be modified and better represented in appropriate software, we have firstly merged the raster images of the related PDF files downloadable as portions of the above seismic profiles. The merged PDF images have been converted into TIFF ones for each seismic profile. By the use of IMAGE2SEGY, a new Matlab program to convert images of seismic profiles to georeferenced SEG-Y formatted files (Farran, 2012), the input files TIFF, together with the corresponding TXT input files (code rows including, for each seismic profile TIFF image, information such as, the trace length in pixels, line number, marine or land position, SEG-Y revision format, SEG-Y numeric format, UTM zone, geographic coordinates, pixel position, delay or time over the datum, time interval of the seismic profile in milliseconds) have been uploaded. Consequently, the output SEG-Y files for each seismic profile have been obtained. Furthermore, a data processing applied to SEG-Y converted dataset in order to remove low frequency noise. In details, a 'boxcar' frequency filter (at 16 Hz low cutoff and 125 Hz high cutoff frequencies) applied basing on poor acquisition data information available by means of DELPH Seismic ® software. Finally, a general improvement of seismic images has been obtained.

Argnani A. et al. (2009) - Tectonics of the Mattinata fault, offshore south Gargano (southern Adriatic Sea, Italy): Implications for active deformation and seismotectonics in the foreland of the Southern Apennines. G.S.A. Bull., 121, 1421-1440, https://doi.org/10.1130/B26326.1.

Farran M. (2012) - Image2segy: Converts rasters to seg-y format, http://gma.icm.csic.es/node/67.

Festa V. et al. (2019) - The enigmatic ascent of Ca-sulphate rocks from a deep dense source layer: evidences of hydration diapirism in the Lesina Marina area (Apulia, southern Italy). Int. J. Earth Sci., 108, 1897-1912, https://doi.org/10.1007/s00531-019-01739-1.

Ridente D. et al. (2008) - Middle Pleistocene to Holocene activity of the Gondola Fault Zone (Southern Adriatic Foreland): Deformation of a regional shear zone and seismotectonic implications. Tectonophysics, 453 (1-4), 110-121, https://doi.org/10.1016/j.tecto.2007.05.009.

Building a comprehensive seismic catalog of the Montello-Collalto area (Eastern Southern Alps, Italy) for seismotectonic and induced seismicity purposes

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Keywords: Montello-Collalto area, seismic monitoring, seismic catalog.

The Montello-Collalto area is located on the outer front of the eastern Southern Alps (Italy), where a fold and thrust belt has formed since the middle Miocene and is still active (Picotti et al., 2022). A medium-high seismic hazard characterizes this area, as a strong earthquake has occurred in the past (the Asolo event of 1695, M6.5), but the causative fault has not yet been identified, even because most of the tectonic structures existing here are buried under recent sediments (e.g. the Montello thrust system). In the study area, seismicity has been monitored by the OGS since 1977 (Bragato et al., 2021) both at the regional scale, and at the local scale, with several temporary surveys carried out for various purposes. A breakthrough in the recording of earthquakes in the Montello-Collalto area is the Collalto seismic network – RSC (Priolo et al., 2015), a local network used to monitor underground gas storage (UGS) located here since 2012 by OGS on behalf of Edison Stoccaggio SpA. The RSC was developed to detect the potential microseismicity induced by the UGS, and after about 12 years, a seismic catalog of more than 3500 events with -0.9. So far, there is no evidence of anthropogenic phenomena, but discriminating between natural and induced earthquakes is still an open challenge, and further analysis needs to be carried out to establish that all the seismicity recorded by the RSC has a natural origin. On the other hand, the spatial pattern of this seismicity has provided insights into the depth geometry of the Montello thrust and its antithetic structure (Peruzza et al., 2022 and references therein), but its seismogenic behavior needs further investigation. These open questions require a multiscale analysis of the seismological data: the local scale for induced seismicity and the regional scale for seismotectonic studies. To this end, we first collected information on all seismic stations operating in the Montello-Collalto area and surroundings since 1977, i.e. location, start and end time, instrumental equipment, and availability of digital data. Then we collected, reviewed, and integrated all the seismic catalogs produced for the area in different periods by different monitoring infrastructures to obtain a unique and as long as possible list of earthquakes to which refer. The next step will be relocating seismicity homogeneously with local velocity models in order to obtain the best picture of seismicity for the study area, which will allow us to analyze its spatio-temporal evolution and understand the local seismogenetic processes.

Bragato P.L. et al. (2021) - The OGS–Northeastern Italy Seismic and Deformation Network: Current Status and Outlook. Seismological Research Letters (2021) 92(3), 1704-1716, https://doi.org/10.1785/0220200372.

Peruzza L. et al. (2022) - An unusually productive microearthquake sequence brings new insights to the buried active thrust system of Montello (Southeastern Alps, Northern Italy). Front. Earth Sci., 10, 1044296, https://doi.org/10.3389/feart.2022.1044296.

Picotti V. et al. (2022) - The Montello thrust and the active mountain front of the eastern Southern Alps (northeast Italy). Tectonics, 41, e2022TC007522. https://doi.org/10.1029/2022TC007522.

Priolo E. et al. (2015) - Seismic Monitoring of an Underground Natural Gas Storage Facility: The Collalto Seismic Network. Seismological Research Letters, 86(1), 109-123, https://doi.org/10.1785/0220140087.

New insights on the Mt. Morrone (Central Apennines) active normal fault and related basin through passive seismic methods

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Keywords: active normal fault, half-graben, geophysical methods.

Understanding the behavior of seismogenic faults from depth to surface is crucial for assessing seismic hazards. This study focuses on investigating the Mt. Morrone normal fault (MF) in the Central Apennines, Italy, to constrain its architecture and the tectonic evolution of the Sulmona basin. As far as the local seismicity is concerned, neither decisive proof of historical earthquakes nor moderate (5.0).

Using a multidisciplinary approach, we integrate geophysical data, geological field analysis, and borehole data to characterize fault structures and basin geometry.

Our findings reveal complex fault geometries and deformation patterns within the half-graben basin, indicating the presence of antithetic faults. Through passive seismic noise measurements and 2D array surveys, we delineate the deep seismo-stratigraphic setting and infer the geometry of faults bounding the basin. Additionally, geological investigations and borehole data provide constraints on sediment thickness and lithology, aiding in the interpretation of seismic velocity profiles.

The results confirm Sulmona basin fault splays forming a half-graben structure elongated NW-SE. Continental deposits reach up to 700 m in the central-southern. Easternmost splays represent master faults, dissecting the Mt. Morrone range, while antithetic structures accommodate eastward downthrow. These findings suggest a complex structural evolution influenced by various fault systems and interference during time. However, complexities such as faulting and velocity inversions pose challenges to this estimation, and fault splays and buried fault systems, influence its geometry and structure.

Overall, our study advances the understanding of fault structures, with implications for seismic risk mitigation and disaster preparedness in tectonically active and populated regions. Despite this is an already-established method and tool, this approach provided new insights and a starting point for future research.

Exploring the significance of fault-earthquake data pairs in unveiling structural and seismotectonic complexities - Case studies across different tectonic regimes in Central Italy

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Keywords: seismotectonics, 3D fault model, Italy.

This study investigates the intricate interplay between fault-earthquake data pairs and their significance in revealing unforeseen structural and seismotectonic complexities. Focusing on central Italy, a region characterized by upper crustal extension and shallow to lower crustal compression, we present three case studies showing relationships between multi-depth fault behaviour, seismic activity, and fluid interaction. Through an integrated analysis involving:

1. Evaluation of the regional tectonic and seismotectonic framework;
2. Detailed examination of outcropping fault geometry, kinematics, and dynamics;
3. Examination of high-quality major earthquakes, microseismicity space-time distribution, and stress pattern features.

We meticulously constrain and reconstruct the 3D fault geometry and earthquake release style of the three case studies, each with distinct depths, kinematics, and earthquake magnitudes. In all three cases, the analysis reveals unexpected geometric complexities, including:

1. Identification of a lower crustal duplex illuminated by background microseismicity within the interconnection area between the Adriatic Basal Thrust (de Nardis et al., 2022) and its major hanging-wall splay;
2. Recognition of an upper crustal extensional system comprising interconnected synthetic and antithetic multi-scale faults, some of which are unexpected, above an east-dipping detachment, as evidenced by the aftershock sequence of the Norcia 2016 earthquake;
3. Discovery of a north-dipping extensional detachment inferred from the distribution of moderate seismic swarms and seismic sequences at middle to lower crust depths in the Sora-Marsicano area (central Apennines).

Furthermore, our results suggest that upper crustal seismicity is closely linked to the configuration of a pre-existing fault system reactivated under the ongoing seismogenic stress field. Conversely, seismicity in the lower crust (>15-20 km) may be influenced by tectonic features, as observed in the ABT duplex, or unrelated to fault discontinuities, as seen in the Sora area. Here, fusiform earthquake volumes observed at the footwall of the north-dipping extensional detachment may be attributed to the upwelling of mantle-derived CO_2 as the result of unloading processes within the footwall rock volume. Our findings underscore the necessity of integrating multidisciplinary approaches to unravel the complexities of fault systems, thereby advancing our comprehension of seismic hazards in tectonically active regions.

De Nardis R. et al. (2022) - Lithospheric Double Shear Zone Unveiled By Microseismicity In A Region Of Slow Deformation" Scientific Reports 12, 21066. https://Doi.Org/10.1038/S41598-022-24903-1

First detailed 3D geometric and kinematic curvilinear fault models of the Southern Italy extensional belt: integrated analysis of surface and deep data

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Keywords: 3D fault model, seismotectonics, Campania-Lucania-Calabria extensional belt.

Since the pioneering work of Plesch et al. (2007), the development of 3D curvilinear fault modeling, integrating fault surface traces with earthquake data (hypocenters and focal mechanisms), has become a standard practice for reconstructing the geometry and kinematics of active and potentially seismogenic structures.

Numerous such reconstructions have been conducted in Italy across various tectonic settings, from the extensional belt of central Italy (Castaldo et al., 2018; RETRACE-3D Working Group,2021 and many others) to the compressional front in northern Italy (Tibaldi et al., 2023).

This paper presents the first comprehensive high-detail 3D geometric and kinematic reconstruction of the Southern Italy extensional belt, spanning from Campania to Calabria. Our reconstruction, also associated with a formal 3D stress inversion of geological and seismological data, models the extensional belt with an average thickness of 10-15 km from the surface down to a recognized basal detachment along the belt.

The fault surfaces are organized in a systematic hierarchical order, ranging from individual fault segments to master fault alignments, all interconnected across a complex system of synthetic and antithetic structures.

Surface data are extrapolated to depth with varying degrees of approximation, leveraging available geological and seismological information such as fault traces, multi-scale cross-sections, fault/slip data, hypocentral datasets, focal mechanisms, and seismic lines.

The uncertainty of the modeled fault geometry is systematically analyzed, considering two key factors: completeness and geometric variability for each fault element. This systematic analysis enhances our understanding and quantification of uncertainty associated with fault geometry modeling, providing crucial insights for seismic hazard assessment and future research in this field.

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Seismological study of transverse faults in a highly segmented extensional front in the Northern Apennines: the case of Sant'Anna Pelago

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Keywords: neotectonics, fault segmentation, Northern Apennines.

The Neogene-to-current tectonic evolution of the Northern Apennines has been characterized by slow-rates contraction in the foreland and extension in the internal domain. At chain-scale, the extensional and contractional fronts migrate NE-ward through anticlockwise rotation, while at local scale deformation is accommodated on a multitude of segmented structures. Rotational extension causes an increase in the width of the internal extensional domain south-eastward as the Northern Apennines steps eastward across Italy.

The Sant'Anna Pelago area, located close to the orographic divide between Modena and Lucca, exhibits pronounced instrumental seismicity over the last ~15 years, forming the focus of this study. Here fault geometries tend to be more complex, in terms of segmentation and mutual geometric relationships, compared to the internal domains. Seismicity is expressed through five seismic sequences from 2006. The precise relocation of the seismicity from the INGV catalogue has revealed five major aligned clusters. The 2007, 2010 clusters align, respectively, on minor ~5-10 km-depth, N dipping high angle normal fault, and ~14-18 km-depth SW dipping medium angle normal fault. In 2013 there was a Mw 4.8 mainshock, relocated to ~18 km depth, which was followed by a dense aftershock sequence on an 8 km-long, 10-18 km deep fault dipping 50 degrees towards the SW. This structure aligns with the southern tip of the Fola master fault, surfacing near Pieve Pelago. The subsequent 2018, 2020 clusters align on two discrete, sub-vertical E-W oriented structures, each approximately 3 km long, in the footwall of the 2013 sequence, and at similar depths. Focal mechanisms show almost normal kinematics on all faults. Only the 2013 main shock focal mechanism shows pure strike slip kinematics, with near vertical NW-SE or SW-NE striking nodal planes. For this main shock, neither nodal planes fit with the 3D distribution of aftershocks. Instead, we interpret the mainshock to be linked to the presence of the subsurface NE continuation of a major transverse fault.

The relocation highlights complex geometries and kinematics on this active front. The NW-SE and E-W trending normal faults are compatible with deformation in an accommodation zone between two stepping extensional fronts. The lateral stepping requires accommodation through a component of lateral fault slip, which we interpret to explain the strike-slip mainshock. The results suggest that the Sant'Anna Pelago area could be interpreted as an immature soft-linkage zone where deformation favourably accommodates on transverse faults at depth and variably oriented normal faults at shallow depths. The next stage of the study will be to use field structural analysis to better define the surface architecture of active faults and use stress change analysis to test whether stress transfer controls the time history of the sequences.

3D imaging and modelling of a complex regional fault system: the Scicli Line (Sicily, Italy)

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Keywords: Scicli Line, 3D crustal model, fault kinematics.

The Italian peninsula is characterized by a complex and somewhat peculiar geodynamic setting which has been driving the attention of scientists for decades. Here, we focus on the Hyblean Plateau, the emerged portion of the Pelagian Block in southeastern Sicily, which pertains to the African foreland. An area densely populated and characterized by high seismicity; the two major historical earthquakes of the area (M≃7, in 1169 and 1693 A.D) and their relationship with the kinematics of tectonic structures in the Hyblean Plateau are still a matter of debate. In particular, the Plateau is cut by a regional a. N-S trending strike-slip fault system known as the Scicli line and several NE-SW, mostly extensional fault lineaments. This overall fault system shows good exposure on outcrop, and influenced deep fluid migration (both groundwater and hydrocarbons), which made it appealing for structural, geological and exploration studies since the ‘50s. However, a high-resolution integrated 3D focused work which links outcropping and subsurface features from onshore to offshore is still missing.

In this study, we combine fieldwork observations and geological mapping with the interpretation of a large dataset of 2D-3D seismic reflection data and deep wells, related to exploration and production activities carried out for more than 70 years by Oil&Gas companies As a result, a comprehensive high-resolution regional 3D crustal model is here presented along a 90x20 km extended volume, connecting the onshore to the offshore. A robust workflow is defined and allows to correlate in detail subsurface and outcropping features.

This work shows new significant insights on the 3D geometry and development, in space and time, of the Scicli Line, considering its relationship with adjacent structural lineaments and fracture systems as well. Moreover, it will support a more accurate and realistic evaluation of potentially active structures and associated seismicity.

This work is framed in the broader effort, called “SPIN Project”, which aims at improving seismic hazard assessment in Italy through advanced tools, analytical, and modelling techniques.

Anatomy of strike-slip Kefalonia fault to Hellenic frontal thrust transitional zone, western Hellenic Arc

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Keywords: transpression, geo-hazard, Ionian Islands.

The area offshore the Ionian Islands (Kefalonia, Lefkada, Zakynthos, and Ithaca), western Greece, exhibits higher seismic activity than any other Mediterranean region, often with high tsunamigenic potential. Here, the Hellenic frontal thrust above the main detachment fault stops against the right-lateral Kefalonia fault, more than 100 km-long, to step back towards the island of Corfu. In recent decades, this area experienced several destructive events, such as the Kefalonia earthquakes (three M6+ events) of 1953 and the more recent Zakynthos earthquake of October 2018.

In order to improve the knowledge on sediment deformation, fault geometry and assessment of hazard associated with the tsunamigenic faults surrounding the islands, we carried out two oceanographic cruises, one in May 2022 and the other in June 2023, collecting several types of geophysical (e.g., bathymetry, seismic data, chirp data, magnetometry) and geological (gravity cores) data with different resolution. The new multichannel seismic data, combined with the high-resolution swath bathymetry, allowed us to define the sediment deformation patterns at the intersection between the Kefalonia strike-slip fault and the thrust fronts of the Hellenic System. In particular, the Kefalonia fault opens toward the south into a fan composed of elongated, sigmoidal positive flower structures. Several seaward-verging anticlines with a strike-slip component, and uplifted blocks have been mapped for the first time off Kefalonia and Zakynthos, filling therefore the knowledge gap of this seismologically "locked" area. Moving farther to southeast offshore Zakynthos, the tectonic regime changes radically with extension prevailing and abundant translational slides, possibly tectonically-triggered, affecting shallow sediments.

This new dataset allowed us to define a transition zone between the strike-slip and compression domain that is much larger and more complex than expected, and the area to the southeast where extension starts to develop. Furthermore, we defined the distribution and lateral continuity of the fault systems affecting shallow sediments whose kinematics could be controlled by the plate boundaries.

Past to recent tectonic activity in the western Ligurian Margin: new insights from geophysical marine data

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Keywords: faults, morphotectonics, Ligurian Margin.

In the framework of the cartographic mapping project CARG 245 - Albenga sheet, new bathymetric and geophysical data have been collected in the offshore of Albenga. The integration of newly acquired and available geological and geophysical datasets allowed a detailed reconstruction of the seismo-stratigraphic architecture of the western portion of the Ligurian margin and its morpho-structural setting. The high-resolution seismic reflection data show the presence, in the continental shelf and in the upper slope areas, of the entire Mio-Pliocene sedimentary cover of the Ligurian Margin and allow a detailed reconstruction of the quaternary sequence, including the Late Quaternary and Holocene deposits. These quaternary seismo-stratigraphic sequences are characterized by evident regional unconformities that can be correlated with the age dated depositional units of the Albenga Plio-Quaternary Basin in the emerged areas. The age dating of the quaternary marine and alluvial sediments of the Albenga Basin have been performed in this study through biostratigraphic and magnetic methods. In the onshore and offshore areas, the stratigraphic sequences of the Ligurian Margin are cut by a well-developed system of faults recording a polyphase evolution with multiple tectonic inversions including the reactivation of Mesozoic tectonic structures. The last Pleistocene inversion, characterized by a transition from transtensional to transpressional regime, is consistent with the Plio-quaternary compressive/ transpressive tectonic event described for the Western Ligurian Margin (e.g., Morelli et al., 2022) and can be associated with the widespread present-day seismicity. In addition, we were able to map the morphological expressions of erosional and gravitational mass movements along the continental slope and within a complex system of submarine canyons. These could be considered the surface effects of the recent tectonic activity described above.

Morelli D. et al. (2022) - Morpho-Structural Setting of the Ligurian Sea: The Role of Structural Heritage and Neotectonic Inversion. J. Mar. Sci. Eng., 10, 1176, https://doi.org/ 10.3390/jmse10091176.

Field and seismic reflection constraints for the geometric and kinematic characterization of the Quaternary extensional fault system in the Campania-Lucania arc (Southern Apennines, Italy)

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Keywords: Campania-Lucania Apennines, seismic section interpretation, extensional quaternary fault.

The Campania-Lucania Apennines have long been a subject of significant scientific interest due to their stratigraphic-structural setting and the hydrocarbon exploration. This portion of the Apennines is also affected by recurrent and intense seismic activity, including some of the strongest historical and instrumental events, such as the "recent" Irpinian earthquake of 1980. The broad scientific literature suggests that much of this seismicity is extensional and is associated with Pleistocene-Holocene normal faults, whose deformation produced NW-SE elongated continental basins.

In the north-eastern sector of the Alburni Mountains, east-dipping normal faults dominate the extensional structural setting; there are clear evidences that they represent the surface expression of a regional synthetic detachment surface. This work aims to understand if the same deformational style can be generalized to the entire internal sector of the Campania-Lucania arc from the Sele plain, to the Mt. Cervati massif, located a few tens of km south-west.

The survey of key-areas provides new data to integrate into a database for the creation of a regional-scale geological-structural map, drawn up by reprocessed seismic data from literature. The area extends onland from the southern flank of the Picentini Mountains to the northwestern border of Mt. Pollino, covering approximately 9000 km2. These data constitute the surface constraint through which four shallow geological cross-sections are drawn; their integration with the logs of some calibration-wells available from literature, enables the interpretation of a grid of 12 seismic lines. The lines are provided by both the Eni and the openly-accessible Videpi database.

Their conversion to depth led to obtain a series of crustal sections that allow us to compare both the contractional and extensional structures across the entire study area.

The geological sections and seismic lines, interpreted down to the top of the Apulian Platform, shed light on the following significant aspects: i) the subsurface geometry of the extensional fault systems, ii) the depth and sense of dip of their detachment surface, iii) the hierarchy between conjugate faults, iv) the relationships occurring at depth between normal faults and the main thrust surfaces, v) the shape of syn-tectonic Quaternary depressions (Auletta basin, Diano Valley and Agri Valley) and the thickness of the sedimentary infill, vi) the role of every single structure in the regional tectonic setting, and vii) the geometry of the pre-extensional state with an estimate of the elongation obtained from the restoration of the main cross-sections.

The results of this work contribute to the building of a comprehensive 3D model of active extensional faults of the southern Apennines, in the context of the MUSE 4D PRIN project.

New analysis of InSAR and seismology for kinematic reconstruction of the 1995 offshore Aigion M6.5 earthquake (Greece)

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Keywords: seismology, inversion, rift.

During the transition from early to mature rifting different fault geometries and kinematics may form. In particular it is debated whether low angle normal faulting occurs during early rifting. It is therefore crucial to constrain how faults slip during earthquakes by thoroughly exploring the variability of the fault models derived from geophysical observations.

Here we study the Mw 6.5 Aigion earthquake that occurred in the Gulf of Corinth on June 15, 1995, using InSAR and seismic waveforms. The Gulf of Corinth is a rift in its early stages, currently extending at a rate of 10-15 mm/yr (Bell et al., 2008) in the N-S direction and characterized by normal faults defining a graben. The Gulf of Corinth can generate major destructive earthquakes, such as the magnitude 6.7 in 1981, and is heavily populated. Therefore it is key to understand the mechanisms of faulting in the Gulf of Corinth rift. The 1995 Aigion seismic sequence included a Mw 6.5 earthquake and an aftershock of Mw 5.2. However, the subsurface geometry and position of the fault is highly debated, including whether it dips to the N or S, and the fault dip angle. The majority of the deformation occurred offshore and analysis of the seismicity or geodetic (InSAR and GPS) data alone leads to non-unique fault solutions.

On the contrary joint inversion of different types of geophysical data can give more robust fault models. In this work, we jointly invert InSAR and teleseismic data for the fault model of the Mw 6.5 Aigion earthquake. Preliminary results show the possibility of a low-angle normal fault as a best-fit model. This multidisciplinary methodology could better constrain subsurface definition of faults in the Gulf of Corinth and other regions, both for past and future deformation events.

Bell R.E. et al. (2008) - Evolution of the offshore western Gulf of Corinth. GSA Bulletin 120 (1/2), 156-178, https://doi.org/10.1130/B26212.1.

Strain-rate estimation and focal mechanism stress inversion in Himalaya-Tibet region

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Keywords: geodesy, seismology, Himalaya.

The India-Eurasia collision zone is one of the most complex and destructive collisional zones globally. The Indian plate converges with the Tibetan Plateau to the north, exhibiting a convergence rate increasing from ~16.5 mm/yr (Kumar et al., 2023) in the west to ~21 mm/yr in the Bhutan region (Dal Zilio et al., 2020). Compression is primarily accommodated by the basal detachment commonly referred to as the Main Himalayan Thrust, whose surface expression is represented by the Main Frontal Thrust. To describe the destructiveness of this zone, historical and instrumental events such as the 1505 Lo Mustang earthquake (Mw 8.2-8.8), the 2015 Gorkha earthquake (Mw 7.8), and the 1714 Bhutan earthquake (Mw 8.1) are remembered. The Tibetan region, on the other hand, is primarily affected by extensional earthquakes that accommodate a west-east directed extension with moderate to high magnitude earthquakes, ranging between Mw 5.5 and Mw 6.8, such as the 2008 Xizang earthquake (Mw 6.7) and the 2008 Damxung earthquake (Mw 6.3) on the Yadung-Gulu rift. Active strike-slip faults are also present, bordering much of the Tibetan plateau and intersecting its central zones (Wang & Barbot, 2023). Notable examples include the Altyn-Tagh fault, the Karakoram fault, and the Gyaring Co fault. Although the region is particularly affected by high rates of seismicity, seismic and geodetic networks are not well-distributed. In such cases, a multidisciplinary approach allows drawing from several data types to obtain a more comprehensive understanding of the seismotectonic setting. We have computed a new velocity field by processing continuous stations throughout the Tibetan-Nepal-Indian territory. Additionally, through Helmert transformations, all pre-existing velocity fields documented in the literature have been merged into a unified large-scale velocity field. This unified velocity field has been utilized to compute a fine strain rate map over the entire study area. A unified catalogue for instrumental seismicity and focal mechanisms, registered in the area since 1980, has also been collected. Such a unified catalogue is the outcome of a meticulous compilation of data sourced from various national and international catalogues aimed at improving the completeness magnitude of the area (approximately Mw 4.0). The same care has been applied to gather historical events preceding 1980, ensuring a comprehensive understanding of the seismic history (Cheng et al., 2017). The deformation pattern can be completely understood by comparing strain rate maps with focal mechanism inversions. This approach allows us to compare stress and strain and to discriminate the contributions of several sources of different kinematics.

Cheng J. et al. (2017) - An Mw–Based Historical Earthquake Catalog for Mainland China. Bull. Seismol. Soc. Am. 107, 2490–2500, https://doi.org/10.1785/0120170102.

Dal Zilio L. et al. (2020) - Segmentation of the Main Himalayan Thrust Illuminated by Bayesian Inference of Interseismic Coupling. Geophys. Res. Lett., 47, e2019GL086424, https://doi.org/10.1029/2019GL086424.

Kumar P. et al. (2023) - Evidence of Strain Accumulation and Coupling Variation in the Himachal Region of NW Himalaya From Short Term Geodetic Measurements. Tectonics, 42, e2022TC007690, https://doi.org/10.1029/2022TC007690.

Wang L. & Barbot S. (2023) - Three-dimensional kinematics of the India–Eurasia collision. Commun. Earth Environ., 4, 164, https://doi.org/10.1038/s43247-023-00815-4.

Structural style and seismicity: a geological focus on the 2022 Mw5.5 Northern Adriatic off-shore earthquake

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Keywords: fold-and-thrust belt, seismicity, Northern Apennines.

The interpretation of a partly unpublished set of nine seismic reflection profiles, calibrated by eight deep boreholes, sheds light on the subsurface stratigraphy and structure of a segment of the active Northern Apennines outer front, in the Northern Adriatic off-shore, between Ancona and Pesaro (Marche region, Italy). On the 9th of November 2022, this area was struck by a Mw 5.5 earthquake, as part of a complex seismic sequence, including six M>4 events, with NW-SE striking thrust fault focal mechanisms. The sequence is coherent with the seismotectonic framework of the outer front of the Northern Apennines fold-and-thrust belt, where geodetic data demonstrate active contraction, with a strain rate of 2-3 mm/yr, accommodated by a set of SW-dipping thrusts, as also testified by the occurrence of instrumental and historical seismicity.

The most important compressional structures of the study area are a pair of én échelon, major anticlines, developed at the hangingwall of SW-dipping thrust ramps. Two deep wells, drilled in the crestal zone of these folds, show that the whole Mesozoic-Paleogene carbonate multilayer, more than 3 km thick, is involved in the anticlines. Geological cross-sections, derived from the interpretation and depth conversion of the seismic profiles, reveal the box-shaped geometry of the anticlines, with a wavelength greater than 7 km. A complex pattern of imbricated thrusts and short-wavelength folds is generated in front of the outer limb of the northern anticline, generating multiple repetitions of the Neogene-Quaternary succession, consisting of a group of marly formations, overlain by sandy and clayey clastic sediments.

The structural style of these buried compressional structures is quite similar to that of the innermost (i.e. westernmost) and older structures exposed at the surface in the mountains of the Umbria-Marche Ridge, sharing a common mechanical stratigraphy and tectonic evolution. The comparison and integration of the observations collected, with different data and techniques, in these two adjacent regions, allow us a complete and detailed description of the buried contractional structures of the study area. This includes the longitudinal continuity of the folds, the length and width of the seismically active thrusts, the slip rate and its variations through time, the depth of the main decollements, the thickness of the seismogenic [layer and the linkage mechanisms of the én-échelon anticlines.

A better comprehension of the geological structures at depth, combined with improved geodetic and seismological data, are essential for a realistic identification of the single seismogenic sources, as well as of their general seismotectonic framework, and ultimately for a correct evaluation of their relevance in terms of seismic hazard.

Exploring historical seismograms: moment tensor inversion of the 1947 Squillace Basin Earthquake (Calabria, South Italy)

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Keywords: Analog seismograms, Waveform inversion, Ionian subducting system.

Seismograms from the analog era span over a century of seismic activity, offering invaluable insights, particularly for assessing seismic risk in regions affected by significant historical events and minor seismic activity in recent decades. In this framework, this study explores the 1947, May 11 Squillace Basin earthquake, that is the only M>5.5 event instrumentally recorded in central Calabria (Southern Italy), according to the official catalog (CPTI15, Rovida et al., 2022). The study area is characterized by high seismic risk and a complex geodynamic context driven by northwest-trending Nubia–Eurasia convergence and southeastward Ionian slab rollback. Thus, the 1947 earthquake could provide crucial information to better characterize regional seismotectonic and seismic hazard.

To investigate the 1947 earthquake, fifteen medium- to long-period analog seismograms with relative instrumental parameters were accurately selected. These collected recordings underwent rigorous processing, including vectorization and waveform corrections, to make them suitable for modern analysis techniques. We applied a technique tailored for time-domain moment tensor computation through waveform inversion of analog seismograms (Stich et al., 2005). The moment tensor solution estimated for the 1947 earthquake reveals a strike-slip mechanism with focal depth of 28 km and moment magnitude Mw=5.1.

The inferred hypocentral depth and left-lateral kinematics along a west-northwest–east-southeast-oriented fault align closely with the local seismotectonic framework and are consistent with STEP fault activity in central Calabria (Orecchio et al., 2014; Corradino et al., 2021). This study serves the dual purpose of contributing new data to the ongoing debate on slab edge kinematics and deepening methodological insights concerning the management of historical seismograms.

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Orecchio B. et al. (2014) - What earthquakes say concerning residual subduction and STEP dynamics in the Calabrian arc region, south Italy. Geophys. J. Int., 199, 1929-1942, https://doi.org/10.1093/gji/ggu373.

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Stich D. et al. (2005) - Moment tensor inversion with single-component historical seismograms: The 1909 Benavente (Portugal) and Lambesc (France) earthquakes. Geophys. J. Int. 162(3), 850-858, https://doi.org/10.1111/j.1365-246X.2005.02680.x.

Geometric constraints for thrust-related deformation in eastern Central-Southern Italy: new insights from travel-time and attenuation tomography

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Keywords: tomography, seismotectonic, fault geometry.

The Outer Thrust System (OTS) segment extending from Pescara to Benevento (Italy) represents a scientific conundrum due to its complex geometry, seismic activity, and deformation style. Traditional seismic analysis methods have been hindered by low seismicity levels, blind thrusting, and inadequate seismic data quality, resulting in an inconsistent seismotectonic model.

This segment of the OTS (Abruzzi Thrust), having an arcuate eastward convex shape, is articulated in two minor arcs, the Abruzzo Citeriore Arc northward and the Frentani Arc southward. The frontal thrust and its splay are buried under Plio-Pleistocene deposits, but they are evident in seismic lines and highlighted as potentially active and seismogenic in recent morphotectonic studies (Ferrarini et al., 2021).

Employing travel time, seismic attenuation, and scattering tomography methods, we improve the characterization of the thrust-related deformation at different depths for the first time in that area.

High anomaly values of attenuation and peak delay are interpreted in the literature as fractured shear zones that trap seismic waves, increasing the scattering effect (King et al., 2022, 2023) and making them lose energy during propagation. Our results show shallow (between 5 and 7 km in depth) and continuous high-attenuation volume located between Campobasso and Benevento, striking N-S for about 80 km: in our interpretation, these features represent the southern prosecution of the Frentani Arc.

At greater depths, in correspondence with the middle-lower crust, travel time tomography reveals a significant Vp inversion recognizable along several cross-sections having different orientations. This result, validated through spike tests, carries out crucial implications for crust-scale geometry and deformation style of the compressive structures and suggests a deep-rooted thrust system.

We have gained insights into the geometry of the Abruzzi Thrust by combining the results obtained from seismic attenuation and travel time tomography. These findings indicate the presence of a crustal doubling zone, which is especially evident in correspondence with the Frentani thrust. The model offers valuable constraints for reconstructing a regional 3D fault model and reveals the geometry and size of this potentially seismogenic structure.

This work emphasizes the importance of tomographic imaging in supporting fault model building to be interpreted from a seismotectonic perspective, particularly in regions with insufficient traditional seismological data and seismic lines. Furthermore, these findings provide a valuable understanding of the structural style of the overall Outer Thrust System, reinforcing a thick-skinned interpretation.

Ferrarini F. et al. (2021) - Multiple Lines of Evidence for a Potentially Seismogenic Fault Along the Central-Apennine (Italy) Active Extensional Belt–An Unexpected Outcome of the MW6.5 Norcia 2016 Earthquake. Frontiers in Earth Science, 9, 642243, https://doi.org/10.3389/feart.2021.642243.

King T. et al. (2022) - Mapping faults in the laboratory with seismic scattering 1: the laboratory perspective. Geophysical Journal International, 232(3), 1590-1599, https://doi.org/10.1093/gji/ggac409.

King T. et al. (2023) - Mapping faults in the laboratory with seismic scattering 2: the modelling perspective. Geophysical Journal International, 234(2), 1024-1031, https://doi.org/10.1093/gji/ggad100an.

A multidisciplinary geophysical approach as help to validate 3D models and investigate the seismotectonics of the Central Apennines (Italy)

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Keywords: 2D model, gravity anomalies, Central Apennines.

Crustal models based on surface geology and seismic lines interpretation can only account for the shallow (within 10 km or less) portion of the crust. Other geophysical investigations, such as receiver functions or tomography, provide information respectively on the depth of the Moho and the velocity distribution within the crust but cannot be interpreted in a unique way. Only an integrated multidisciplinary approach that combines those techniques with other independent data, such as Bouguer anomalies, could validate the results and help with the interpretation. Here we present a 2D gravity model across the Central Apennines, in the area affected by the 2016-17 Amatrice-Visso-Norcia seismic sequence, as a part of the RETRACE-3D project and aimed at completing and verifying the crustal geometries resulting from the 3D geological model. The cross-section was built integrating different data types, such as surface geology, hydrocarbon wells, seismic lines, and results from receiver function analysis. It was then checked against gravity anomalies and the velocity distribution from Local Earthquake Tomography (LET), adding further details, and, finally, against seismicity recorded during the 2016-2017 sequence. The results substantiate the reliability of the geometries proposed in the RETRACE 3D model. Furthermore, the integration of different types of data allowed us to describe in detail the structural setting of the Apennine chain also in the surroundings of the RETRACE study area, where the cross-section length exceeds the 3D model, and to add some new elements at seismogenic depths, that exceed those typical of hydrocarbon exploration. In particular, we were able to investigate the nature of the basement top and its relationship with seismotectonics.

From active faults to seismogenic sources: understanding their geometry, hierarchy, and earthquake potential through a fully multidisciplinary approach

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Keywords: earthquakes, seismotectonics, faults, seismogenic sources.

The modern concept of active faulting has been developed in the aftermath of the great 1891 Nōbi and 1906, San Francisco earthquakes. But up until the late 1970s there was little perception of the importance of the size, geometry, or simply of the existence of faults that are non immediately visible at the surface, and yet participate in the evolution of geology and landscape (let alone, in the generation of earthquakes).

The large earthquakes that occurred around the turn of the 19th-20th century raised awareness that a large earthquake requires a large fault, both in width and in length. But in most countries worldwide, this perception did not clearly develop until the occurrence of a large earthquake.

The 23 November 1980, Ms 6.9, Campania-Basilicata earthquake is the event that modified this trend in Italy. The event caused undisputable surface faulting over a length of about 40 km, disrespecting all the minor faults that had been previously mapped as active or potentially active. Suddenly it became clear that even in the Italian Apennines, fault come in different sizes, entail different hierarchy levels, and may be generated by an extremely youthful tectonic regime. It became also clear that the geologic and geomorphic signal left by the activity of that certainly active and seismogenic fault is almost hopelessly hidden by the cumulative deformation caused by extinct faults and by the associated landforms.

In the following years the Italian active faulting community turned to the two largest earthquakes of the 20th century, namely the 1908 Mw 7.1 Messina Straits and the Mw 7.1 Avezzano-Marsica events, both of which featured early seismometric and geodetic observations. The first turned out to be a blind faulting event generated by a rather shallow dipping normal fault; once again, the deformation it caused did not much resemble the topography of the Messina Straits, and it became clear that it had very little to do with the numerous normal faults mapped on both sides of the Straits. The second caused sizable and relatively clear surface faulting, and deformed the Fucino Plain consistently with its current physiography and subsurface geology, and yet it did not match many of the secondary faults that had been mapped in the area by previous workers.

These three earthquakes were a clear and strong indication that the faults responsabile for a large earthquake are much more difficult to identify than most of us thought prior to 1990s. Almost forty years later, we have learned that we cannot rely on the surface evidence of brittle faulting alone, but we have to match structural evidence with subsurface data, geomorphic data, instrumental data, and in many cases also with earthquake intensity data. Where a large earthquake occurs there must be a large fault, but it may be from hard to impossible to derive its properties that from outcrop data alone; keeping in mind that many Italian earthquakes are generated by blind, hidden or downright inaccessible faults. This awareness comprises the corner stone of Italy's Database of Individual Seismogenic Sources.

S50.

Unveiling earthquake mechanics, from field to laboratory based approach

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Fault roughness associated to fault growth mechanisms along high-angle normal faults, first results from the field-based structural analysis of the Monte Capo di Serre Fault, Abruzzo, Italy

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Keywords: fault roughness, fault linkage, co-seismic ruptures.

Studies on natural and laboratory slip surfaces demonstrate that roughness evolves with increasing slip and displays a scale-dependency inversely proportional to the fault length regardless of lithology. However, only a few studies have quantified the possible variation of roughness along single slip surfaces and at linkage zone between adjacent fault segments.

In this study we aim at highlighting the influence of fault growth processes (i.e. fault linkage) on fault roughness. We integrated structural analysis, Structure from Motion-Multi-view stereo (SfM-MVS) photogrammetric modeling, and microtextural characterization of fault rocks along two principal slip surfaces associated with the Monte Capo di Serre Fault, which is a high-angle and c. 8 km long seismically active normal fault in the Central Apennines (Italy). The Monte Capo di Serre Fault cuts Triassic dolostones, Lower Jurassic limestones and dolostones, and Quaternary carbonate slope debris. In detail, we focus on the roughness of slip surfaces that interact along their mode III edges forming mesoscale relay ramps with left- and right-steps and containing patches of sheared slopes debris.

Our field and microtextural analyses indicate that the Monte Capo di Serre Fault registered co-seismic ruptures, as indicated by ring cracks, truncated clasts, and fluidized and very fine-grained microlayer observed at the microscale. Undulated m-scale grooves are characterized by periclinal terminations along dip. These features are thought to exert a control on rupture propagation at depth.

Kinematic analysis highlights a dominant pure dip-slip normal kinematics accommodated by the individual slip surfaces. Kinematic variations are documented along m-scale grooves along the linkage zones among right-stepping slip surfaces. The aforementioned data collected along the Monte Capo di Serre Fault are compatible with stress fields characterized by both NW-SE and NE-SW trending shmax. In particular, the result of stress inversion analysis is consistent with a local shmax-shmin permutation in correspondence of linkage zones between the different fault segments. There, marked left-lateral components of slip are assessed for the ca. E-W striking slip surfaces which connects two left-stepping main (i.e., NW-SE striking) fault segments and is characterized by a few m-thick, sheared slope debris deposit. Such a linkage zone can be viewed as a 10 m-scale groove for the Monte Capo di Serre.

Utilizing a combination of smartphone, drone, and single-lens camera, SfM-MVS photogrammetric modeling enabled us to conduct detailed roughness analysis on 1 m2 to 0.4 m2 portions of distinct fault planes.

Field and digital structural analyses indicate that the local dispersion of the kinematic vector along m-scale grooves is invariably associated with the overall (seismic) slip along the main fault surfaces.

Preliminary results of Fourier power spectrum analysis conducted on several portions of single slip surfaces confirm the self-affine behavior of the fault roughness at all scales. In particular, we document that the Hurst's exponent and so the fault roughness scales differently in the slip direction compared to the perpendicular to slip direction and that different exponents are recorded on the different portions of the fault. In summary, the result of our work should find application in seismological studies to constrain the fault roughness properties at very shallow depths during low-velocity upward rupture propagation from deeper seismic slip.

Asymmetric microfracture pattern associated to seismic rupture (Gole Larghe Fault, Italy)

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Keywords: pseudotachylytes, microfractures, rupture.

Earthquakes are the result of propagation, (at ~km/s) of a rupture and related fault slip (at ~m/s). Rupture propagation generates a transient high-stress field in the rock volume surrounding the fault. Neglecting the work against gravity, during rupture propagation and subsequent fault slip, the elastic strain energy stored in the wall rocks is converted into fracturing, frictional heat, and elastic waves. Pseudotachylytes are solidified frictional melts found in exhumed faults produced during seismic slip (Sibson, 1975) and thus can be studied, together with the associated microstructures, to better understand earthquake source parameters and mechanics.

The natural pseudotachylyte-bearing fault selected for this study belongs to the east-west-striking, dextral, strike-slip Gole Larghe Fault Zone (Adamello, Italian Alps), exhumed from the base of the brittle crust. Microstructural studies were carried out employing EBSD, FESEM-CL and high resolution mid-angle FESEM-BSE. In particular, FESEM-CL imaging reveals a microfracture network in the wall rocks surrounding the frictional melt invisible to other imaging techniques. The microstructural analysis evidences (i) a high degree of fragmentation of the wall rock adjacent to the pseudotachylyte fault vein (formed along the slip surface), with clast size down to <90 nm in diameter, and (ii) a systematic difference in fracture density and orientation of the microfractures in the two opposite wall rock sides of the fault. In the northern wall rock, the fracture density is low and the microfractures strike preferentially east-west (i.e., sub-parallel to the fault), while in the southern wall rock the fracture density is high and the microfractures are oriented preferentially north-south (i.e. sub-vertical to the fault). Instead, this asymmetric microfracture pattern is absent in the experimental pseudotachylyte, produced by shearing at seismic slip rates the tonalite that hosts natural pseudotachylytes.

The asymmetric pattern can be interpreted as the result of the dynamic stress field surrounding the rupture during its propagation, that cannot be simulated in the experimental setup involving seismic frictional slip along pre-cut fault surfaces. According to numerical models, for the studied fault, with a rupture propagating from west to east, the transient stresses will impose compression in the northern wall rock and tension in the southern one. The orientation of the principal stresses becomes sub-parallel to the fault in the compressional side and orthogonal in the tensional side, as mirrored by the microfracture pattern. Moreover, the analysis of the extremely fine damaged domain and the pseudotachylyte allows the estimate of the energy dissipated in fracturing processes (0.008-1.35 MJ/m2) and frictional heat (32 MJ/m2) (Pittarello et al., 2008). A comparison between the two quantities suggests that frictional heat is likely the major energy sink during rupture propagation.

Pittarello L. et al. (2008) - Energy partitioning during seismic slip in pseudotachylyte-bearing faults (Gole Larghe Fault, Adamello, Italy). Earth Planet. Sci. Lett., 269(1), 131-139, https://doi.org/10.1016/j.epsl.2008.01.052.

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Evolution of the Vp/Vs ratio during deformation tests at high fluid pressure: implications for earthquake mechanics

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Keywords: seismic velocities, mechanical properties, fluid-rock interactions.

In seismogenic zones, anomalously high P- to S-waves ratio (Vp/Vs) is often recorded, being related to fluid pressure approaching lithostatic levels. In the last decades, several mechanisms have been proposed to explain high Vp/Vs values, including poroelasticity and anisotropy effects, however the relation between high pore pressure and Vp/Vs evolution remains still unclear.

In this study we conducted a series of hydrostatic and non-hydrostatic deformation experiments to investigate the evolution of Vp/Vs changes during fluid pressure changes on both undeformed and deformed samples. We used Fontainebleau sandstone as starting material and tested it hydrostatically between 4 and 30 MPa of effective pressure, with a pore-fluid factor l (Pf/Pc) up to 0.8. During the fluid pressurization under hydrostatic conditions, Vp/Vs increases up to 1.5%, from ~1.63 to ~1.67. This increase is mostly achieved for l above 0.5 when we recorded a progressive decrease of both Vp and Vs. However, Vs decreases at larger rate with respect to Vp leading to a consequent increase of Vp/Vs ratio. We then applied differential stress at the same boundary conditions. Under the application of differential stress, we observe a larger increase of the Vp/Vs with respect to hydrostatic experiments reaching values ranging from approximately 2 to 2.4. Most of this increase appended during the dilatational dominated deformation up to macroscopic failure in particular when the samples where under near-lithostatic fluid pressurization condition (l = 0.8). In agreement with hydrostatic tests, during deformation tests the Vp/Vs increase is due to a larger decrease of Vs with respect to Vp.

These results suggests that the combination of poroelastic effects and crack-induced anisotropy may play a significant role in generating high Vp/Vs leading to changes in the mechanical properties of deformed rocks. These values are in agreement with those observed in natural cases, at crustal scale especially in shallow depth conditions. Our study, thus, contributes to the understanding of processes governing earthquake mechanics. Moreover, it suggests that the ability to monitor fluid pressure in the Earth's crust by examining changes in the Vp/Vs ratio holds great value for assessing potential seismic hazards and risks associated with fluid-rock interaction.

Origin of mirror-like fault surfaces in bituminous dolostones (Central Apennines, Italy)

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Keywords: mirror-like surfaces, thermal maturity, fault surfaces.

Mirror-like Surfaces (MSs) are ultra-polished fault surfaces that reflect visible light, thanks to their nanometer-scale surface roughness. They are often found in seismogenic fault zones cutting limestones and dolostones. Both natural and experimentally-produced fault-related MSs have been described in spatial association with ultrafine matrix (grain size <10μm), nanograins (<100nm in size), amorphous carbon, decomposition products of calcite/dolomite, and larger but "truncated" clasts. However, the formation mechanism of MSs is still debated. Experiments show that MSs can develop both under seismic (slip rate ≈1 m/s) and sub-seismic (slip rate ≈0.1-10 μm/s) deformation conditions, involving various physical-chemical processes.

To evaluate whether the MSs formed during the co-seismic (possibly associated with frictional heat pulses) or the inter-seismic (no heat pulses) phases where temperature might serve as a distinguishing factor, we assessed the thermal maturity of "bitumen" using biomarkers. We acquired data for natural and artificial MSs in bituminous dolostones. We collected natural samples from faults located in the Italian Central Apennines (Monte Camicia Thrust Zone, past burial depths up to ~3 km; measured displacement from few mm to few m). We obtained MSs in the laboratory by deforming powdered bituminous dolostones in a rotary shear apparatus (SHIVA, INGV) at sub-seismic (V = 10-4 m/s) and seismic (V = 1-3 m/s) slip rates for 1-2 m of slip, under room temperature and humidity conditions, and 20 MPa of normal stress.

We extracted solid bitumen of pre-oil window thermal maturity from the MSs and from the underlying slip zone of natural and artificial samples and we analysed the bitumen using Gas Chromatography–Mass Spectrometry. We identified Steranes and other biomarkers based on relative retention time and measured peak heights to obtain thermal maturity parameters. By comparing different samples, changes in thermal maturity could be measured across slip zones bounded by the MS and possibly associated with frictional heat pulses during co-seismic slip.

Biomarker thermal maturity parameters are consistent with the immaturity of the host rock. In the experimental MSs produced at seismic slip velocity, where frictional heat pulses reached T~400°C, thermal maturity of bitumen in MSs is slightly higher than that of MS produced at sub-seismic slip rate; higher thermal maturities were measured also in natural MSs respect to the entire slip zone.

Microstructural analysis done previously revealed that these slip zones recorded the main phases of the seismic cycle, from rapid co-seismic slip to post/inter-seismic viscous flow and fault strength recovery. The results presented here (1) confirm this interpretation, (2) show that the frictional heat pulse associated with seismic slip may be recorded by biomarkers thermal maturity of bitumen in the MSs, and (3) some natural MSs are associated with heat anomalies caused by seismic ruptures.

Frictional fault healing under hydrothermal conditions

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Keywords: hydrothermal conditions, fluid-rock interaction, seismic cycle.

Fault healing is the ability of a fault to recover its strength over time after a seismic event and is one of the main factors controlling the seismic cycle. There is ample geophysical and geological evidence that most natural and human-induced seismic sequences are associated with the circulation of fluids (H_2O, CO_2) at depth. However, the investigation of rock friction in the presence of hot and pressurized fluids (hydrothermal conditions, up to 450°C) at slip velocities ranging from plate tectonic (~ nm/s) to seismic (~ m/s) rates and for slip displacements (> 0.2 m) typical of moderate to large magnitude earthquakes has been partly hampered by technical challenges.

Here we discuss the results obtained with a newly-conceived experimental configuration which exploits a rotary shear machine and a dedicated hydrothermal vessel. The combination of the two devices allows us to study fault friction and healing at pore fluid pressures up to 70 MPa, normal stresses up to 100 MPa, slip rates from nm/s to m/s, and nominally infinite displacements in experiments that can last up to several weeks. These experimental conditions reproduce, for example, the liquid, vapor and supercritical states of water in high-enthalpy geothermal systems. Rock samples and fluids are recovered after the experiments, allowing us to conduct microanalytical investigations, probe the deformation processes and document the type of fluid-rock interaction responsible for the measured mechanical data and healing.

Through this approach, we found that the physical state of the water and the degree of alteration of the rock have a profound impact on the friction response. For example, common basement rocks, such as gabbros or granodiorites, (1) in the presence of water in the liquid and supercritical state, have frictional strength that is about half that in the presence of water in the vapor state or, (2) have fault healing that decreases, rather than increases like for their altered equivalents, during long hold times in the presence of hot, pressurized fluids. In addition, the friction is higher and the fault "more unstable" under the same effective stress in the presence of steam and superheated steam rather than under liquid or supercritical conditions. Depending on the pressure-temperature conditions of the fluid, microanalytical investigations on the rock and on the fluids recovered after the experiments evidence the dissolution of silicate-bearing minerals and the neo-formation of clays, zeolites, etc. These newly formed "weak" minerals may contribute to the observed decrease of healing of the experimental faults.

In conclusion, the physical state of water has profound effects on the mechanical response of faults and fractures under hydrothermal conditions, something that has been somewhat overlooked so far. The experimental approach proposed here may provide new insight into the mechanical behavior of faults during the seismic cycle.

Rheology of Triassic evaporites and implications for seismicity of the Apennines: insights from triaxial laboratory experiments

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Keywords: triassic evaporites, distributed seismicity, rheology.

The integration of seismic reflection profiles with precisely located seismicity shows that a large number of earthquakes of the Northern Apennines nucleate within the Triassic Evaporites (TE), a lithology made of dolostones and anhydrites (Miller et al., 2004; Barchi et al., 2021). TE hosts the nucleation of the mainshock of the Colfiorito 1997, Mw 6.0 and Norcia 2016-2017, Mw 6.5 seismic sequences, together with widespread distributed seismicity (Collettini et al., 2022).

To better characterize the rheology of the TE and improve our understanding on the seismicity of the Northern Apennines, we performed triaxial rock deformation experiments on TE borehole samples, exploring the role of textural heterogeneities, confining pressure, and strain rate.

We tested a suite of cylindrical samples with different fabric represented by nearly pure anhydrites, foliated anhydrite/dolostone and mixed-chaotic anhydrite/dolostone at confining pressure of 10 and 20 MPa and strain rates of 2·10-5 and 2·10-4 s-1. We loaded the samples up to failure, then, after a holding time of 1000 seconds, we reloaded the samples to investigate fault reactivation. Some tests have been stopped at earlier stages to constrain the evolution of deformation processes through microstructural analysis.

Upon failure, brittle behavior with associated stress drop is observed for all tested specimens. Samples with high dolostone content show thin experimental fault zones characterized by localized ruptures, which gradually become wider and accompanied by distributed damage across the sample as the anhydrite content increases. Lower confining pressure promoted faster fault slip during failure whereas high strain rate promoted larger stress drops and higher fault slip velocity.

Fault reactivation has been characterized after the holding time, and it occurs via slow slip instabilities mostly detected at 10 MPa of confining pressure, independently of rock fabric.

Our observations suggest that lithology, confining pressure and strain rate exert a major role on the rheology of TE. We observe a spectrum of fault slip behavior, spanning from fast instabilities to slow slip events, that seems to be mostly controlled by the boundary conditions of the experiments, i.e. experiments near the brittle-ductile transition of the TE, rather than the frictional properties of the rocks. This research topic will be further investigated through a more detailed characterization of the mechanical data and ongoing microstructural analysis.

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Collettini C. et al. (2022) - Rock and fault rheology explain differences between on fault and distributed seismicity. Nature Communications, 13(1), 5627, https://doi.org/10.1038/s41467-022-33373-y.

Miller S.A. et al. (2004) - Aftershocks driven by a high-pressure CO_2 source at depth. Nature, 427(6976), 724-727, https://doi.org/10.1038/nature02251.

A study on how the damage geometry governs the stress distribution within a fault zone

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Keywords: fault damage, FEM, stress.

The geometrical heterogeneity in fault rocks is observable from the micro- to meter-scale, at the contact zones between grains or clasts and along the fault-surface topography. Among the other, heterogeneity may be represented as a succession of cracks and structural defects within the rock medium. The presence of voids, cracks and anisotropic fabric are all proven factors that perturb the stress field in rocks subjected to deformation. For example, fault roughness is considered a controlling parameter of the inhomogeneous stress distribution over a critically stressed fault surface (e.g. Candela et al., 2012). The density and geometry of the damage control the location of the high local concentration of stress driving the macroscopic failure of the rock and the aseismic/seismic slip. In this contribution, we show a Finite Element Method-based study to investigate the differential stress response to the variations in the damage configuration of a rock body undergoing elastic deformation. We test how stress distribution and concentration vary in relation to a set of geometries, including: collinear, echelon and Riedel crack patterns, each with changing number, distance and length. Configurations reproducing typical roughness of fault surfaces at different scales, as well as random distribution are also performed. Results indicate that the different geometries have dramatic effects on the stress distribution and orientation, with particular emphasis for the geometry that produce constructive interferences in the stress concentration governing the switch from aseismic to seismic slip. The results are compared with fault zones and surfaces from different geological settings.

Candela T. et al. (2012) - Roughness of fault surfaces over nine decades of length scales. Journal of Geophysical Research: Solid Earth, 117(B8).

Deformation processes and origin of fluids during Miocene exhumation of Alpine Corsica

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Keywords: Alpine Corsica, pseudotachylyte, cockade breccia.

Alpine Corsica formed during the Alpine subduction-collision history followed by Oligocene-Miocene lithospheric extension controlled by the eastward migration of Apenninic subduction. Here we integrate field geological surveys, microstructural analysis and carbonate stable isotope ($\delta^{18}O$–$\delta^{13}C$) geochemistry of fault zone rocks to constrain the evolution of the W-dipping extensional Patrimonio Fault System (PFS). The PFS puts in contact the HP-LT Schistes Lustrés (e.g., impure quartzites, marbles, calcschists, serpentines) and slices of Hercynian granitoids, in the footwall block, with the LP-LT Nebbio units and the syn-extensional Miocene sequences, in the hanging wall block.

We describe a deformation sequence during extensional exhumation of the HP-LT units consisting of D_{1ext} ductile shearing followed by two stages of brittle faulting (D_{2ext} and D_{3ext}). D_{1ext} deformation occurred at greenschist conditions (i.e., 300-400 °C) and produced a meter-thick mylonitic zone, part of the roots of the PFS, and diffuse extensional crenulation cleavages and quartz ± chlorite veins in the footwall units. D_{2ext} faults were seismogenic as attested by (i) altered pseudotachylytes and (ii) cockade-bearing fault-veins observed in the footwall splay faults. Cockade-bearing fault-veins exhibit internal inverse grading, injected the host-rocks, and mutually overprinted dolomite-rich veinlet mesh and mirror-like slip surfaces. Seismic faulting was also accommodated by dolomite-quartz(-chalcedony) crack-seal veins, whose isotopic composition is similar to that of the carbonate-rich units of the Schistes Lustrés. These structural and geochemical observations indicate that ancient seismicity was modulated by pressurized fluids with host-rock-buffered isotopic composition. D_{3ext} corresponds to shallow faulting and consists of (i) gouge-bearing fault strands, cutting Burdigalian-Langhian carbonates, and (ii) meteoric-derived calcite-bearing veins and concretions filling open fractures. We speculate that D_{2ext} Early-Mid Miocene faults represent a fossil analogue of the extensional faults currently active in the Apennines where seismicity is driven by CO_2-rich deep-sourced fluids.

Probing the micromechanics of laboratory faults using ultrasonic waves: insights from borehole samples from Delaware Basin, Texas

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Keywords: frictional behavior, induced seismicity, ultrasonic waves testing.

Induced seismicity is an increasingly relevant topic due to its socioeconomic implications and hazard impact. Since 2008, seismicity in the central United States has been associated with hydraulic fracturing and injection operations, which have led to the reactivation of critically stressed faults.

Over the last decade, production and saltwater injection have surged in the Delaware Basin, a prolific petroleum-producing region in western Texas. The basin has experienced an increased number of earthquakes beginning in 2009, suggesting a causal relationship with industry operations. However, whether earthquake clusters are related to hydraulic fracturing or saltwater disposal, and therefore the mechanism of fault reactivation, is still unclear due to seismic station siting challenges.

Faults can slip in a wide spectrum of modes, ranging from stable aseismic creep to unstable dynamic slip with many quasi-dynamic transient phenomena between these two end members.

Frictional laboratory experiments allow the evaluation of experimental fault stability using the Rate and State Friction (RSF) framework. However, reconciling these empirical laws formulated in laboratory with natural cases is still challenging due to a fundamental lack of understanding of the microphysical processes governing friction.

In the laboratory, experimental faults can be probed with ultrasonic waves (UW) to investigate the mechanics and evolution of contacts under applied stress variations.

Here we present preliminary results on the stability of experimental fault gouges derived from borehole samples from the Delaware basin. Samples were selected from formations linked to shallow and deep operations, spanning various locations marked by ongoing seismicity.

The experiments were conducted using the biaxial apparatus BRAVA2 in the Rock Mechanics and Earthquake Physics laboratory at Sapienza University of Rome.

Velocity steps experiments were performed in Double Direct Shear configuration to obtain RSF parameters under different normal stress conditions (20 to 60 MPa). The apparatus is instrumented with a recently developed UW generation and acquisition system.

The system comprises transversal polarized piezoelectric transducers, where a well-characterized pulse and frequency response allow the exploitation of information contained in the entire waveforms. Transmitted amplitude and velocity variation is used to track the changes in gouge elastic properties.

We show that frictional properties of the samples are strongly influenced by phyllosilicate content. Most of the tested lithologies show velocity strengthening behavior and a tendency to velocity weakening with decreasing amount of phyllosilicates. Noteworthy, formations that are not hosting seismicity have 0% of phyllosilicate content and are velocity weakening. To understand this observation and microphysical processes linked to RSF laws, we integrate mechanical and ultrasonic measurements with microstructural analysis.

From fault weakening to re-strengthening, new insights on fluidization in carbonate-hosted normal fault

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Keywords: deformation mechanisms, carbonate bearing fault, fluidization processes.

The role of fluids in faults during single seismic cycles is a greatly debated topic. An increasingly literature suggests that fluids might trigger instability favoring slip during nucleation and/or propagation of coseismic fault ruptures, and due to fracturing might affect the long-term structural diagenesis of fault zones. Indeed, both cementation processes and mineralogical alteration could influence the fault behavior.

For this reason, in order to contribute to the better understanding of the fluid-rock interactions during seismic cycles, we present results of a microstructural analysis conducted on samples of a carbonate-hosted, low-angle normal fault exposed in the Val d'Agri area of southern Italy.

The low-angle fault crosscut Mesozoic dolostone, dolomitic limestones and limestones, includes low-to-moderate dip-angle principal slip surface (PSS) and secondary slip surfaces. The PSS are wrapped by a white ultractaclasite containing dark fluidized ultractaclastic layers characterized by injection bands and protrusions inclined toward the sense of shear.

In detail, the polished specimen show presence of two types of fluidized layers: i) proximal to PSS fluidized layers (PFL), and ii) detached fluidized layers (DFL). The PFL are in contact with the PSS, and mainly localize within the hanging wall rocks. Differently the DFL occurs as relicts within the slip zone. Both PFL and DFL might exhibit a locally pervasive foliation within the slip zone.

Microscale investigation revealed that the PFL is made up of multiple sub-layer with varying amount of clasts and calcite matrix. In this regard, the sub-layers in contact with the PSS, which are interpreted as due to more recent fluidization events, are characterized by greater amount of calcite matrix. Locally, the boundary between the PFL and cataclastic rocks is provided by either shear veins or secondary slip surfaces.

At the nanoscale, the calcite matrix of the PFL is characterized by spherules and tubes tens of nm in width. The nanospherules show either as nanoparticles like-foam aggregates, or as patches wrapping rhombohedral crystals. Our preliminary results hence suggest that the fluidization processes were active during the faulting events.

The geometry of the PFL suggests that a sudden release of fluids occurred during the single slip event, which were probably associated to seismic ruptures as shown by the nanoparticles, suggesting that fault ruptures were associated to either shear heating or decarbonation mechanisms. In this framework, we proposed that the aforementioned fluidized layers might represent the fingerprint of past earthquakes.

On the other hand, fluidization processes promote pervasive calcite cementation producing the fault re-strengthening, and consequently rheological contrasts within the evolving fault zones that in turn could favor shear localization.

Shallow earthquakes affecting high-porosity rocks in forearc basin settings: a combined meso-microstructural, mineralogical, and experimental approach

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Keywords: fault gouge, coseismic deformation, shallow burial conditions.

The unstable portion of the seismogenic zone is the locus of most of the earthquakes occurring in the Earth's crust and is located between 5 and 35 km of depth. The uppermost part (< 5 km) of the seismogenic zone is typically considered stable crosscutting low cohesion rocks and sediments. Nevertheless, many earthquakes have been documented to nucleate at depths shallower than 5 km in different geodynamic settings and kinematics. Such shallow seismicity could represent an additional threat to be accounted for in seismically active regions.

To shed light on this matter, we present the results of a study dealing with shallow coseismic deformation recorded within the fault core of an extensional fault zone. The studied fault zone is exposed along the Vitravo Creek canyon, in the central part of the Crotone Basin, South Italy and affects high porosity, Pleistocene siliciclastic rocks. The total displacement of the fault reaches ~50 m and due to the high porosity of deformed rocks, deformation is achieved by development of deformation bands and subsidiary faults. The fault damage zone width is ~8 m in the footwall and ~6 m in the hanging wall block. The master slip surface is decorated with a 2-3 cm-thick dark gouge layer. The gouge is continuous and isopachous along the entire outcrop exposure and locally has been injected in the brittle fractures affecting the calcite cemented fault core. Secondary, thinner (~1 mm) gouge layers are located at a few cm of distance from the main one in the hanging wall block. Microstructural and granulometric analyses conducted on the dark gouge allowed to document a severe cataclastic particle size reduction and a gradient in comminution from the footwall toward the hanging wall side. XRD mineralogical analysis performed on the < 2 μm size fraction of the dark gouge, revealed high percentage of illite in the illite-smectite mixed layers, suggesting deformation temperature up to 100-120 °C. XRD analyses conducted on samples collected along the entire fault zone returned estimated deformation temperatures of < 50 °C, which are compatible with the calculated sediment overburden (< 800 m). The anomalous and localized increase in temperature within the dark gouge has been linked with flash heating processes during coseismic deformation under shallow burial conditions. Frictional experiments run on natural sand samples collected along the fault zone allowed to constrain their mechanical behavior at different slip rates (aseismic and coseismic) and under different water contents (dry vs water damped). The multidisciplinary approach combining field survey, microstructural and mineralogical analysis with rock mechanics experiments could be useful to the study of seismic deformation of sediments and high porosity rocks in near surface conditions. The systematic adoption of such approach to several fault zones and fault systems could enhance and improve the earthquake risk and hazard assessment in seismically active regions.

Friction, mineralogy, and microstructures: how complex is the brittle deformation of faults?

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Keywords: fault, friction, fabric.

Faults accommodate most of the brittle deformation that occurs in the lithosphere. They are also the loci that generate and propagate seismic to aseismic slip. The rocks deforming inside the core of the faults are the main actors that control the modality of slip and thus their mechanical properties are a key subject of study that is carried out through experimental investigation. The most relevant mechanical property is friction, a parameter that commensurates the resistance to shear motion of the rocks. Nevertheless, friction is not an intrinsic, constant feature of the investigated materials. It is instead modulated by several attributes and external factors. For instance, the rate and state framework describes the sensitivity of friction to the sliding velocity, proving a successful theory to quantify the potential of the onset of seismic slip in natural faults. Several works have also demonstrated that the frictional properties of the same material can dramatically change as function of the fabric (the textural, geometrical attributes of the deforming rock).

It is therefore evident that brittle deformation of rocks cannot be assessed in isolation of the conditions at which the phenomenon is measured. To fully understand the complex bulk behaviour of a deforming rock we must investigate the interaction of several mechanisms that are active from the grain-scale up to the entire fault zone.

In this work we present the collection > 60 friction experiments performed on BRAVA biaxial apparatus (INGV, Italy), presented here by associating the analysis of mechanical data with the analysis of rock microstructures. This joined investigation highlights the mechanisms that control rock friction: cataclasis, crystal plasticity, pressure-solution, grain-boundary sliding, cementation, and indentation. We also show the emergence of complex slip behaviours (experimental fault stability) as function of the coexistence of processes with different timescales and explained by the spatial arrangement of the mineral phases in the fault core.

Our results shed light on the origin of the macroscopic frictional properties of fault rocks, stressing the fact that they are not a characterising property but rather the observable of a complex, dynamic, and highly non-linear system.

Frictional strength, healing behaviour and deformation mechanism of low-grade serpentinites at hydrothermal conditions

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Keywords: serpentinites, experiments, friction.

Serpentinites are "weak" rocks that play a critical role in the nucleation and propagation of slow slip events, tremors and earthquakes due to their unique rheological properties that promote strain localization and are common in many tectonic settings, from mid-ocean ridges, to transform faults and subduction zones.

The studied serpentinites pertain to the exhumed Monte Fico shear zone (Elba Island, Italy) that reached greenschist facies conditions where they were most likely deformed. The shear zone is made of 1-10 dm scale lenses of massive serpentines wrapped by foliated serpentinites and cut by brittle faults. Bulk deformation was accommodated by anastomosing and pervasive S/C foliations. Brittle faults are covered with slickenfibers composed of chrysotile and polygonal serpentine.

To determine the frictional and healing properties of these serpentinite-bearing faults we performed experiments on powders obtained from the lenses and from the slickenfibers with a rotary shear apparatus and a hydrothermal vessel (ROSA-HYDROS). We conducted slide-hold-slide experiments at σ'_n=20 MPa, Pf=6 MPa, Vshear= 10 μm/s and at temperatures from room T to 400°C. Powders from the lenses show an increase of friction coefficient with temperature when water is liquid (from 0.3 to 0.5), and a stronger increase (from 0.6 to 0.89) at higher temperatures (300°C and 400°C) when water is in vapour conditions. Moreover, we observe stick-slip behaviour at 400°C. Instead, powders from the slickenfibers show similar friction coefficient for temperatures up to 200°C (0.23), an increase at 300°C (0.34) with water is still in liquid conditions and a further increase (0.47 to 0.57) when water is in vapour conditions (300°C and 400°C). Contrary to the case for powders from the lenses, in the case of "slickenfibers", at 400°C (vapor conditions) no stick-slip behavior is observed.

The frictional healing properties document how the strength of these heterogeneous brittle-ductile shear zones evolves during the interseismic period. The healing behavior is different between the powders obtained from the lenses with respect to those from the slickenfibers. The "lenses" show a continuous increase toward positive healing with increasing temperature while showing a maximum at 200°C; the "slickenfibers" show negative healing for all temperature but not at 200°C, where a postive healing maximum is observed instead.

Our observations highlight a strong rheological difference between massive lenses and bounding faults (slickenfibers). The difference in friction and healing properties is important during subduction and exhumation as they cause different behaviours in the massive lenses and the bounding faults with increasing/decreasing temperature (and depth).

The study of the seismic cycle in hydrothermal conditions through experiments, analysis and modeling in the SCHOTTA project

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Keywords: fluid-rock interaction, seismic cycle, hydrothermal conditions.

The nucleation and propagation of earthquakes are often connected with the circulation of fluids at hydrothermal conditions (150°C < T < 450°C and Pf < 25 MPa). Geophysical investigations of buried structures and petrological studies of exposed faults evidence how hydrothermal fluids can drive fault mechanics during the seismic cycle by altering both rock properties and pore pressure, across a complex process of sub-critical crack growth, sealing, and healing. Due to technical difficulties in experiments and the timescale of fluid-rock reactions, direct observations of hot and pressurized fluids in rock deformation upon rupture are not well-known.

In order to address this gap, the SCHOTTA project (*The Seismic Cycle under HydrOThermal conditions: experimenTAl, analytical and modeling studies*), funded by Unione Europea-Next Generation EU - PRIN 2022, aims to combine laboratory rock friction experiments with geochemical and mineralogical analyses of fluids and rocks, performed both before and after experiments. The simulation of fluid-rock interaction over time using geochemical models that are properly calibrated with analytical, petrographic, and chemical data is planned, with the constraint being on thermodynamic and kinetic datasets to extrapolate experimental observations to natural faults. The challenge of calibrating models under extreme conditions is necessary as the most commonly used geochemical software is limited to water sub-critical conditions (T < 300°C, Pf < 8.6 MPa).

Through this innovative multidisciplinary study, we will build our ability to identify the primary factors that contribute to the seismic behavior of natural faults in hydrothermal conditions and the relationship between fluid-rock interaction and rock deformation. Our final goal is to assess the outcomes of natural and induced seismicity that develops in geothermal and volcanic environments.

The structural geology of fault healing: a preliminary view

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Keywords: earthquakes, friction, fault.

Fault rocks recover strength after being ruptured during an earthquake or another slip event, thus this mechanism controls the recurrence of the seismic cycle. This recovery is commonly known as "fault healing" and is caused by many physical processes that include cementation, compaction, asperity growth etc. In nature, fault healing is generally ascribed to cementation, demonstrated by the transition from incohesive to cohesive fault rocks (e.g., from gouges to cataclasites). However, the mechanics of healing is mostly studied through laboratory studies or inferred from geodetic measurements. This approach is yet unsatisfactory since healing phenomena occur in all rock types and at large scales that laboratory experiments can only partially capture.

Here, we propose a field-based perspective of fault healing that goes beyond the simplistic view of incohesive vs. cohesive fault rocks. We take advantage of outstanding exposures of some Italian faults to propose other indicators of healing, for example: re-worked cataclasites, adhesion phenomena (sidewall ripouts and fault surface patches), and geometrical complexity of the slip surfaces themselves. We also address the complexity due to the juxtaposition of rocks with different strength and composition along major faults, and the role of minor faults.

We compare these observations with frictional healing experiments carried out on both fault gouges and cohesive (=completely healed) slip surfaces. We propose that fault surface "patches" of more cohesive fault rocks bounded by anastomosing slip zones are the result of complex cycles of gouge formation and healing, which modulate the interplay of cohesion, adhesion and localization along the fault surface. These individual structural features can be the target of specific laboratory investigation, which is currently underway.

Microstructural record of seismic brittle failure at intermediate-depth conditions

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Keywords: pseudotachylyte, earthquake, microstructure.

Exhumed pseudotachylytes (quenched coseismic frictional melts) and their wall-rocks are a tool to study earthquake mechanics at hypocentre depth. In particular, pseudotachylytes produced at eclogite-facies conditions in subducted oceanic rocks provide clues to investigate the elusive mechanics of intermediate-depth earthquakes (Toffol et al., 2022).

We study pseudotachylytes hosted in the oceanic gabbros and peridotites of Moncuni (Lanzo Massif, W Alps). These pseudotachylytes were produced at ca. 70 km of depth during subduction and have been interpreted as the result of brittle failure under high differential stress of the dry and metastable rocks of the oceanic lithosphere (Pennacchioni et al., 2020).

We have characterized the pervasive damage surrounding pseudotachylytes within olivine-bearing gabbros. Brittle deformation comprises aseismic (cataclasite bands and foliated cataclasites) and coseismic (pulverized domains with shattering in-situ) features associated with the pseudotachylyte veins. Since their formation the pristine brittle features, including pseudotachylyte glass, escaped alteration and deformation overprint during the exhumation path thanks to fluid-absent conditions.

The pseudotachylyte fault veins are thin (a mm in thickness at most) and internally heterogeneous, with alternating clast-rich and melt-rich layers. Pseudotachylytes are bound by cataclastic bands showing an S-C fabric, with strain progressively localized toward a foliated ultracataclastic core sharply in contact with the overprinting pseudotachylyte. Rare clasts of ultracataclasite and pseudotachylyte are embedded in the foliated cataclasite.

Wall-rock olivine grains are deformed by low-temperature plasticity (LTP) recorded by deformation lamellae, undulatory extinction and associated microfracturing. These deformation features are also present in olivine clasts within the cataclasites suggesting a temporal sequence of (i) crystal plastic deformation at increasing stress conditions, and (ii) shattering and pulverization during seismic rupture propagation. Pulverized olivine fragments are made of healed aggregates of small (50 nm in size) olivine clasts that locally preserve amorphous domains and nano-twins.

We interpret LTP in olivine and the progressive evolution of the S-C fabric to represent the precursory stages of stress localization predating the abrupt propagation of the seismic rupture, responsible for the instantaneous high stress pulse recorded by the shattered wall-rock minerals. The presence of pseudotachylyte clasts and of olivine clasts with evidence of LTP embedded in the cataclasites suggest cyclicity of seismic failure and aseismic creep, potentially explaining the pervasive damage of the wall rocks.

Toffol G. et al. (2022) - How to quake a subducting dry slab at intermediate depths: Inferences from numerical modelling. Earth and Planetary Science Letters, 578, 117289.

Pennacchioni G. et al. (2020) - Record of intermediate-depth subduction seismicity in a dry slab from an exhumed ophiolite. Earth and Planetary Science Letters, 548, 116490.

S51.

Unveiling the long-lasting evolution of active margins from field to micro-scale

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Tectonic evolution of the northern sectors of the Iranian Plateau: insights from thermo-kinematic modelling into Neogene plateau building processes

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Keywords: Iranian Plateau, low-temperature thermochronology, thermo-kinematic models.

The Iranian Plateau represents a NW-SE striking, elevated morphotectonic feature within the upper plate of the Arabia-Eurasia collision zone. The southern margin of the plateau includes the High Zagros Mountains while the northern margin comprises of the Urumieh-Dokhtar Magmatic Zone and the western Alborz-Talesh Mountains. The plateau interior is characterized by low-topographic relief with several, mostly internally drained, intermontane sedimentary basins. The backbones of these basins are represented by the Sanandaj-Sirjan Zone. Plateau uplift began after ~17 Ma as evidenced by the presence of Lower Miocene shallow-water marine sediments of the Qom Formation within the plateau interior.

Here we present low-temperature thermochronologic data (apatite fission-track and (U-Th-Sm)/He data, denoted as AFT and AHe, respectively), from the northern plateau and its interior to extract information regarding fault slip rates and timing of fault activity along three structural transects across the northern plateau sectors. To achieve this, we employ a numerical thermo-kinematic modeling approach utilizing the Pecube software (Braun, 2003) with its new graphical user interface PecubeGUI(Bernard et al., 2023).

The modeling process involves incorporating field observations, such as back- and fore-limb dip angles, to define the characteristics of the faults, including their typical flat-ramp geometries. A forward model is performed to check if the observed data can be reproduced within a reasonable fit. Then and inverse model is performed in which a prior model space is sampled to find the parameters that yield smallest misfit between observed and predicted data.

Combining our findings with regional structural, stratigraphic, and existing thermochronology data, we discern that after a period of mild post-late Eocene contractional deformation, significant collisional deformation commenced in the early Miocene (~20 Ma) along the plate suture to the southern edge of the plateau and in the middle Miocene (~16-15 Ma) in the Talesh Mountains along the northern plateau boundary. Around 12-10 Ma, deformation intensified in the plateau interior without a discernible pattern of fault propagation. This thrusting activity contributed to the topographic growth of several mountain ranges, with wavelengths spanning approximately 50-60 km, alongside the compartmentalization of the plateau and the development of intermontane basins. Within these basins, filling processes inhibited intrabasinal deformation and faulting along the major range-bounding faults, resulting in the characteristic smoothed, low-relief landscape typical of an orogenic plateau.

Bernard M. et al. (2023) - PecubeGUI-beta (1.0.0-beta). Zenodo. https://doi.org/10.5281/zenodo.8362722.

Braun J. (2003) - Pecube: A new finite-element code to solve the 3D heat transport equation including the effects of a time-varying, finite amplitude surface topography. Comput.Geosci., 29, 787-794, https://doi.org/10.1016/S0098-3004(03)00052-9.

The importance of regional-scale shear zones in paleogeographic reconstructions: the case study of the Variscan belt in the Mediterranean area

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Keywords: East-Variscan Shear Zone, Variscan Belt, paleogeographic reconstructions.

Paleogeographic reconstruction and recognition of the tectono-metamorphic evolution of ancient orogenic belt is often complex. The combination of an adequate amountof paleomagnetic, metamorphic, structural and geochronological data is necessary. Fundamental data derive from the study of regional-scale shear zones by combining detailed field work with structural analysis, microstructural analysis and petrochronology. The Southern European Variscan Belt in the Mediterranean area was partially overprinted by the Alpine cycle and correlations are mainly based on lithological similarities. Little attention has been paid to the compatibility of structures in the dispersed fragments. A main debate is the connection among the Corsica-Sardinia Block (CSB), the Maures-TanneronMassif (MTM) and the future Alpine External Crystalline Massifs (ECM) and if these sectors were all affected by a network of shear zones of regional extent, known as the East Variscan Shear Zone (EVSZ). We present a multidisciplinary study of shear zones cropping out in the CSB (the Posada-Asinara shear zone; Carosi et al., 2020), in the MTM (the Cavalaire Fault; Simonettiet al., 2020a) and in the ECM (the Ferriere-Mollières and the Emosson-Berard shear zones; Simonetti et al., 2018, 2020b). Kinematic and finite strain analysis allowed to recognize a transpressional deformation, with a major component of pure shear and a variable component of simple shear, coupled with general flattening deformation. Syn-kinematic paragenesis, microstructures and quartz c-axis fabrics revealed that shear deformation, in all the studied sectors, occurred under decreasing temperature starting from amphibolite-facies up to greenschist-facies. A systematic petrochronological study (U-Th-Pb on monazite collected in the sheared rocks) was conducted in order to constrain the timing of deformation. We obtained ages ranging between ~340 Ma and ~320 Ma. Ages of ~340-330 Ma can be interpreted as the beginning of the activity of the EVSZ along its older branches while ages of ~320 Ma, obtained in all the shear zones, demonstrate that they were all active in the same time span. The multidisciplinary approach revealed a similar kinematics and tectono-metamorphic evolution of the studied shear zones and contribute to better constrain the extensionand timing the EVSZ strengthening the paleogeographic reconstructions of the Southern Variscan belt during Late Carboniferous time. This have important implications on the evolution of the Mediterranean area after the Late Paleozoic. Furthermore this case study demonstrates how paleogeographic reconstructions could benefit from datasets obtained from large-scale structures that can be directly investigated.

Carosi R. et al. (2020) - Kinematics and timing constraints in a transpressive tectonic regime: the example of the Posada-Asinara shear zone (NE Sardinia, Italy). Geoscience, https://doi.org/10.3390/geosciences10080288.

Simonetti M. et al. (2018) - Kinematic and geochronological constraints on shear deformation in the ferriere-mollières shear zone (Argentera- Mercantour Massif, Western Alps): implications for the evolution of the Southern European Variscan Belt. Int. J. Earth Sci., 107(6), 2163-2189, https://doi.org/10.1007/s00531-018-1593-y.

Simonetti M. et al. (2020a) - Timing and kinematics of flow in a transpressive dextral shear zone, Maures Massif (Southern France). Int. J. Earth Sci., https://doi.org/10.1007/s00531-020-01898-6.

Simonetti M. et al. (2020b) - Transpressive deformation in the Southern European Variscan Belt: new insights from the Aiguilles Rouges Massif (Western Alps). Tectonics, 39, 6, https://doi.org/10.1029/2020TC006153.

A journey into the Permian lower continental crust: a multisciplinary approach to reconstruct migmatization in the Valpelline Series (Dent-Blanche Nappe, Western Alps)

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Keywords: migmatite, lower crust, partial melting.

The lower continental crust represents a lithospheric portion where partial melting, occurring under different deformation regimes, contribute to the internal differentiation of the whole continental crust. Despite significant research on lower crustal sections (e.g., Ivrea-Verbano Zone in the Southern Western Alps; IVZ), a comprehensive model of migmatization that combines relations between lithological associations, pressure (*P*) – temperature (*T*) conditions and timing with the structural evolution is often missing. In this work we analyse the Valpelline Series (VP; Dent-Blanche Nappe, Western Alps) as a benchmark to unveil processes and structures occurring in the Permian lower continental crust. Our approach integrates detailed lithological characterization and multiscale structural analysis with quantitative results (i.e., combining 3D outcrop-model analysis and quantitative microstructural analysis through Electron Backscattered Diffraction and X-ray Micro-CT), thermodynamic modelling, geochemistry and geochronology (U-Pb, Ar/Ar). The VP consists of Permian migmatitic metapelite with different mineral assemblages (i.e., garnet-, cordierite- and orthopyroxene-bearing), migmatitic amphibolite, and marble, intruded by aplite and pegmatite (Caso et al., 2024a). Three deformation stages have been recognized: the D1 is preserved as an S1 foliation in metabasite lenses and locally within metapelites; the regional foliation S2 developed during the D2 phase is related to melt production and is locally transposed during the D3 into an S3 foliation, which is sillimanite-rich and wraps around garnet, cordierite and orthopyroxene (Caso et al., 2024a, 2024b). Contrasting *P–T* conditions related to the D2 stage are detected: (i) 850-900°C and 0.80-0.95 GPa in orthopyroxene-bearing migmatites and migmatitic amphibolites; (ii) 700-770 °C and 0.4-0.6 GPa in cordierite-bearing migmatites. This *P–T* discrepancy is associated with different U-Pb ages consistently older in orthopyroxene-bearing leucosomes (293 ± 2 Ma) than in cordierite-bearing ones (285 ± 2 Ma) and late pegmatites (277 ± 2 Ma). As a final consideration, despite showing many affinities with the well known IVZ, our results highlight few differences between VP and IVZ: (i) the absence of a mafic complex in the VP and related contact metamorphism; (ii) the lack in the VP of evidence of transition from the white mica up to the orthopyroxene-bearing metapelites; iii) migmatites are associated only with biotite and sillimanite, plus the occurrence of cordierite or orthopyroxene, showing difference in ages of migmatization and in the *P-T* conditions.

Caso F. et al. (2024a) - Structural, lithostratigraphic and thermal features of a permian lower crust from the western Italian Alps (valpelline series, valle d'Aosta). Geol. Mag., 160(11), 1983-2009, https://doi.org/10.1017/S0016756824000037.

Caso F. et al. (2024b) - Combining traditional and quantitative multiscale structural analysis to reconstruct the tectono-metamorphic evolution of migmatitic basements: the case of the Valpelline Series, Dent-Blanche Tectonic System, Western Alps. J. Struct. Geol., 182, 105099, https://doi.org/10.1016/j.jsg.2024.105099.

Evidence of strain partitioning and localization in carpholite-bearing hybrid veins: a case study from the Piedmont Zone, Western Italian Alps

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Keywords: shear zones, brittle-ductile deformation, crack-and-seal veins.

Strain partitioning and localization of deformation have a direct impact on subduction zone dynamics. Localization of ductile deformation may occur along brittle precursors, such as veins. In the Western Alps, the Piedmont Zone high pressure (HP) metasediments display preserved lawsonite and carpholite-bearing veins formed at 30–60 km of depth (Herviou et al., 2023). Similar veins have been recently considered to be a possible fossil record of deep episodic tremor and slow slip events (ETS; Giuntoli & Viola, 2022).

We studied the Lago Nero Unit of the Piedmont Zone deformed at blueschist facies conditions (BS, ~350°C and ~1.7 GPa; Agard, 2021 and references therein). We performed detailed fieldwork, microstructural and petrological analysis on carpholite-bearing HP veins hosted in mylonitic marbles. The host rock marble is massive and shows a mylonitic foliation associated with a S-C-C' fabric marked by elongated and recrystallized carbonate grains and fine-grained aggregates of quartz. We distinguished two sets of quartz + carbonate + carpholite HP veins: i) hybrid veins oriented parallel to the main foliation and ii) dilatant veins slightly inclined in respect to the foliation. In both cases, fibres are oriented parallel to the measured lineation in the host rock. Both veins display crack-and-seal textures. Later iii) quartz + carbonate dilatant veins cut all the previous structural elements and are oriented at high angle with respect to the foliation. The two first sets of veins can be considered contemporaneous, as the second set joins into the first one. Furthermore, the mylonitic foliation is broadly coeval with these two carpholite-bearing HP veins. Considering the presence of carpholite, veins developed at a minimum pressure of 0.8 GPa.

Hybrid veins parallel to the host rock foliation are intensely deformed in carbonate ultramylonitic bands wrapping around relics carbonate ribbons. Quartz and carpholite rich portions of the veins are fractured and boudinated. Therefore, crack seal veins display partitioning into brittle/ductile domains and act as zones where deformation is preferentially localized. Strain could initially localize at the interface between vein and host-rock and quartz-carpholite rich and carbonate rich bands.

Conclusion, the Piedmont Zone HP metasediments display broadly coeval cyclic brittle and ductile deformation, likely related to fluctuation of pore-fluid pressure that reached sub-lithostatic values at low differential stress conditions. These structures can provide insights in the complex deformation mechanisms occurring during deep ETS (Fagereng et al., 2011).

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Agard P. (2021) - Subduction of oceanic lithosphere in the Alps: Selective and archetypal from (slow-spreading) oceans, Earth-Science Reviews, 214, 103517, https://doi.org/10.1016/j.earscirev.2021.103517.

Herviou C. et al. (2023) - Fractal distribution of subduction-related crack-seal veins (Schistes Lustrés, W. Alps): Implications for fluid flow and rupture processes at the downdip end of the seismogenic zone. Journal of Geophysical Research: Solid Earth, 128, e2022JB026317, https://doi.org/10.1029/2022JB026317.

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Giuntoli F. & Viola G. (2022) - A likely geological record of deep tremor and slow slip events from a subducted continental broken formation. Sci. Rep., 12, 4506, https://doi.org/10.1038/s41598-022-08489-2.

Limited Neogene dip-slip tectonics in the northwestern Iranian Plateau: evidence from low-temperature thermochronology

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Keywords: far-field deformation, low-temperature thermochronology, collisional tectonics.

Thermal history solutions obtained from integrated fission-track and (U-Th-Sm)/He analyses of plutonic and metamorphic rock units ranging in age from the Precambrian to the Oligocene indicate consistently that the NW Iranian Plateau has largely escaped significant Neogene dip-slip deformation. Integration of structural, stratigraphic and thermochronologic data shows that cooling/exhumation related to the mid-Miocene hard collision of Arabia along the southwestern Eurasian continental margin focused along the Bitlis-Zagros collisional front and the south Caspian (Alborz) backstop (Ballato et al., 2013; Cavazza et al., 2018) whereas the bulk of NW Iran was affected by pervasive strike-slip deformation with limited local exhumation along transpressional domains and properly oriented inherited structures. The thermochronometric evolution of the NW Iranian Plateau mimics the one of eastern Anatolia, where collisional deformation focused along the Bitlis segment of the collisional front and in the eastern Pontides, located at the rheological transition between the continental lithosphere of eastern Turkey and the quasi-oceanic lithosphere of the eastern Black Sea. Both the Anatolian and Iranian orogenic plateaus were thus by-passed by far-field collisional stresses which focused instead on (i) major rheological contrasts such as the south Caspian and Black Sea backstops or (ii) inherited and easily inverted hinterland structures such as the Adjara-Trialeti, Greater Caucasus, and Talysh backarc basins (e.g. Gusmeo et al., 2021; Cavazza et al., 2024).

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Evolution of active margins? A link with the tectonic reactivation in foreland area

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Keywords: Monte Giove, Apulian Foreland, fault reactivation.

The so-called Monte Giove submerged relief/structural high (Adriatic Sea, offshore the Apulia), represents an interesting example of tectonic reactivation in the Apulian Foreland related to the Apennines evolution (Festa et al., 2019; Cicala et al., 2023).

To detect the faults that control the slopes of Monte Giove, the Adriatic Sea offshore from Polignano a Mare–Monopoli towns was examined up to ~30 km from the coastal line, where several reflection seismic profiles, from ViDEPI Project (www.videpi.com/videpi/videpi.asp), were interpreted. Moreover, the cliff between the above towns was surveyed geologically in detail, to seek structural evidence for a possible onshore continuation, in the Murge area, of the submarine relief.

The geometry of the northern and southern margins of the Monte Giove are controlled by faults. The northern structure is an NNE- to N-dipping fault, striking from north of Polignano a Mare to the east, in the Adriatic Sea. This fault is sub-vertical and characterized by post-Lower Pleistocene dextral oblique-slip kinematics. Syn-sedimentary tectonics during the Oligo-Miocene, Pliocene and Quaternary are shown by the increase in thickness of the related seismostratigraphic units in the hanging wall of the fault. It shows clues to Cretaceous activity, represented by ductile deformation structures under diagenetic conditions within the outcropping limestones of the "Calcare di Bari" Fm. involved in faulting.

As regards the southern margin of the submerged relief, two main high-angle faults, active during the Quaternary, have been recognized forming a graben-like structure, that corresponds to the Upper Cretaceous Rosaria Mare intra-platform basin: the northern one is a E-W to NW-SE striking and S-dipping fault; the southern one is a NW-SE striking and NNE-dipping fault. Both faults mostly show dip-slip movement (even though a right transtensional kinematic cannot be excluded), and gave rise to a Quaternary negative flower structure: the S-dipping fault (showing vertical offset of the base of the Quaternary unit up to 200 m) and the NNE-dipping one (showing slightly lower offset) represent the main and the subsidiary fault, respectively.

The faults bordering Monte Giove represent the offshore lateral continuation to the east, in the Adriatic Sea, of the Northern Deformation Zone within the Murge area, active since the late Cretaceous. The faults of the Northern Deformation Zone and those bordering Monte Giove may have been reactivated during post-Lower Pleistocene time with normal dip-slip and dextral oblique-slip kinematics along NE-dipping and N-dipping/E-W striking sub-vertical planes, respectively. The reactivation of these faults may be related to the continental lithospheric gentle buckling of the Apulian Foreland occuring due to halting of the roll-back of the subducting lithosphere, which was accompanied by arching/uplift since the Middle Pleistocene.

Festa V. et al. (2019) - In search of the seismogenic fault of the March 23rd 2018 earthquake (Mw 3.7) near Brindisi (Puglia, Southern Italy). Geol. Croat., 72, 137- 144, https://doi.org/10.4154/gc.2019.10.

Cicala M. et al. (2023) - The northern fault of the on shore-offshore Monte Giove relief in the southern Adriatic Sea, Italy: implications for tectonic reactivation in the Apulian Foreland. Geol. Q., 67, 11, https://doi.org/10.7306/gq.1681.

Reconciling the onset of Tethyan rifting in the Ivrea Verbano Zone (European Southern Alps)

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Keywords: Ivrea-Verbano Zone, monazite, Alpine Tethys rifting.

Extensional faults, both in the ductile and brittle realm, play a significant role throughout the evolution of a crustal rift. Constraining the age of faulting, and how and when deformation shifts from the lower to the upper crustal domains, is crucial for the reconstruction of the rifting related processes. The rifting of the Alpine Tethys began in the Early Jurassic due to the propagation of the Central Atlantic rifting, marking the onset of Pangea break-up.

We report on the Premosello Shear Zone (PSZ) in the Ivrea-Verbano Zone (European Southern Alps), a top-to-the-W extensional shear zone consisting in alternated layers of extremely sheared felsic and mafic granulites transformed into mylonites and ultramylonites in which mm-to-dm size garnet and stretched mm-size pyroxene porphyroclasts are the peculiar textural features. Clear cross cutting relationships suggest a progressive development of mylonites, ultramylonites and, finally, pseudotachylyte veins which cross cut the previous fabric.

The studied samples were selected as representative of different textural features for U-Th-Pb monazite dating and pseudotachylites for $^{40}Ar/^{39}Ar$ dating.

Laser ablation-inductively coupled plasma-mass spectrometry U-Th-Pb monazite dating yields concordant ages with a spread from 215 to 188 Ma where $^{40}Ar/^{39}Ar$ on pseudotachylyte yields age of 199 Ma. The new U-Th-Pb and 40Ar/39Ar radiometric ages here presented provide the first quantitative temporal constraints on the onset of the Jurassic extensional regime along the PSZ in the Ivrea Verbano Zone, suggesting that the PSZ was active across the Middle-Late Trias to Early Jurassic.

Our data reveal the propagation of extensional structures from the lower toward upper crust, with crustal extension that finally led to the opening of the Alpine Tethys, as also testified by geochronological data on faults that bordered the Jurassic basins developed in the present-day Southalpine Domain. The bottom-to-top propagation of the deformation is testified by the deformation age of monazite in the lower crust and subsequently by the age of pseudotachylyte in the relatively shallower crust. The pseudotachylyte, with an age of 199 Ma, represents the connection between the shearing along shear zones in the lower crust and along faults in the upper crust, covering a time span from 215-188 (i.e., high temperature shearing in the lower crust from this study) to 192-169 Ma (i.e., low temperature faulting in the upper crust).

This chrono-structural model has significant implications on the role of major extensional faults in focusing deformation involving progressively the lower and the upper crust during the Tethyan rift evolution.

Petrological constraints and geodynamic significance of a Triassic lamprophyre dyke crosscutting the Palaeozoic basement of NE Sardinia, Italy

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Keywords: lamprophyre, geochemistry, Sardinia.

A Triassic lamprophyre dyke crosscutting the Palaeozoic basement of northeastern Sardinia, in the south-eastern sector of the Posada-Asinara Shear Zone, is investigated with the aim to decipher the magma source, genesis and P-T conditions of crystallization and emplacement. The lamprophyre dyke shows a porphyritic texture with centimeter-sized amphibole, biotite, ulvöspinel and apatite phenocrystals. The lamprophyre also contains feldspar cluster and xenolithic nodules. The groundmass mainly consists of brownish amphibole, ± biotite, ulvöspinel microcrystals, apatite needles, and feldspar clusters. Biotite phenocrysts (XMg: 0.54-0.60) are not zoned and have high TiO2 contents (~7 wt.%). The centimetric amphiboles are characterized by a wide Fe-rich/Mg-poor core, surrounded by a rim with increasing Mg and decreasing Fe. The rim is followed by an outer rim in which decreasing Mg and Ti and increasing Fe is observed. Small amphiboles in the groundmass match the compositional trend observed for the rim and outer rim of the above mentioned crystals. The core of the amphibole reflects the deepest crystallization conditions, whereas the surrounding rims and amphiboles from the groundmass point to slightly higher temperature and lower pressure. The whole-rock samples, which are Si-undersaturated, resemble the composition of alkaline lamprophyres. The incompatible trace element patterns show weak positive anomalies for Ba, Nb, K and P and negative ones for Th and Ta, whereas the chondrite-normalized REE pattern reflects a constant fractionation from light REEs to heavy REEs with no Eu anomaly. The radiogenic isotope composition clusters between the E-DMM and BSE mantle components at 220 Ma. The REE fractionation pattern (Lan/Ybn) suggests a derivation from a garnet-lherzolite mantle where the residual garnet tends to fractionate HREE whereas the more incompatible LREE are concentrated in the melt. Comparison with other European lamprophyres and palaeogeographic reconstruction suggest that the Sardinia lamprophyre, located along the eastern branch of the fault system that led to the opening of the Alpine Tethys, belongs to the wide Triassic, “rifting-related” magmatism which records the Pangea break-up.

Geology and petrology of the Northern Dora-Maira Massif in the Tredici Laghi - Conca Cialancia area (Germanasca - Pellice Valleys, Western Alps)

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Keywords: Western Alps, geological mapping, Dora-Maira Massif.

While numerous studies have been done in the southern Dora-Maira Massif, and recent syntheses have provided an updated view of its metamorphic (Bonnet et al., 2022) and structural (Michard et al., 2022) history, the northern Dora-Maira Massif has been little studied. Recent investigations in the northern-western part of the massif (Manzotti et al., 2022; Nosenzo et al., 2024) have shed new light on the structural architecture and metamorphism of the various tectonic units, with the discovery of a new UHP tectonic unit (Manzotti et al., 2022). Despite these efforts, many open questions regarding its structural architecture and tectono-metamorphic evolution remain. In this contribution, we present preliminary data from an area comprised between the Tredici Laghi and Conca Cialancia natural park (Germanasca - Pellice Valleys), a mountainous region with an elevation comprised between 2000-2800m asl. This previously poorly explored area consists of a polycyclic basement (made up of micaschist, orthogneiss, paragneiss, marble and metabasite) associated with metaintrusive rocks and a monocyclic cover. With the aid of a new structural map and geological cross-sections, realized in the framework of the CARG mapping project (Sheet 172 –"Pinerolo"), the structural setting of the area has been reconstructed. Microtectonics studies and preliminary P-T-t data, derived from ongoing petrological and geochronological studies, will be integrated to tentatively provide a state-of-the-art picture of the tectono-metamorphic evolution of the studied area. Structures referable to at least four deformation phases have been recognized. The S1 foliation, rarely preserved in microlithons, developed at peak P-T conditions and is associated to the syn-kinematic recrystallization of phengite, paragonite, chloritoid, garnet and rutile. A subsequent S2 foliation (the main foliation in the field, defined by phengite, paragonite, chloritoid, garnet, albite, epidote, and ilmenite) developed associated to E-W trending folds. Subsequently, a D3 event, associated to the development of a local S3 foliation, parallel to the axial planes of generally open folds, deformed all the previous structures. S3 foliation is associated with metamorphic re-equilibration and growth of greenschist facies assemblages. Several examples of superimposed D2 and D3 folds are documented at various scales. Final doming of the Dora-Maira nappe stack (D4), is associated to the displacement of the Adria mantle indentor.

Bonnet G. et al. (2022) - Protracted Subduction of the European Hyperextended Margin Revealed by Rutile U–Pb Geochronology Across the Dora–Maira Massif (Western Alps). Tectonics, 41(4), e2021TC007170.

Manzotti P. et al. (2022) - A journey towards the forbidden zone: a new, cold, UHP unit in the Dora-Maira Massif (Western Alps). Contributions to Mineralogy and Petrology, 177(6), 59.

Michard A. et al. (2022) - The Maira-Sampeyre and Val Grana Allochthons (south Western Alps): review and new data on the tectonometamorphic evolution of the Briançonnais distal margin. Swiss Journal of Geosciences, 115(1), 1-43, https://doi.org/10.1186/s00015-022-00419-8.

Nosenzo F. et al. (2024) - Tectonic architecture of the northern Dora-Maira Massif (Western Alps, Italy): field and geochronological data. Swiss Journal of Geosciences, 117(1), 6.

Unveiling the tectono-metamorphic framework of northern Dora-Maira Massif (Western Alps): insights from Pellice and Chisone valley

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Keywords: Western Alps, Dora-Maira,structural evolution.

The Dora-Maira Massif plays a key role in understanding the geodynamics that shaped the Alpine belt. Extensive studies have been already conducted mostly in the southern portion (e.g., Chopin et al., 1991; Bonnet et al., 2022). Recent investigations by Manzotti et al. (2022) and Nosenzo et al. (2024) have renewed the interest in the northern portion of the Dora-Maira Massif. These authors provided new structural and metamorphic data on the area, particularly with the discovery of a new important ultra-high-pressure unit (the Chasteiran Unit). Despite these important contributions, many open questions persist at the scale of the whole massif. In this contribution, we present new data obtained within the framework of CARG mapping project (Foglio 172-Pinerolo). Our aim is to improve the geological knowledge about the structural and metamorphic architecture in the Val Pellice and Val Chisone area. We present a geological map with related geological cross-sections, at the scale 1:10.000, covering the region between Colle Lazzarà and Colle Vaccera. In addition, we performed microtectonic and petrographic studies to reconstruct the area's structural and metamorphic evolution. Within this relatively unexplored terrain, three distinct tectono-metamorphic units crop out, that from bottom to top are: the Pinerolo-Sanfront Unit, the Chasteiran Unit, and the poly-cyclic basement unit of the Dora-Maira Massif. Particular attention has been paid to mapping the tectonic contact between the Chasteiran unit, sandwiched between the other two tectono-metamorphic units. The contact has been mapped, further south, up to Colle Vaccera. At least four deformation phases have been recognized: the D1 phase associated with the development of an S1 foliation at the peak metamorphic condition, preserved only within the microlithons of the S2 foliation. A second deformation phase, associated with the development of the main foliation (S2), axial plane of metric to pluridecametric tight to isoclinal folds with an E-W trends developed during the nappe stack. The main foliation is deformed by structures subsequently attributable to a later D3 deformation phase, which develop an axial plane foliation associated with the thermal re-equilibration. Finally, a D4 deformational phase is recognized in association with the doming of the Dora-Maira Massif.

Bonnet G. et al. (2022) - Protracted Subduction of the European Hyperextended Margin Revealed by Rutile U–Pb Geochronology Across the Dora–Maira Massif (Western Alps). Tectonics, 41(4), e2021TC007170, https://doi.org/10.1029/2021TC007170.

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Unveiling complex fault architecture evolution through (micro)structural, geochronological and petrophysical investigations: the case of the Carboneras Fault (SE Spain)

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Keywords: brittle-structural-facies, radiometric dating, permeability.

Fault zones are dynamic structural features commonly embedding a complex patchwork of diverse, non-coeval brittle structural facies (BSFs; *sensu* Tartaglia et al., 2020). The present-day tight juxtaposition of BSFs may represent the end-result of protracted, cumulative and complex histories, characterized by multiple episodes of deformation localization and fluid inflow, possibly also causing a range of different slip behaviors. Thus, (micro)structural, mineralogical, thermal, petrophysical and mechanical data need to be integrated over the lifespan of the studied fault system to unravel intricate tectonic histories and understand fluid flow patterns and seismotectonic styles in the brittle crust.

In this perspective, by means of a multitechnique and multiscalar approach that builds upon the examination and characterization of BSFs, we studied the Carboneras Fault (CF), a c. 140 km-long, active, crustal-scale fault zone in the Betic Cordillera, which is inferred to have accommodated c. 40 km of cumulative offset since the Miocene along its main NE-SW strike. We integrated high-resolution field structural analysis, in-situ air-permeability measurements of BSFs and microstructural characterization and K-Ar geochronology of fault gouge samples with previously presented data (including 8 K-Ar ages, mineral assemblage and maximum temperature of synkinematic clay minerals of fault gouges) to unravel the long-term spatiotemporal and thermal evolution of the CF.

The CF has accommodated progressive deformation over a > 20 Myr time span (from 24.72 ± 0.53 Ma to 0.48 ± 0.77 Ma) through repeated episodes of deformation localization and fluid inflow, interaction with inherited structural discontinuities, selective fault (de)activation and formation of a stark fault rock and permeability heterogeneity (up to 3 orders of magnitude) at progressively colder (from ≥ 275 down to 70°C) and presumably shallower structural levels.

These findings are currently being used to aid well-informed numerical modelling to gain new insights into the mechanisms of growth and exhumation of major fault zones as well as into the understanding of their 3D hydro-mechanical behavior.

Tartaglia G. et al. (2020) - "Brittle structural facies" analysis: A diagnostic method to unravel and date multiple slip events of long-lived faults. Earth Planet. Sci. Lett., 545, 116420, https://doi.org/10.1016/j.epsl.2020.116420.

The heritage of Tethyan oceanic transform faults within Alpine orogens: The Shkoder-Peja transverse zone (SPTZ) of Northern Albania

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Keywords: tectonic inheritance, Shkoder-Peja transverse zone, Dinarides-Hellenides boundary.

The Shkoder-Peja transverse zone (SPTZ) of Northern Albania marks the boundary between the Dinarides and the Albano-Hellenides chains and corresponds to a ~100 km SW-ward shift of the ophiolitic nappe front. Over the last sixty years, it has been variably interpreted as an inherited paleogeographic feature, a dextral strike-slip fault, the hinge of the clockwise (CW) rotating Albano-Hellenides system, and a Miocene-to-recent normal fault. Here we report on the paleomagnetism of 27 Triassic-Cretaceous sites from the Krasta-Cukali and the High Karst domain, both within and north of the SPTZ. Two sites yielded only a pre-tilting magnetization, 15 sites were found to be remagnetized after mid-Eocene-lower Miocene tilt, while 8 sites showed both pre- and post-tilt magnetizations. Both pre- and post-tilt paleomagnetic directions yielded a 60-70° clockwise (CW) rotation with respect to Adria/Africa, except 9 sites from the Koman zone at the ophiolitic nappe boundary showing a smaller 38°±15° CW rotation. Thus, the well-known regional CW rotation of the Albano-Hellenides extends northward in the southern Dinarides, and the SPTZ is not a rotation boundary as previously assumed. The ~70° CW rotation is consistent with available data from the nearby ophiolitic nappe complex, and is assumed to represent the sum of a 30° lower Miocene rotation during thrusting of the Kasta-Cukali over Kruja nappe plus the 40° Miocene-Pleistocene rotation well documented in the external zones of Albania. We suggest that the SPTZ is the heritage of a mid-Triassic transform fault of the Maliac Tethyan ocean, later overprinted by the lower Cretaceous obduction of the Vardar ocean, replacing Maliac since the middle-Jurassic.

Textural footprint of orogenic processes: convergence, collision and reequilibration

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Keywords: texture, orogen.

From the closure of an ocean to the gravitational collapse, the orogenic architecture is the result of a complex interaction of mass and energy, which have been recorded at both the macro and microscopic scale. While texture and microstructure represent the local expression of large-scale processes, their investigation in context provides critical evidence to understand the geodynamic evolution of an orogen and to shed light on new questions. Examples from different orogenic contexts are discussed.

Long-lived activity of a regional thrust-system in a pre-collisional setting: the Orobic Thrust (Southern Alps, N Italy)

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Keywords: Orobic Thrust, pseudotachylyte, cataclasites.

The Orobic Thrust is a regional-scale fault zone, more than 80 km in length, representing the largest structure of the European Alps retro-belt. Along the thrust plane the Variscan basement is thrusted southward over the Upper Carboniferous to Lower Triassic volcano-sedimentary cover of the Southalpine Domain. The 250-300 meters thick fault zone is continuously exposed in several areas, allowing the detailed reconstruction of the fault architecture. A narrow (20-25 m) protomylonitic band marks the top of fault zone suggesting temperature of at least 300°C in the early stage of fault activity. Temperature in excess of 200°C are also supported by analysis of the thermal maturity of clay minerals (<2 μm size fraction) in terrigenous rocks in the footwall of the thrust plane. Different fault rock types decorate the thrust fault zone: cataclasites, foliated cataclasites, pseudotachylyte bearing cataclastic bands and incoherent fault gouges. Apart from fault gouges occurring along discrete plane that appear to be undeformed, all the other fault rocks display mutual crosscutting relationships, testifying for multiple switching between seismic slip and aseismic creep during the fault history. ^{40}Ar-^{39}Ar ages obtained from pseudotachylytes span from 83 to 64 Ma, whereas illite (<0.1 μm size fraction), separated from the gouge along a non-deformed fault plane with a reverse kinematic at the core of the Orobic Thrust fault zone, provided a K-Ar age of 53 Ma. Pseudotachylyte age distribution shows older ages of ca. 80 Ma occurring both at the top and the bottom of the fault zone, with a superposed pattern that display instead a bottom forward younging direction of ages between 76 and 64 Ma.

The geochronological dataset highlights how regional-scale fault systems may benefit of long-lived activity. Due to their relative rheological weakness with respect to host rocks, they can experience multiple re-activations, recording also the change of ambient conditions and regional stress.

The Orobic Thrust was active from the Late Cretaceous to the Early Eocene, as testified by the age of fault gouges associated to reverse faults that mark the last stage of activity. The age pattern testifies for a long-lived (about 30 Myrs) thrust system in the present-day Southalpine Domain, developed in the upper plate of the ongoing Alpine Tethys subduction as a pre-collisional fold-and-thrust belt.

Shearing at the top of the Adula nappe: syn-collisional exhumation of the San Bernardino eclogites

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Keywords: eclogite,exhumation, shear zone.

In the Central Alps, the Adula nappe exposes (U)HP mafic and ultramafic rocks, providing insights into the subduction history of the distal European margin during the final stages of Europe-Adria collision. The Adula nappe is sandwiched between non-eclogitic Sub-Penninic nappes derived from the distal European margin, below, and non-eclogitic Middle Penninic nappes (Tambò and Suretta) consisting of pre-Permian basement and Mesozoic covers of the Briançonnais terrane that stands above. The upper tectonic contact of the Adula nappe consists of a complex shear zone, the Misox zone, along which lenses of non-metamorphic sheared Mesozoic sediments and volcanics also occur.

It is commonly accepted that these three units were thrusted over each other during extensive mylonitic shearing directed towards the north.

The actual structural frame and the metamorphic gap existing between the (U)HP Adula unit and the eclogite-free Tambò-Suretta nappe complex requires instead a normal sense shear zone that at certain time, during the tectonic evolution of the Central Alps, was able to accommodate the exhumation of the Adula nappe. We documented the occurrence of this shear zone between the top of the Adula nappe and the bottom of the Misox zone in the San Bernardino pass area (Switzerland). The shear zone is mainly developed within Adula nappe orthogneisses with eclosed lenses of paragneisses and megnesite-bearing eclogites at the top of the shear zone. Eclogites invariably show a mylonitic texture with the mylonitic foliation that always display rotation at variable angles with respect to the shear zone-related foliation.

The P-T equilibrium conditions of eclogite have been constrained at c. 2.0-2.1 GPa and 520-645°C, that are considered coeval with the mylonitic texture on the base of microstructures. $^{40}Ar/^{39}Ar$ age of phengite in eclogites resulted in 37-39 Ma.

The $^{40}Ar/^{39}Ar$ age distribution across the mylonitic orthogneiss of the shear zone supports a younging direction from the bottom to the top (eclogite-bearing zone) of the shear zone itself, from c. 37 to 29 Ma, that is considered to be coherent with a top-to-E normal shearing that begun just after the HP metamorphism.

Multistage evolution of a regional shear zone: constraints from the South Tibetan Detachment System

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Keywords: low angle normal fault, paleopiezometry, Himalaya.

The South Tibetan Detachment System (STDS) is one of the most spectacular example of low-angle normal fault on earth getting in contact the lower high-grade metamorphic rocks of the Greater Himalayan Sequence with the upper very-low grade to non metamorphic rocks of the Tethyan Himalayan Sequence. It covers a primary role in the exhumation of the metamorphic core of the belt and for a long time it has been considered coeval with the lower Main Central Thrust, characterized by an opposite kinematic.

Its architecture is quite complex and it has been previously described as made by a lower ductile shear zone and by an upper brittle fault in the Everest area where it is spectacularly exposed.

Detailed investigation along several sectors of the belt highlight that the upper brittle fault did not developed.

Detailed meso and microstructural analyses, on oriented thin sections, provide new data for the development and tectonic evolution of the South Tibetan Detachment System in these areas.

Microstructural analyses combined with crystallographic preferred orientation, paleopiezometric and vorticity analyses highlighted a complex multistage tectonic evolution (Nania et al., 2024).

Two different stages of non-coaxial deformation have been recognized during which the STDS experienced deformation from lower to upper structural levels with a decreasing temperature.

The first stage, at deeper structural levels, occurred at low differential stress values (<15MPa) while the second one is characterized by higher differential stress (>100 MPa).

Cooling, accompanied by increasing of differential stress, has been interpreted as a progressive exhumation of the STDS during which strain hardening occurred so that ductile shearing persisted at shallower structural levels without localizing the upper brittle fault.

In addition geochronological investigation (Carosi et al., 2013; Iaccarino et al., 2017; Montemagni et al., 2018) pointed out that along several study sections it is not coeval with the lower Main Central Thrust opening new scenarios on the exhumation processes of the belt.

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Montemagni C. et al. (2018) - Age constraints on the deformation style of the South Tibetan Detachment System in Garhwal. Ital. J. Geosci., 137, 175-187, https://doi.org/10.3301/IJG.2018.07.

Nania L. et al. (2024) - Calcite fabric development in calc-mylonite during progressive shallowing of a shear zone: an example from the South Tibetan Detachment system (Kali Gandaki valley, Central Nepal). Tectonophysics, 872, 230176, https://doi.org/10.1016/j.tecto.2023.230176.

Heterogeneous rock response to deformation in subduction-related continental shear zones: a possible record of episodic tremors and slow slip events from the Saih Hatat window, Oman

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Keywords: hybrid veins, mylonites, crack-seal microstructures.

Episodic tremor and slow slip events (ETS) are persistent, low-frequency seismic signals associated with slip larger than the average plate motion. They have been documented worldwide in several active and fossil subduction settings (Behr & Bürgmann, 2021). Heterogeneous deformation style and hybrid veins in shear zones are at times interpreted as relicts of ETS preserved in exhumed oceanic terranes. Noteworthy, only a few reports are, instead, available from continental settings (e.g., Giuntoli & Viola, 2021). Here, we document structures possibly related to fossil ETS in the continental framework of the Oman obduction orogen.

We study the Hulw Shear Zone (HSZ), also referred to in the literature as the "upper plate–lower plate discontinuity", which separates two units recording comparable blueschist facies conditions in the Saih Hatat Window (NE Oman; Agard et al., 2010). The HSZ is made up of 60-100 m thick high-strain zones with an overall block-in-matrix fabric and a top-to-the N/NE sense of shear. Field observations reveal that the lower unit of the HSZ is mainly composed of weak metapelite enclosing brownish dolostone lenses. This metapelite is affected by a pervasive mylonitic foliation marked by white mica and pyrophyllite. Brownish dolostone is massive and intensely fractured with no clear preferential orientation. Similarly, the upper unit of the HSZ is composed of foliated/massive mylonitic marble that embeds boudinated and brecciated layers and lenses of grey dolostone. Mode I veins occur in the more viscous rock types (e.g., massive marble) oriented at a high angle to the mylonitic foliation. In contrast, dilational shear veins are more common in weaker rocks (e.g., metapelite) and are subparallel to the mylonitic foliation. Those veins commonly contain crack-and-seal textures within calcite, quartz, and minor white mica infills. K-white mica barometry and forward thermodynamic modelling indicate that the HSZ localised and sheared in the pyrophyllite stability field during retrogression. Nevertheless, in agreement with previous thermo-barometric estimates (e.g., Yamato et al., 2007), we found higher pressure relicts pointing close to blueschist facies conditions.

In conclusion, the HSZ displays evidence of a heterogeneous deformation style with block-in-matrix fabrics and evidence supporting cyclically repeating localised brittle failure and more diffuse ductile deformation developed at minimum high-pressure greenschist facies conditions. These structures may be a fossil geological record of ETS in the Oman continental subduction framework.

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Tectono-metamorphic evolution of continental and oceanic crustal slices in the Alpine Subduction Complex (Piemonte – Sesia-Lanzo Zone boundary, Western Italian Alps)

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Keywords: tectonic mixing, subduction mélange, eclogite facies.

At the boundary between the Piemonte Zone (PZ) metaophiolites and the Austroalpine continental crust a tectonic mélange of thin slivers of calcschists, quartzites, metabasites, serpentinites and fine-grained gneisses (metapelites and metagranitoids) occurs all along the western margin of the central and southern Sesia-Lanzo Zone (SLZ), from Santanel klippe to Lanzo Massif (Spalla et al., 1983; Battiston et al., 1984). All the rocks belonging to SLZ and PZ together underwent four episodes of deformation, giving rise to a complex regional tectonostratigraphy. The metamorphic mineral assemblages marking successive foliations, detected from the central to the southern part of the SLZ western margin, indicate that various metamorphic conditions dominate in different portions of this tectonic mixing. In the southern sector of this "mixing zone" parageneses indicate that rocks experienced an early eclogite facies imprint, followed by re-equilibration under blueschist facies conditions, and that they were finally widely retrogressed under greenschist facies, during the last two deformational stages. The origin of this rock assemblage architecture could be the result of transposition in the mantle wedge, otherwise it may represent the reworked primary series of an extensionally-thinned continental margin. The tectonic picture along the boundary between the PZ and the southern SLZ indicates that during the Alpine convergence slices of oceanic lithosphere, recording different thermal and structural imprints during burial and exhumation paths, are mixed with rocks of Adria continental margin (Assanelli et al., 2020). Similar kinds of tectonic mélange of continental and oceanic crustal slices, with variably serpentinized peridotites, are expected to be generated in an hydrated mantle wedge during ablative subduction as it results by 2D numerical simulations of ocean/continent subduction systems (Roda et al., 2020).

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New insights on the Late Cretaceous S-verging thrusting in the central Southern Alps: clues from structural, geochemical, and geochronological analyses

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Keywords: Southern Alps, Late Cretaceous, U-Pb carbonate dating.

The central Southern Alps (cSA) represent the south-verging retro-belt of the Alpine chain, forming since the initial stages of Alpine orogeny. In the northern region, the Variscan basement was thrust onto the Permian-Triassic sedimentary cover along the Orobic Thrust during the Late Cretaceous, evidenced by the ages of pseudotachylytes (Zanchetta et al., 2011). Additional evidence of pre-Eocene Alpine compression is inferred from indirect cross-cut relationships between Eocene magmatic dikes trending E-W and thrust planes.

The absence of absolute ages can be attributed to the limited availability of dating techniques, until the last decade with the emergence of *in-situ* U-Pb dating on carbonates. Within the scope of the FAST PRIN project, this study aims to provide new evidence supporting the Late Cretaceous involvement of the central Southern Alps as a part of a doubly-vergent pre-collisional belt, as proposed by Zanchetta et al. (2012).

The examined carbonate-bearing structures in the central and southern regions of the cSA consist of growth fibers, veins, and calc-mylonites sampled along regional thrust planes deforming the Lower to Upper Triassic carbonate succession. The absolute ages obtained indicate a Late Cretaceous tectonic activity, superimposing with the Orobic Thrust. Sampling also targeted the Paleogene units within the exposed frontal part of the belt, yielding younger ages. Microstructural analyses were conducted on all samples using optical and cathodoluminescence microscopy. Furthermore, carbonate phases were characterized using O-C stable-isotope analysis, while paleotemperatures of fluids were inferred through microthermometry of fluid inclusions and X-ray diffraction analysis of sediments' clay-size fraction.

These findings confirm the involvement of the central Southern Alps in a Late Cretaceous pre-collisional belt and provide insights into paleo-fluid circulation during Alpine compression.

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Evolution of a rift-related mid-crustal shear zone: the case study of the Forno-Rosarolo shear zone (Ivrea-Verbano Zone, Southern Alps)

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Keywords: Forno-Rosarolo shear zone, Ivrea-Verbano Zone, Tethyan rifting.

Studies of rifted margins have benefited from an increasing quantity of high-quality data from several disciplines but the direct investigation of rift-related structures at the mesoscale is not so common and often the structures related to rifting processes lack of a complete characterisation.

The Ivrea-Verbano Zone (IVZ), in the Italian Southern Alps, represents a complete section of middle to lower continental crust, which records both the Variscan and subsequent Alpine Tethys rift-related tectonics (Beltrando et al., 2015; Simonetti et al., 2023).

One of the most important structures is the Forno-Rosarolo shear zone (Siegesmund et al., 2008). It is a NE-SW-oriented, subvertical shear zone made of metapelites, amphibolites, calc-silicates and granulites involved in anastomosed proto- to ultra-mylonite layers enveloping weakly deformed lenses (Simonetti et al., 2023). Mylonites formation postdate Variscan metamorphism and deformation and predate Jurassic brittle fracturing and faulting, locally associated with pseudotachylites.

In present day orientation, the kinematic indicators point to a sinistral sense of shear. Removing the Alpine tilt at high angle of the IVZ, this kinematic points to a former extensional shear zone. Investigations on the mylonitic flow kinematic reveal a non-coaxial deformation characterized by dominant pure shear (between 70% and 50%) and minor simple shear. Metamorphic conditions of the wall rocks vary from the upper amphibolite (SE, footwall) to the granulite facies (NW, hanging wall). Within the mylonites, PT estimate from mineral assemblage points to amphibolite facies conditions during deformation (~650°C and ~5.5 kbar).

Such kinematic data and metamorphic conditions allow to constrain the development of the Forno-Rosarolo shear zone mylonitic deformation, together with other similar structures of the IVZ, during the intermediate phase of the Tethyan rift (Beltrando et al., 2015; Simonetti et al., 2023) known as "thinning mode" (Manatschal et al., 2007). This stage was characterized by general shear conditions (pure shear between 70% and 50%) suggesting a phase of transition from a symmetric to an asymmetric configuration of rift.

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Orogenic wedge formation during obduction: insights, implications and new perspectives from the Oman Mountains

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Keywords: obduction, orogenic wedge, blueschist metamorphism.

Obduction is an uncommon plate tectonics process at convergent margins causing overthrusting of dense oceanic rocks on top of light continental units. Despite many conceptual models addressing both its initiation and the mechanisms allowing for the significant horizontal displacements of large rafts of oceanic lithosphere, obduction is only partially understood and remains quite an enigmatic process. Uncertainty remains on the triggering tectonic setting and the emplacement modes under mechanically unfavourable frameworks, with recent contributions stressing the role of far-field boundary conditions, such as the impact of bursts of "plate acceleration". Additionally, no research efforts have analysed the processes governing orogenic wedge formation in association with obduction and ophiolite emplacement, when complex orogenic architectures form during the imbrication of highly mobile and deformable slivers of continental crust underneath advancing, and possibly several kilometre-thick, ophiolitic successions.

The northeastern Oman Mountains allow studying one such orogenic wedge in the Jabal Akhdar Dome (JAD), a tectonic domain of Arabian Plate affinity that is now exhumed to the surface from beneath the allochthonous and far-travelled Semail Ophiolite. At odds with the general view, recent studies have shown that parts of the Arabian Plate therefrom experienced a complete cycle of subduction-exhumation concurrently with the Semail Ophiolite obduction in the Late Cretaceous, thus recording high pressure-low temperature (HP-LT) blueschist facies conditions of $\geq$ 0.9 GPa (based on aragonite in carbonates) and $\simeq$ 350 °C (Zuccari et al., 2023). On-going investigations confirm HP-LT conditions elsewhere in the JAD. Preservation of this metamorphic signature in the framework of the relatively undeformed external portion of the Arabian Plate calls for a re-evaluation (i) of the regional picture framing HP-LT metamorphism formation in the absence of obvious links with long-lived subduction or a major continental collision and (ii) of the mechanisms capable to exhume the HP-LT rocks and accrete them beneath the Semail ophiolitic sequence.

Preliminary structural, stratigraphic and metamorphic investigations within the JAD suggest a twofold history sequentially encompassing: 1) Cenomanian top-to-the NE imbrication and accretion under HP-LT conditions in the subduction channel of a SW-dipping Arabian Plate-directed subduction zone nucleating on transitional passive margin crust; 2) top-to-the SW lower-grade shearing during SW-ward thrusting and imbrication of the Hawasina nappes and the obduction of the Semail Ophiolite. This was triggered by an embryonic NE-ward intraoceanic subduction close to the Semail spreading centre, which set in motion the ophiolite thrust that, through >400 km of SW-ward transport, overrode the by-then failed subduction zone of 1). Finally, the current NE-ward Makran subduction zone initiated in the Paleogene.

Zuccari C. et al. (2023) - Forming and preserving aragonite in shear zones: First report of blueschist facies metamorphism in the Jabal Akhdar Dome, Oman Mountains. Geology, 51(5), 454-459.

The Sesia-Lanzo Zone in the Western Alps Subduction Complex: Alpine evolution and pre-Alpine remnants

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Keywords: Sesia-Lanzo Zone, Alpine subduction, eclogitization.

The Sesia-Lanzo Zone (SLZ) is probably the known largest worldwide subducted fragment of continental crust. It beautifully preserves the eclogite facies mineral associations and structures at all scales of observations.

It is well-known to show km-scale intrusive volumes, commonly of Permian age, that spectacularly preserve their igneous features but now replaced by metamorphic eclogite-facies minerals (e.g., Monte Mucrone and Lago della Vecchia). The almost complete eclogitization of the country rocks surrounding these Permian intrusive only locally preserve structures and mineral phases from the Permian high temperature granulite-migmatite stages, associated with an extensional tectonic regime. These pre-Alpine remnants are small, scattered and poorly preserved throughout the SLZ. We used a combination of structural analysis and minero-chemical investigations to discriminate between low- and high- strain domains inferring the Degree of Fabric Evolution and Degree of Metamorphic transformation ratios. This approach allows a more effective identification and mapping of remnants. The quantitative description has been performed combining micro-tomography associated with EMPA XR-mapping, geochemistry, geochronology and neutron texture analysis and comparing the results with numerical modelling outputs. The SLZ is part of the Western Alps Subduction Complex together with the Piemontese Zone and to the Rocca Canavese Thrust Sheet. These domains exhibit complex tectono-metamorphic histories of coupling and decoupling from extensional tectonics to burial and exhumation and show specific traces of tectonic erosion processes and the developed of tectonic mélanges. This area of the Alps provides an ideal setting for testing the reliability of continental crust subduction-related processes, as suggested by numerical modelling or crustal geology.

Fault architecture, age and deformation localisation history of the Mykonos Detachment, Cyclades, Greece

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Keywords: Aegean detachment system, K-Ar dating, fault architecture.

During the evolution of back-arc extensional systems, crustal-scale extensional detachments accommodate and aid the exhumation of even deeply subducted crustal slivers, promoting the formation of metamorphic core complexes. Such an evolution is often accompanied by the development of thick mylonitic shear zones that accommodate deformation at mid-to-deep crustal conditions. At the same time brittle fault zones form and slip at shallower crustal levels by cumulating important horizontal and vertical displacements over several million years, potentially through repeated and multiple slip events. An in-depth analysis of fault zone architecture, possibly coupled with the absolute dating of strain and deformation localisation, is therefore crucial for deciphering the long-lasting evolution of back-arc basins in active margins.

In order to provide new insights into those dynamic systems, we analysed brittle structures related to the propagation and evolution of the brittle Mykonos Detachment (MD), which is thought to have facilitated the emplacement of the Mykonos granite, which emplaced and finally exhumed at ~14 and ~9 Ma, respectively. The MD potentially accompanied this exhumation, after the former activation of the (ductile) Livada Detachment (LD), which favoured the beginning of granite unroofing. However, the age of the MD remains only loosely and indirectly constrained, and no absolute ages exist on the activation of the brittle MD, nor a detailed description of the internal architecture of the fault zone.

We carried out a detailed study coupling a Brittle Structural Facies (*sensu* Tartaglia et al. 2020) – based structural analysis with K-Ar dating on syn-kinematic illite from fault gouges that compose the MD fault core in the northern part of Mykonos Island. These gouges rest on and are cut by the MD principal slip surface (PSS), which represents the youngest analysed BSF. Four dated gouges yielded four different K-Ar ages, spanning from 9.3±0.4 Ma to 7.1±0.2 Ma. The results suggest that the evolution of the MD outlasted the exhumation of the granite (which ended by ~9Ma).

These new chronological data and the characterisation of the architecture of the MD fault zone, consistently with existing thermochronological data that indicate a rapid cooling of the granite from ~14 to ~ 10 Ma, stress the role of the MD during the unroofing of the granite, which, in this perspective, exhumed mostly assisted by the ductile LD, which acted before the MD. The latter acted instead only at a later stage, once the granite had exhumed to very shallow crustal levels and cooled to ~40°C, ~ 2Ma before the latest Late Miocene activation of the MD, as shown by our preliminary age constraints.

Tartaglia G. et al. (2020) - "Brittle structural facies" analysis: A diagnostic method to unravel and date multiple slip events of long-lived faults. Earth and Planetary Science Letters, 545, 116420.

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Open session on volcanic processes

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The 3ka Búrfellshraun lava flow field, Northeastern Iceland: lava dynamics and surface morphology

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Keywords: lava dynamics, platy-ridged surface morphology, Búrfellshraun.

The 3ka Búrfellshraun eruption is part of Iceland's North Volcanic Zone and has gained attention due to its platy-ridged surface morphology and as a terrestrial analogue to Martian flood lavas (Keszthelyi et al., 2004; 2006). Through comprehensive satellite mapping, geochemical analysis and studying syn-emplacement processes and surface features. This study provides insights into its eruptive history, lava dynamics and the formation of its platy-ridged surface morphology. Our results challenge the previous interpretations put forth by Haack et al. (2006) that the platy-ridged surface morphology in Búrfellshraun is a result of a major breakout event. The preservation of pahoehoe at the leading flow front and along the margins of the Búrfellshraun lava flow field contradicts the inference of a turbulent drainage from the core of the flow field: rather these evidence are suggestive of a slower, more nuanced formation process typical for pahoehoe. We propose that the formation of this surface morphology shares similarities with the processes that shape sea ice, and that this process is more widespread than previously recognized. In sea ice formation plates and pancakes, resembling a honeycomb or a polygonal pattern, emerge due to the interplay of temperature gradients and a wavy-motion behaviour. Similarly, we suggest that it may be a result of the interplay between lava temperature differentials and cooling mechanisms, as well as due to a wavy-motion behaviour of the liquid lava, probably generated by a pulsating activity of the vent. The ponding of lava within the graben where the Búrfellshraun eruptive fissure is situated played a role in setting up the right condition for the wavy-motion behaviour. Furthermore, field mapping along with image analyses of aerial photographs has revealed a striking absence of clear borders within the platy-ridged surface morphology. Notably, two distinct lava channels originating from different eruptive fissures are observed, yet no contact is observed in between these channels. This strongly suggests that the Búrfellshraun eruption was not a singular event, but rather a series of eruptions interspersed with brief cessation periods. This phenomenon is reminiscent of other Icelandic volcanic eruptions, such as the 1975-1984 Krafla Fires and the recent 2021, 2022 and 2023 Fagradalsfjall eruptions, where successive eruptions overlapped and obliterated contact between different lava flows. These new insights into the platy-ridged lava have implications for our understanding of the emplacement histories of Martian flood lavas.

Haack H. et al. (2006) - SAR mapping of Burfellshraun: A terrestrial analog for recent volcanism on Mars. J. Geophys. Res., 111, E06S13, https://doi.org/10.1029/2005JE002536.

Keszthelyi L. et al. (2004) - Icelandic analogs to Martian flood lavas. Geochem. Geophys. Geosys., 5, Q11014, https://doi.org/10.1029/2004GC000758.

Keszthelyi L. et al. (2006) - Flood lavas on Earth, Io and Mars. J. Geol. Soc., 163, 253-264, https://doi.org/10.1144/0016-764904-503.

Volcano- and chemostratigraphy of the calk-alkaline and peralkaline succession of Sulcis region, SW Sardinia, Italy: new pyroclastic units, redefinition of others, and improvement of the mapping of volcanic units

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Keywords: vulcano- and chemostratigraphy, Sulcis, SW Sardinia.

For more than 125 years the Sulcis region has been known as the site of outcropping of a complex sequence of volcanic (mainly pyroclastic) units, including an orogenic suite more complete in the north and central part of Sardinia, and several postorogenic peralkaline units restricted to the SW of Sardinia. This communication refers mainly to the middle and upper part (post-andesitic) of the volcanic succession. The great number of pyroclastic units and macroscopic similarity of some of them has traditionally created conflict in the identification and mapping of these units. Also, the correlation of the units in between the islands of San Pietro and Santo Antioco, and the Sulcis mainland was a permanent matter of discussion. Assorgia et al. (1990) provided the first formal definition of the volcanic sequence supported by 59 whole-rock analysis conducted at Universitat de Barcelona (UB). Successively this situation begin to change with the work of CarboSulcis SpA geologists and several university teams leading to the Sulcis mainland map (Assorgia et al., 1992). Additionally the pyroclastic comenditic units of the upper part of the succession were analyzed with modern methods (Assorgia et al., 1994). Over the last three decades most of the research by the Italian side has focused on CARG mapping. Independently, our group at UB conducted research including 3 Ms Thesis and 2 PhD thesis, leading to the production of a huge amount (718 whole rock, major and trace elements) of field, petrographical and geochemical data. This geochemical dataset is three times larger than the rest of available data, which has allowed us a better definition of the volcanic units and the improvement of their cartography.

Gisbert & Gimeno (2017) provided new geochemical criteria and a protocol for delimitation of pyroclastic units. This work updates that paper, by incorporation new data and significantly modifying the volcano- and chemostratigraphic succession. Particularly noteworthy are the revisions in the upper part of the succession, the San Pietro island sector and in the northwestern part of Santo Antioco island. This includes two new units at San Pietro island (Trachyandesite and Acquedotto units), the accurate placement by chronostratigraphy of the Punta dei Cannoni unit, identification of Pantellerite terms in the formerly named Comenditic unit (and mapping of up to 15 subunits in the Lower and Upper Comendite units). Furthermore, the formerly named Serra di Paringianu unit is redefined as Calasetta unit (as in fact initially was named, because of the locality-type of better expression). Lastly, a new Post-Calasetta unit is here identified for the first time.

This presentation aims to explain these key findings, as a preliminary step to the divulgation of new thematic maps for each of the three sites: the San Pietro and Santo Antioco islands, and the Sulcis mainland.

Assorgia A. et al. (1990) - Le successioni ignimbritiche terziarie del Sulcis (Sardegna Sud-Occidentale). Bol. Soc. Geol. It., 45, 951-963.

Assorgia A. et al. (1992) - Carta geologica in scala 1:50.000 del Distretto Vulcanico del Sulcis (Sardegna Sud-Occidentale). S.EL.CA. Firenze.

Assorgia A. et al. (1994) - Il complesso comenditico miocenico dell'entroterra sulcitano (Sardegna Sud-occidentale). Caratteri geologici, vulcanologici e petrochimici. Mem. Descr. Carta Geol. d'It., XLIX, 347-362.

Gisbert G. & Gimeno D. (2017) - Ignimbrite correlation using whole rock geochemistry: an example from the Sulcis (SW Sardinia, Italy). Geol. Mag. 154, 740-756, https://doi.org/10.1017/S0016756816000327.

A novel approach to assess magma ascent times through crystal zonation analysis

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Keywords: explosive, volcano, crystals.

Understanding the mechanisms governing magma ascent prior to eruption is crucial for hazard assessment and risk mitigation strategies. Traditional methods of assessing magma ascent times have relied on geophysical monitoring and petrological analysis of erupted materials although such techniques often lack the spatial and temporal resolutions required to precisely assess magma ascent times.

In this regard, crystals are a precious resource since they act as recorders of magmatic processes, accumulate distinct chemical and textural layers as they grow in response to changes in temperature, pressure, and composition along the ascent path.

In this study, we propose a combined methodology to infer magma ascent times by analyzing the size and complexity of the crystal zoning features through advanced techniques such as Laser Ablation-ICPMS, SEM imaging and validating them within a finite-element modelling of the magma flow within the conduit feeding system.

To do this, we select the well-studied Pomici di Avellino (PdA) eruption of Somma-Vesuvius (Italy) occurred approximately 3.9 thousand years ago, as described by Sulpizio et al. (2010) for which the conduit geometry has been indirectly derived (Massaro et al., 2018). We focused on the magmatic Plinian phase (EU2-EU3) considering different crystal size classes (from 125 mic to 2 mm). Preliminary results show interesting correlations between chemical elements for different crystal size populations.

Massaro S. et al. (2018) - Evolution of the magma feeding system during a Plinian eruption: the case of Pomici di Avellino eruption of Somma-Vesuvius, Italy. Earth Planet. Sci. Lett., 482, 545-555.

Sulpizio R. et al. (2010) - The Pomici di Avellino eruption of Somma-Vesuvius (3.9 ka BP). Part I: stratigraphy, compositional variability and eruptive dynamics. Bull. Volcanol., 72, 539-558.

Petrological evolution of the trans-crustal plumbing system of Marsili volcano (Tyrrhenian Sea, Italy): insights into crystal mush heterogeneity from glomerocrysts variability

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Keywords: Marsili volcano, magma differentiation, crystal mush.

Located in the Tyrrhenian Sea, the Marsili seamount is a submarine volcano that formed within a back-arc setting. Aiming to define the complexity of its trans-crustal plumbing system, we investigated the compositional and textural variability of crystal cargoes found within basaltic to andesitic lavas collected from three different sectors of the volcano (northern, axial, and lateral). Lavas erupted from the northern sector are only basalts and generally more primitive in character compared to lavas erupted from the lateral and axial sectors, the latter dominantly basalts and basaltic andesites with a broader variability in terms of mineral assemblage and chemistry. Crystal-poor andesitic magmas were only erupted at the summit axial sector of the volcano. The large abundance of glomerocrysts of different mineralogy and composition is a peculiar feature of samples from all these sectors, providing evidence of a laterally extended and petrologically heterogeneous crystal mush. Thermobarometric calculations performed on clinopyroxene coupled to mass-balance and thermodynamic modeling collectively support the petrographic evidence of a polybaric plumbing system, where relatively less differentiated basaltic magmas reside at depth (300-450 MPa, 1040-1080°C) and either feed eruptions at the northern sector or evolve to form andesitic magmas stored at shallow depth (< 250 MPa, 920-980°C) in the axial sector. Furthermore, basaltic and basaltic andesitic magmas erupted from the lateral sector testify to intermediate storage conditions (200-400 MPa, 980-1060°C). The variable content of incompatible (TAl and Ti) and REE in clinopyroxene contained in lavas from the three sectors relates to different undercooling conditions, with magmas erupted from the northern sector recording higher undercooling compared to those erupted from the lateral and axial sectors. The emerging scenario is that basaltic magmas erupted from the northern sector experienced a more rapid ascent (also testified by the occurrence of high-Fo olivine and dendritic clinopyroxene in the groundmass) compared to magmas erupted at the lateral and axial sectors, otherwise experiencing prolonged time within the crust.

The 1538 eruption at Campi Flegrei resurgent caldera: implications for unrest evolution and eruption hazard

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Keywords: caldera unrest, volcanic seismicity, Campi Flegrei.

The recent unrests in the Campi Flegrei caldera which began several decades ago, pose a high risk, in a densely populated area, due to the occurrence of large uplift, very shallow earthquakes of intermediate magnitude and possible evolution towards eruption. Given the high population density it is crucial, especially for civil defense purposes, to consider realistic scenarios for the evolution of these phenomena, particularly seismicity and potential eruptions. The eruption of 1538, the sole historical eruption in the area, provides a valuable basis for understanding how unrest episodes in this caldera, in particular seismicity, may evolve towards eruption. In this paper, we provide a new, reliable historical reconstruction and analysis of the precursory phenomena for the 1538 eruption, in the light of recent volcanological observations and results obtained in the last decades. We can then build a coherent picture of the mechanism and possible evolution of the present unrest, both in terms of expected seismicity, ground uplift and eruption. Our work points out two main alternative scenarios, providing a robust guideline for civil protection measures, and facilitating the development of effective emergency plans in this highly risky area.

Skarn formation associated with alkaline magma chambers: comparison of Somma-Vesuvius, Colli Albani and Merapi volcanic systems

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Keywords: skarn, Vesuvius, magma.

Skarn formation is common process when shallow magma chambers are emplaced in the carbonate basement. The thermo-metamorphic reaction of the magma with the surrounding carbonate-bearing host-rocks results in the formation of exoskarns, endoskarns, cumulates, exsolved fluids and differentiated melts. This process is well documented through mineralogical and geochemical studies of ejected skarns and cumulates and through fluid and melt inclusion studies of these samples. We compared the results of several studies on skarns associated with shallow alkaline magma chambers from three distinct volcanic settings: i) Somma-Vesuvius, ii) Colli Albani (both Italy) and iii) Merapi (Indonesia).

Our results indicate that the major mineral phases are very similar and do not reflect the changes in magma composition between the three systems. Instead, host-rock composition (Ca-rich limestone or dolomite) and the availability of a melt to assimilate the host rock define the major mineral composition. In already silica-undersaturated systems (here: Somma-Vesuvius and Colli Albani) the formation of Skarns drive the magma to an even higher degree of silica-undersaturation and enrichment of Ca and Mg in the melt. In parental magma s with higher SiO_2-contents (here: Merapi) skarn formation does not affect the major element magma composition and might only be recognized by isotope systematics like $\delta^{18}O$ and Sr-ratio. The accessory mineral assemblage crystallizes from the magmatic brines during magma cooling in which incompatible elements are enriched. Here it depends on the dominating volatile phase which minerals crystallize.

Plagioclase dissolution and reaction in a hydrous basaltic melt: a proxy for deciphering time scales of mixing events at Stromboli volcano (Italy)

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Keywords: plagioclase, dissolution, reaction.

Plagioclase is a widespread mineral component in basaltic magmas across all geodynamic settings. The physico-chemical (P-T-Xi) conditions of a magma primarily determine the stability field of plagioclase in silicate magmas and the composition of the An-Ab solid solution. For this reason, plagioclase is commonly used to decipher pre-eruptive conditions, whilst the diversity of textures and chemical zoning patterns of plagioclase phenocrysts can provide clues on the magmatic processes in active volcanoes. Several experimental works have constrained the stability and composition of plagioclase in hydrous basaltic systems, but only a limited number investigated the behaviour of plagioclase crystals under disequilibrium conditions. Here we present the results of time series experiments designed to constrain the time scale of plagioclase dissolution and reaction in a hydrous basaltic magma from Stromboli volcano (Italy). Experiments were performed at 1150°C and 150 MPa, under both anhydrous and hydrous conditions (H_2O = 2-3 wt.%) and with time varying from 30 to 240 minutes, using natural crystals separated and selected from basaltic mingled-pumices erupted during major explosions and paroxysms. The experimental strategy is based on the comparison of textural and chemical features of plagioclase phenocrysts before and after the dissolution-reaction experiment. Plagioclase dissolution is observed only at hydrous conditions and in phenocrysts characterized by a homogeneous (low-An) outer rim, whereas phenocrysts characterized by pre-existing (high-An) reaction rims show no evidence of reaction with the melt. The formation of the An-rich reaction rim testifies to a rapid chemical re-equilibration of the plagioclase with the hydrous silicate melt at the crystal interface. These reaction rims are very similar in terms of both texture and composition, to resorption bands occurring as concentric layers in natural phenocrysts. The width of crystal dissolution and the thickness of the reaction rim increase with the duration of the experiments following an exponential law. A linear regression derived from the experimental data permits to quantify the time scale of dissolution-reaction processes, simply by measuring the thickness of the reaction bands of natural plagioclase phenocrysts. Specifically, in the case of Stromboli volcano, reaction bands are attributable to the periodic interaction between a deeper volatile-rich magma (lp-magma) with a degassed magma residing at shallow depths (hp-magma). By employing this methodology, it is possible to identify characteristic time scales for mixing events occurring during the normal activity and preceding the more energetic explosions.

New evidence of syn-eruptive magma-carbonate interaction: the case study of the Pomici di Avellino eruption at Somma-Vesuvius (Italy)

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Keywords: Pomici di Avellino eruption, magma-carbonate interaction, carbonate assimilation.

Calithics are commonly found within the products of some explosive eruptions of Somma-Vesuvius, but their short-term contribution to the eruption dynamics has never been evaluated. The pumice fragments from the final phase of the Plinian fallout event of the Pomici di Avellino eruption contain abundant calcareous xenoliths. Previous works on that eruption, as resulting from numerical simulations, suggested that the release of CO_2 from the entrapment of carbonates may have prolonged the magmatic phase of the eruption by maintaining sufficient driving pressure in the feeding dyke.

The texture and thermo-metamorphic reactions of carbonate xenolith-bearing pumice fragments of the Pomici di Avellino eruption are analysed through petrography, scanning electron microscope images, energy dispersive spectrometer, and micro-computed X-ray tomography to deduce the behaviour of short-term carbonate-magma interaction and its contribution to the eruption dynamics.

Results show that calcareous xenoliths experienced short-term magma-carbonate interaction, which took place in three steps: i) ingestion, i.e., the physic-mechanical process of carbonate xenoliths entrainment, ii) decarbonation, related to high-temperature decomposition reaction, and iii) digestion or dissolution of the incorporated calcareous xenoliths into the melt with diffusion of Ca and Mg. The CO_2 released during the syn-eruptive decarbonation process thus provided extra volatiles to the rising magma, which may have maintained magma buoyancy longer than expected if only magmatic volatiles were involved in the eruption.

H_2O-CO_2 fluid infiltration and the Campi Flegrei unrest: from hydrothermal drying to shallow magma rejuvenation

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Keywords: H_2O-CO_2 fluids, magma rejuvenation, thermodynamics.

In the last two decades consensus has developed that the current unrest at Campi Flegrei caldera (CFc) involves or is even triggered by the arrival of magmatic gases. Different but reconcilable geochemical scenarios have sparked debates about the state of magma(s) releasing fluids, particularly the depth of the degassing magma(s). In a series of papers since 2013 (see references in Moretti et al., 2018; 2020) and based on data until 2016, coauthors and I have shown that such fluids were released by a ~8 km deep magma, whereas a shallow one at ~4 km has contributed through the 1982-84 unrest until year 2000, when it exhausted its volatiles. The volatile exhaustion of the shallow magma was related to its crystallization. In this scenario, the subsequent evolution until 2016 (based on data available at the time of publications) was mainly due to the infiltration of the deepest gases and their interaction with the hydrothermal system. It was also proposed that the progressive heating of the Solfatara hydrothermal system by CO_2-rich magmatic fluids was the main driver of the CFc unrest, essentially triggered by the thermoelastic response of the hydrothermal reservoir (Moretti et al., 2018). Several studies have recognized the role played by the double magmatic degassing reservoir. It is a fact that the chemistry of gases discharged at Solfatara fumaroles since decades bear a depth-varying magmatic signature which through time has differently modulated the hydrothermal interaction (e.g., Caliro et al. 2014; Buono et al. 2022). With reference to the recent unrest dynamics felt by population, the main in question has become whether the shallow reservoir at ~4 km is active or not which of course means whether it can be mobilized or not via a magmatic eruption. By using the data available from the current literature, in this contribution I show that gas ratios point to the drying of the bottom part of the hydrothermal system operated by a magmatic gas with H_2O:CO_2 proportions of about 70:30. However, whether this fluid is directly released from the 8 km deep magma or not, becomes secondary. Energy budgets coupled to phase equilibria show in fact that the heating process promoted by the deep fluid ascent may lead to the remelting of the shallow magmatic rock. The (re) forming magma will then buffer the fluxing volatile components, hence the H_2O:CO_2 gas composition released upward. How this process should affect the other gas ratios is then discussed.

In conclusion, we cannot discard the possibility that a shallow magma batch is rejuvenating or has already rejuvenated. Only the infiltration of a CO_2-rich fluid is required to reactivate a "ghost" magma at shallow depths. This process would occur in absence of clear geophysical evidence for magma migration and ascent from the 8 km deep caldera reservoir. This should be seriously considered for volcanic hazard assessment. Finally, I also speculate how such a process may have produced the 1538 CE eruption.

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Linking crystal textural and chemical features to pre-eruptive magmatic processes: insights from dynamic experiments on natural Mt. Etna trachybasalts

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Keywords: strain rate, crystallisation, magma dynamics.

Crystallization processes occurring in trans-crustal magmatic systems strongly influence magma rheology, conduit dynamics, and eruptive style. The presence of deformation fields within magma storage regions and plumbing systems can impact crystal nucleation and growth processes. Here we present novel experiments designed to investigate the effect of strain rates on crystal texture and zoning patterns, crystal nucleation and growth rate, mineral phase proportions, and the chemical composition of the residual glass. The experiments were carried out at controlled pressure and temperature conditions on natural trachybasalts from Mt. Etna. Mineral zoning was forced by oscillating temperature (1170-1130°C) at a constant strain rate ($1s^{-1}$) using a concentric cylinder viscometer. Major element single spot analyses and elemental maps were collected with an electron probe microanalyzer (EPMA) at the University of Geneva. The data were analysed using custom-built unsupervised and supervised machine learning algorithms (e.g., Hierarchical Clustering and Random Forest). We quantify the impact of strain rate on nucleation, growth, and mineral phase proportions through electron backscattered diffraction (EBSD) scans conducted at the University of Vienna. The EBSD analysis provide the strength of crystallographic preferred orientations (CPO), with plagioclase CPO used as a proxy for the degree of deformation experienced by the crystals in different regions of the experiments. The experimental results show that a small increase in strain rate can lead to a large increase in nucleation rate and thus in crystal number density. This process has a direct influence on the growth competition between different mineral phases, controlling their growth rates, the final proportion of mineral phases, and the composition of the residual melt. These results highlight the need to take deformation processes into account when linking textures and chemistry of volcanic products to pre-eruptive magmatic processes and emplacement dynamics.

Solid-state synthesis of calcosilicates mimics pyroclastic rheomorphic rhyolitic- xenolith interaction in the Monte Ulmus peralkaline unit (SW Sardinia, Italy)

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Keywords: calcosilicates, solid-state synthesis, powder X-ray analysis.

The Upper and Middle part of the volcanic Miocene succession in Sulcis region is mainly built up by pyroclastic units rhyolitic in composition. Most of these units are of ignimbritic type and some of them present a syndepositional rheomorphic basal vithophyre (Gisbert & Gimeno, 2017). Basal vithophyres correspond to high temperature flows (i.e. of boiling-over type, see i.e. Gimeno et al., 2003) and are more ubiquitous in the postorogenic peralkaline upper part of the succession. An example of this is the pyroclastic Monte Ulmus comenditic unit; this unit marks a sharp compositional change within the peralkaline part of the volcanic succession. The lower part of this unit contains abundant xenoliths that can be related (taking into account our current knowledge of the tridimensional geologic framework at Sulcis region) to the host rock into the upper part of a shallow magmatic chamber. Previous petrographic, mineralogical (XRD) and isotopic study (Carrazana et al., 2018) has shown that calk-silicate xenoliths came from the Lower Cambrian carbonatic platform of Iglesiente-Sulcis. At that stratigraphic level other constituents (mainly clay-rich and siliciclastic material from Precambrian and Lower Cambrian) are also present, but are not considered here. Different solid-state synthesis experiments were prepared in order to determine the conditions and reaction times of the calcosilicate pyrometamorphic paragenesis found in the more reactable protoliths of a presumed starting carbonatic composition. A stoichiometric Monte Ulmus-like typical composition was created from natural and synthetic reactants (limestone, Tripoli, hematite, 700°C calcined metakaolin, Na_2CO_3, and KCl).

The tests were carried out in a solid state and different runs at 400-550-650-700-750-850°C and atmospheric pressure, with relative proportions between the theoretical magma and carbonate rocks (1:1 to 1:05). The reaction times were from 12 to 504 hours. In the paragenesis found at 400 and 550°C, the amorphous silica has just crystallized (cristobalite and quartz or exclusively quartz if it is a lower content of limestone). The runs at 650°C show the beginning of the vesuvianite formation. At 700°C wollastonite, vesuvianite and diopside were formed. Runs at 750°C show the gradual replacement of quartz by tridymite. Finally, run at 850°C shows the persistence of quartz-wollastonite with minor proportions of amorphous phases. All these experiments are in good agreement with published data and are compatible with short reaction times and natural paragenesis. The expected range of temperature in peralkaline rhyolitic rocks fits well with the absence of diopside and wollastonite in the paragenesis and experimental data (Novembre et al., 2018), while it has been described i.e.in carbonate xenoliths present in basaltic lavas and plugs. These data provide new criteria for successive synthesis experiments looking for minor present phases in xenoliths (i.e. grossular garnet).

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Alkali feldspar dissolution kinetics in trachytic melts

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Keywords: alkali feldspar, dissolution kinetics, trachyte.

Mineral dissolution is an important process in magmatic systems, as it can affect the remobilization of cold reservoirs, magma transport dynamics, and magma ascent rates. Investigating the dissolution kinetics of minerals is important to constrain the timescales of the crystal-liquid interaction and mineral resorption rates at magmatic conditions.

Previous studies have investigated mineral dissolution in silicate melts focusing on clinopyroxene (Neave & Maclennan, 2020; Bonechi et al., 2021) olivine (Donaldson, 1985; Chen & Zhang, 2008), plagioclase (Donaldson, 1985) and quartz (Donaldson, 1985). However, dissolution of alkali feldspar has not been investigated. For this reason, we performed melting experiments to investigate alkali feldspar dissolution in trachytic melts at high pressure and high temperature conditions.

Our experimental results are relevant for magma transport dynamics and magma ascent rates in trachytic magmatic systems.

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Monitoring fumarole emissions on the flanks of mount Etna and correlation with volcanic activity

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Keywords: lava fountains, volcanology, carbon dioxide.

Etna's activity over the last ten years has been characterized by intense explosive activity with numerous lava fountains.

In order to test new monitoring parameters for monitoring volcanic activity at Mt. Etna, a geochemical station for the measurement of soil CO_2 concentrations was first installed in 2019 for one month into a vent formed in 2002 along the North-East rift, at altitude of 2450 m asl. The 2002 vent was chosen because inside it there are some steam fumaroles characterized by large gas emissions both of CO_2 and of CH_4.

In 2019 it was observed that shortly before a strong explosive episode on 8 September at the NE summit crater there was a decrease in measured CO_2 concentrations that could not be attributed to changes in environmental factors (mostly wind speed and barometric pressure). In that occasion, the observed fluctuations could be related with the fast dynamics of magmatic fluids into Etna's conduits. In the following years we had the opportunity to test and better evaluate that preliminary hypothesis, as numerous paroxysmal episodes occurred on Etna.

It is noteworthy that during the first two years of the station operation, until about mid-July 2021, CO_2 anomalies (mostly in terms of strong and short-lived negative peaks) were systematically followed after about 24-48 hours by increases in volcanic activity in the summit craters (Strombolian activity at Northeast Crater in 2019 and Strombolian activity at Southeast Crater in 2020) or by more intense eruptive events (as in the case of the 2021 cycle of paroxysms at the Southeast crater.

From this point of view, negative CO_2 anomalies are interpreted as due to sudden movements of gas-rich magma from a reservoir located between 1 and 6 km below sea level towards a shallow reservoir located between 1 and 2 km above sea level.

Finding the best protocol to characterize the rheological behavior of fine volcanic sediment suspensions

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Keywords: rheology, lahars, fine suspensions.

The rheological characterization of fine sediments suspensions has been carried out over time through various rheometers geometries. The geometries can be classified in absolute and relative geometries. The absolute geometries, such as concentric cylinders, plate-plate and cone-plate can vary depending on the measuring gap and the size of the tools. These scales determine the sample volume, the maximum sediment size, and the strain condition (range of shear rate) applied as well as the measurement time. Most studies on the rheological characterization of fine sediments suspensions have been performed in small-scale rheometer geometries, which consist of a gap of a few millimeters between the measurement systems. One requirement for employing this measurement scale is that the gap must be at least 10 times greater than the largest particle size of the material. So, the selection of the best protocol for the rheological characterization of fine sediment suspensions is not trivial; it depends on the rheometer geometries and on the sample conditions. Numerous works have aimed at constructing and discussing theoretical models that allow to describe the rheological behavior of fine sediment suspensions. Throughout this work, a comprehensive database of the principal rheological properties (viscosity and yield strength) has been compiled by collecting the work of various authors from the academic literature. The database comprises measurements of samples with a maximum clast size of 63 microns (silt and clay) and small-scale geometries with various shapes. A significant variability in the measurement protocols proposed by different authors was observed (O'Brien & Julien, 1988; Jeong, 2010). From this database, arose the need to establish an appropriate protocol for the rheological characterization of homogeneous suspensions of volcanic sediments from lahars of the Popocatepetl volcano, Mexico. The samples were collected from deposits of representative eruptive events, which are classified as the three lahar hazard scenarios (Martín-Del Pozo et al., 2017). Those hazard scenarios are established based on their magnitude and probability of occurrence (low, medium and high probability). Also, they were related to different compositions of clasts, mainly composed by pumice, pumice and lava, and lava fragments. Therefore, knowing the rheological behavior of these volcanic sediment suspensions will allow us to go deeper in particle transport and sedimentation processes inside different types of lahars to propose a transport and sedimentation model for these eruption events. As an initial result of this research, we compared data obtained using our proposed measurement protocol for the rheological characterization of fine volcanic sediment suspensions in an Anton Paar rheometer (small-scale concentric cylinder geometry) with those from a Fungilab viscometer (Tranquilino, 2023), under similar conditions. We discuss the instruments' advantages and disadvantages, along with proposed improvements to the measurement protocol.

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S53.

Open Poster Session

CONVENERS & CHAIRPERSONS

Sandro Conticelli (Università di Firenze)

ISOBatA's contribution and strategy to Antarctic Seabed Exploration

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Keywords: bathymetry, anderway data, Antarctic.

The ISOBatA project, supported by the Italian National Antarctic Research Program (PNRA), is designed to enhance knowledge of the Antarctic seabed in crucial areas for the Italian Antarctic community and contribute to the Seabed2030 and the International Bathymetric Chart of the Southern Ocean (IBCSO) initiatives (Dorschel B. et al., 2022).

Over the last three PNRA expeditions, the project utilized voyages of the R/V Laura Bassi between Antarctica and New Zealand to focus on opportunistic data collection in geodynamically significant areas, such as the Macquarie Triple Junction and the Emerald Fracture Zone, as well as in relevant zones at the Italian mooring sites in the Ross Sea (MORSEA observatory and LASAGNE project), critical to investigate oceanographic patterns and dynamics. Our main objective was to optimize data collection during transit times by adapting our methods to the constraints of each expedition, without compromising other research projects. ISOBatA allocated dedicated ship time to reduce speed and redirected navigation along designated corridors to explore uncharted regions. Strategic replanning, using the IBCSO coverage map and metadata from prior PNRA expeditions (e.g., Seismic Data Library, PNRA Core Sites), enabled us to enhance our data collection techniques. We acquired comprehensive datasets, including bathymetric, magnetometric, sub-bottom profiling, and ADCP data. Established best practices and workflows ensured high-quality data acquisition, processing, analysis, and archiving.

Peliminary results include:

A discrepancy of up to 1200 meters, compared to the IBCSO map, in the proximity of the Emerald Fracture Zone, featuring a masked tectonic structure. This highlights how gaps in bathymetric knowledge can obscure our understanding of geodynamic processes.

In the Ross Sea, the strategic use of metadata from previous PNRA surveys was instrumental in our planning process, allowing for a more nuanced understanding of the complex interactions between the seafloor, ocean currents, and ice sheets. Particularly at the Mooring G sites, spiral geometries, carved by gouging icebergs, show the interaction of tidal rise and geostrophic currents on huge icebergs paths (Newton et al., 2016).

The expeditions highlighted the challenges of high speed underway data collection, especially in regions frequently affected by adverse weather as well as sea ice, which sometimes compromised data quality for comprehensive mapping. Nonetheless, the dataset not only fills significant bathymetric gaps but also enhances our understanding of the surveyed areas. This experience underscores the importance of adopting appropriate best practices and workflows tailored to the expeditions aims, weather condition, the geomorphological setting of the study areas and available dataset.

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Investigation on bioaugmentation as a sustainable alternative to chemical fertilizers: preliminary results

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Keywords: nitrate, bioaugmentation, fertilizers.

Intensive farming practices can negatively impact the environment, with consequences on both soil and water quality. As an instance, excessive fertilizer use and animal manures can be primary sources of nitrate leaching into groundwaters. High nitrate concentrations can cause adverse effects on human health and impacts aquatic ecosystems by promoting algae growth and depleting oxygen levels in water bodies (Sing & Craswell, 2020). To mitigate nitrate contamination, various strategies can be employed, including improved agricultural practices (e.g., precision farming and reduced fertilizer use), and proper waste management (Power et al., 2001). Plant Growth-Promoting Bacteria (PGPB) are beneficial microorganisms that colonize the rhizosphere and enhance plant growth and health through various mechanisms. PGPB exert positive effects on plant growth by facilitating nutrient uptake (e.g., nitrogen fixation, phosphate or potassium solubilization), producing phytohormones, and enhancing tolerance to biotic and abiotic stresses (e.g., pathogens, drought, salinity) (Pathania et al., 2020). The present study investigates the effect of bioaugmentation on plant growth and soil/water quality, with the aim to assess the potential use of biofertilizers as substitute for chemical fertilization and the consequent advantageous for both farmers and environment. For this purpose, a tailored microbial formula, composed by eight indigenous strains selected from a soil sampled at Cooperativa Santa Margherita (SW Sardinia, Italy) for their PGP functions, was developed as biofertilizer. The comparison between bio and chemical fertilization effects on plant productivity was performed by means of greenhouse experiments carried out with several tomato varieties (i.e. Camone, Oblungo, Cherry) and the same soil used to develop the PGPB formula. Results indicated that bioaugmentation may substitute chemical fertilizers without compromising yield, thus improving the sustainability of the agroecosystem (Paganin et al., 2023). Ongoing greenhouse pot experiment aims to assess the effect of the different above-mentioned fertilization methods on both plant growth and productivity (plant height, fruit weight and number) and quality of percolation water (e.g., nitrate concentrations). Greenhouse pot experiment will be carried out using different soils: i) the soil sampled from Pula (Azienda Agricola Siclari Gianfranco) and ii) a second one collected from an area (Campidano area, SW Sardinia, Italy), interested by intensive agricultural practice and groundwater nitrate pollution. Achieved results will be very useful to implement sustainable agricultural practices, i.e. to reduce the use of chemical fertilizers and optimize the use of PGPB for enhancing crop sustainability, allowing agriculture to move towards more eco-friendly practices thereby enhancing soil and water health.

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Middle Triassic tetrapods: a triumphant faunal return after the Permo-Triassic mass extinction

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Keywords: Middle Triassic, Permo-Triassic mass extinction, tetrapod fossil record.

The aftermath of the Permian-Triassic Mass Extinction (PTME) left Earth's terrestrial ecosystems in disarray, with only a fraction of species surviving the biotic crisis. The Early-Middle Triassic transition witnessed a gradual recovery, characterized by the emergence of novel ecological niches and the establishment of more complex ecosystems (e.g., Bernardi et al., 2017; Romano et al., 2020). This contribution presents the findings of a comprehensive review of Middle Triassic terrestrial tetrapod faunas worldwide, through a semi-quantitative taxonomic analysis approach to elucidate patterns of diversity and distribution. Our results delineate three primary clusters: firstly, the Gondwanan fauna in the Southern Hemisphere, dominated by therapsids, showing a similar distribution to that of the Late Permian and the Early Triassic; secondly, the Asian fauna, spanning Russian and Chinese regions, clustering with the Gondwanan fauna, as opposed to the results obtained for the Early Triassic (see Romano et al., 2020); lastly, the European-North American-North African fauna, occupying the Western part of the Northern Hemisphere, exhibiting dominance by derived archosauriforms and lepidosauromorphs. The highest biodiversity is observed in the Northern Hemisphere sub-equatorial zone, reminiscent of Late Permian patterns. Temnospondyls, though ubiquitous, display a preference for higher warm-temperate latitudes across hemispheres. Avemetarsalians are notably present in both the North-Western and Gondwanan faunas but are absent in Asian regions. Pseudosuchians are predominant in the Northern Hemisphere, showing an antithetical distribution to therapsids. By visually delineating the biogeographic distributions of terrestrial tetrapod groups, our contribution aims to provide a clearer understanding of how the recovery shaped the evolution and establishment of stable terrestrial ecosystems during the Middle Triassic.

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A geological and geotechnical modelling of Alpine sulphates: the SALT project

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Keywords: sulphates, tunneling, Alps.

The excavation of underground infrastructures in geological sequences containing sulphates represents a tough challenge. Excavation indeed causes swelling phenomena, water weakening, creep deformation and karst phenomena in these rocks, leading to technical problems that are nowadays not completely addressed. However, the deformation mechanisms and behavior of the evaporites are not perfectly understood and modelled, and this arises problems in ground-support designs to geo-engineering projects especially in tectonically complex areas such as the Alpine orogenetic belt. In the Alps, masses of evaporite, mainly consisting of sulphate minerals, acted as main décollement units in the growing of the belt and now outcrop all over the arc mainly in correspondence of main regional shear zones. Alpine evaporites usually have irregular lateral continuity and variable thickness through the mountain chain due to the complex tectonic history and their mechanical response need to be evaluated contextually to the complexity of fracture network and 3D geometries.

In this contribution we present the first results obtained by the recently started SALT project (MultiScale and interdiSciplinary characterization of Alpine sulphates for geologicaL and geotechnicaL modeLing: applications for Tunneling and underground energy sTorage - PRIN bando 2022), aimed at investigating the sulphate units of the Alpine chain. The project focuses on two selected sites in High Susa Valley (Western Alps) and Brenner region (Eastern Alps), and merges several approaches and investigation scales:

- the 3D geometries and volumes of sulphates will be estimated through on-site geological and geo-structural surveys;
- the mechanical behavior of the material will be experimentally assessed at the laboratory scale through compression tests;
- the miner-petrographic and micro-structural characteristics of the rock will be investigated through analytic techniques (namely, scanner electron microscope with energy dispersive spectroscopy - SEM-EDS - and X-ray powder diffractometry);
- the micro-mechanisms involved in the swelling process will be studied by X-ray computed tomographies.

The integration of these different data will offer a thorough understanding of the behavior of the investigated sulphate units, producing new theoretical perspectives on the geomechanics of these materials. This will represent a fundamental contribution for risk mitigation in underground infrastructures, including tunnels and salt caverns.

Exploring the relationship between the microseism long-term energy trend and wave power in the Mediterranean Sea during the period 1996-2023

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Keywords: microseism, Mediterranean Sea, climate change.

In this study, we combined seismic data collected from nine stations installed along the Mediterranean coastal areas with the wave characteristics derived from hindcast data spanning from 1 January 1996 to 15 October 2023. Specifically, we explored the relationship between microseisms (the most continuous and ubiquitous seismic signal on the Earth generated by the interaction between the hydrosphere, atmosphere, and solid Earth) in terms of spectral properties, root mean square amplitude time series, and microseism power spectral density, and the main sea wave features (e.g. significant wave heights, wave periods, and wave power that is an indicator of wave energy). To investigate the correlation between microseisms and sea conditions, we performed a correlation analysis between the root mean square amplitude time series and significant wave height time series across the entire Mediterranean Sea from 1996 to 2023. Moreover, to identify significant variations in microseism amplitude and wave power associated with climate change and their interrelation, we determined long-term trends for both microseism energy and wave power by using singular spectrum analysis algorithms. In addition, we calculated the Spearman correlation coefficient between the microseism energy and wave power trend time series to explore the relationships among these two parameters.

Despite the limited number of stations used in this study (just nine), which is insufficient for robust statistical analysis, our exploratory analysis provides insights into the potential of microseisms and their relationships with sea states and wave power over the long term analysis. This research serves as a pioneering effort for the Mediterranean Sea region. With the recent expansion in the number of seismic stations, increased data-sharing, and the escalation of climate-related extreme events, the findings from this study can be further refined and expanded in the future to enhance coastal monitoring efforts both in the Mediterranean Sea and at a global scale.

Mapping of *Posidonia oceanica* meadows in the Capo San Marco offshore (Sciacca, Sicily): evaluation of the lower limit using geophysical methods

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Keywords: habitat mapping, Posidonia oceanica, Sciacca offshore.

Posidonia oceanica, one of the most important and abundant endemic seagrass in the Mediterranean Sea, forms large meadows from the sea surface down to about 40 m, colonizing rocky and sandy substratum. Environmental factors (e.g. salinity, temperature, turbidity, chlorophyll A) influence the spatial configuration of *P. oceanica* meadows. In particular, the literature suggests that the increase in turbidity results in a decrease in lighting and, consequently, the rising of the lower limit of the seagrass meadow.

In this work, we map the *P. oceanica* meadows in the Capo San Marco offshore (Sciacca, Sicily), using geophysical data acquired by a Side Scan Sonar (SSS) and Multibeam sonar system from about 20 m to 45 m of water depth. Several video and photo images were acquired in selected locations to validate acoustic data. SSS images revealed the presence of acoustical facies related to rocky substratum colonized by the *P. oceanica* as patchy zones and dense, extensive meadows. An anomalous signal of the multibeam image overlaps to with the SSS acoustical pattern, revealing that the *P. oceanica* meadows extend up to about 35m of water depth. This value represents the lower limit of seagrass meadows in the Capo San Marco offshore and differs from the depth of 25 m documented in the literature (Andaloro et al., 2007; Perzia et al., 2011). Photo and video images, acquired up to about 33 m of water depth, showed *P. oceanica* meadows of turbid water and zones of widespread suspended sediments.

This research documents the deepening of the lower limit of the *P. oceanica* in the study area, which is a key factor in evaluating the extension/regression balancing of the meadows. Also, this work would imply a re-evaluation of the influence of the turbidity in the *P. oceanica* growth and could allow for a better estimate of the extent of meadow in turbid water.

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Coastal boulder production controlled by columnar joints of ignimbrite and extreme waves along the high-energy rocky coast of Pantelleria Island (Sicily Channel, Mediterranean Sea)

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Keywords: coastal boulders, columnar joints, extreme waves.

Coastal boulder accumulations are the result of the detachment of blocks from the rocky shore platform, their transport and deposition along the coastal area under the action of extreme waves. We examined the distribution, dimension, geometry and lithology of boulders detected in the volcanic island of Pantelleria (Sicily Channel, Mediterranean Sea), highlighting the relationship between the boulder production and the volcanic rock features (i.e., columnar cooling fractures and horizontal layers defined by ignimbrite flows). We used geological data for 125 boulders and 21 rupture surfaces, integrated with the fracture analysis, two radiocarbon dating, numerical hydrodynamic analysis, and hindcast numerical model of the wave characterization. The boulder field extends up to ~60 m from the shoreline of Punta Sidere (NW coast of Pantelleria) and consists of isolated blocks or groups elongated obliquely, perpendicular or parallel to the coast. Boulders are composed of ignimbrite and, to a lesser extent, basalt. The average dimension is ~120×85×40 cm on the major (A), medium (B), and minor (C) axes, respectively. Boulders were dislodged from the rocky platform as suggested by 1) the correspondence between the lithology of boulders and the rocks outcropping along the coast and 2) the compatibility between the shape of the boulders and the rupture surfaces carved out in the rocky platform. The morphometric analysis of the characteristics of boulders and outcropping rocks demonstrates that the columnar fracture set and the thickness of horizontal planes within the ignimbrite flow controlled the polygonal surfaces and size (A- and B-axis) of the boulders and their thickness (C-axis), respectively. The numerical hydrodynamic analysis indicates that the quarrying, transport and deposition of boulders was mainly the result of storm events characterized by wave heights ranging from ~2 m to ~8 m. The comparison between the storm wave heights computed by hydrodynamic equations and the results of the hindcast numerical model confirms that the waves approaching the coastline can reach heights of ~8 m. The storm events occurred at different times, even very recent, as suggested by two radiocarbon dating of biogenic encrustations collected from the boulders surface and presence of woods and plastics embedded within the boulder deposits.

The evolution of the Mortorio submarine canyon (Eastern Sardinia Margin): preliminary ideas from a process-oriented morphologic interpretation of a shelf-indenting canyon

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Keywords: submarine canyon, morphology, sub-bottom profiles.

In this contribution we present an initial interpretation, resulting from a Master's degree thesis work, of the processes that contribute to the shaping of a submarine canyon located along the Sardinian Margin. In particular, our poster focuses on the study of the Mortorio Canyon located along the Eastern Sardinian Margin. Our analysis has been carried out through the integrated interpretation of multibeam bathymetric data and CHIRP sub-bottom profiles.

The Mortorio submarine Canyon, located in the northeastern part of the Sardinian margin, has its head 15 km from the coastline, deeply incises the external shelf and then mostly develops in the Olbia Basin slope.

A preliminary morphological analysis was carried out to identify the elements that could be represented in a morphologic map in order to highlight the processes that have contributed to the evolution of the canyon. This has led to the construction of a legend were all the erosional and depositional features in the canyon head, flanks and floor are symbolized. Successively, the interpretation of the canyon morphology was complemented with the analysis of CHIRP sub-bottom profiles. The latter allowed the analysis of the most superficial layers of the seabed, the definition of their character and geometries and the interpretation of their sedimentary significance. In summary, the present analysis sheds light on the processes -landslides, gullying, axial thalweg entrenchment, bottom currents- that lead to canyon excavation. It shows that also depositional processes occur in some portion of the Mortorio Canyon. Our analysis highlights a complex spatial interplay of erosional and depositional processes that leads to marked longitudinal variations in the morphologic architecture of the canyon. Thus, it can aid in the interpretation of similar environmental settings in fossil examples exposed on land or imaged on seismic data. The preliminary results of the Master's degree thesis may contribute to the definition of the geological hazard associated with a canyon. In addition, they show the large variability of environments that must be considered when addressing studies on biodiversity development in submarine canyons.

Drone remote sensing and geopedological analyses for precision farming viticulture in the area of Montalcino (Siena, Italy)

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Keywords: precision agriculture, UAV remote sensing, vineyard crops health management.

Precision agriculture has emerged as a crucial approach in modern farming, leveraging advanced technologies to optimize crop management practices (Samreen et al., 2022). Among these technologies, remote sensing plays a pivotal role in providing valuable insights into crop health and facilitating informed decision-making (Khanal et al., 2017). This article explores the integrated use of remote sensing techniques and geopedological analysis for studying vegetation health, focusing on vineyard crops in Montalcino area (Siena, Italy). In this context, the utilization of drones equipped with multispectral and thermal sensors allowed the creation of thematic maps, which provide valuable information on crop health, soil moisture content, and water stress. These data serve as input for the generation of prescription maps for either irrigation or fertilization, enabling precision agriculture practices tailored to specific crop requirements (Sishodia et al., 2020). However, despite the potential benefits, further research is needed to deepen remote sensed info and to address relevant mathematical indices for disease identification, water content assessment, and water quality evaluation (Hunt & Daughtry, 2018). Close-range hyperspectral data can be particularly useful in this regard, allowing for the identification of wavelengths correlated with vegetation health indicators and soil moisture content. Moreover, remote sensing enables the estimation of soil moisture variability, facilitating the differentiation of areas with high electrical conductivity due to either water content or clay minerals. Achieving optimal soil moisture content is essential for agricultural productivity and water conservation efforts, especially in the context of climate change adaptation and socio-economic dynamics. By integrating remote sensing and laboratory geopedological analyses, precision agriculture practices can contribute to sustainable farming production while addressing challenges related to water scarcity and climate variability.

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Natural sections of incised valleys partly filled by late Quaternary alluvial deposits perched on rocky sea-cliff of Gargano (Apulia, Southern Italy)

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Keywords: Quaternary alluvial deposits, Gargano.

Gargano is a morphostructural karstic high of Apulia (Southern Italy) affected by severe uplift and active seismicity. Locally, due to uplift, alluvial deposits perched on rocky sea-cliff cutting incised valleys may be observed along the eastern coast of Gargano. Up to about 20 m-thick natural sections exposed at Mattinatella locality show that alluvial sediments alternate with eluvial/colluvial deposits, in which several generations of paleosoils and some tephra layers may be observed. According to preliminary age obtained by some handmade objects found in a soil layer, studied sections should represent the sedimentary record of the last glacial period, probably characterized by a significant rate of relief erosion and by active sedimentation at the toe of the morphostructural karstic high. Present-day alluvial basins seem to be starved and the main active process is the erosional retreat of sea-cliffs. A detailed facies analysis, currently in progress, and new awaited dating could contribute both to better understand the sedimentological evolution and to constrain the age of these continental deposits.

From waste to resource: recovery of quarry by-products for zinc foliar fertilization

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Keywords: zinc biofortication, zeolite and pumice, rain leaching.

Zinc (Zn) is an essential micronutrient for plants, particularly involved in bolstering disease tolerance of crops. When plants require more Zn than the amount available in the soil, using Zn fertilizers (biofortication) becomes essential (Cakmak, 2008). However, conventional methods often rely on soluble Zn salts, that once applied to the soil are easily subject to complexation with soil components or precipitate, becoming unavailable to the root system. Even when applied as foliar treatments, these salts (commonly $ZnSO_4$) are prone to leaching (Chen et al., 2022).

We therefore propose a novel controlled-release formulation that involve the adsorption of Zn in reactive zeolites: mineral phases known for their capacity to separe and recover cations from aqueous solutions (e.g., Galamini et al., 2024), and their subsequent use as carriers for Zn foliar application. The process involves the reutilization of mine wastes (pumice and lapillus) along with zeolitized tuff. Different proportions have been tested for Zn adsorption, and the subsequent release, identifying a 70% zeolite-rich tuff and 30% pumice (containing significant amount of zeolite species) as the most viable.

A greenhouse test was performed on Vitis vinifera, comparing the most promising formulate with conventional $ZnSO_4$. The aim was to assess differences in the permanence of Zn on plant leaves after several treatments and a simulated rainy event. The results showed a greater resistance of the formulation respect to conventional $ZnSO_4$, also concurrently suggesting the potential for dosage reduction. Furthermore, the incorporation of 30% pumice scraps in the formulate may allow to revaluate important fractions of mining byproducts.

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Climate variations and crop yields: a sustainability issue illustrated by a case study from the Abruzzo region, Italy

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Keywords: climate variations, crop yield, climatic trend, correlation analysis, sustainability.

Climate variations, of short- and long-term, pose a major sustainability challenge, with potential far-reaching economic and social impacts, including fluctuations in agricultural yields and subsequent volatility in prices and the availability to populations of essential food resources. To investigate the effects of short- and long-term climate variation on crop yields, the four provinces of the Abruzzo region, in central Italy, were studied in terms of temperature, precipitation and agricultural yields of wheat, olive and grape.

This study illustrates a detailed statistical analysis involving climatic variables and crop yields over the time range 1952-2014, at a provincial scale in the Abruzzo Region. To individuate variations in the correlation between agricultural production and climatic condition over time, the statistical correlation was analyzed between indices, such as standardized precipitation indexes (SPI and SPEI) calculated over different months of the year, with the oscillations of crop yield around the trend, described by standardized residual yield series (Guerriero et al., 2023). Such correlation has been calculated for several time windows, each of thirty years wide, over the time range 1952-2014.

The results are summarized as follows:

- In the studied provinces, the maximum and minimum daily temperatures show variation in the trend over the past 60 years;
- In the studied provinces, climate is moving from temperate towards temperate-arid, with an increase in drought intensity and persistence, starting from the 1980s;
- The correlation analysis highlighted an increase in correlation between crop yield and climatic fluctuations, over the past 60 years. Such rise can be interpreted as an increasing sensitivity of the agricultural production system to climate fluctuations, over time.

Although the considered agricultural production system exhibits a progressive yield growth, an increase in correlation between production and climatic fluctuations highlights, on the one hand, an inability of the system itself to maintain high performance even in unfavorable climatic conditions. On the other hand, yield fluctuations (even positive ones) always represent a potential disturbing element of related market equilibria.

Guerriero V. et al. (2023) - Impact of Climate Change on Crop Yields: Insights from the Abruzzo Region, Central Italy. Sustainability, 15, 14235, https://doi.org/10.3390/su151914235.

From emplacement to exhumation of a granitic intrusion in a highly extended continental crust: insights from the Pliocene Gavorrano granite (Northern Apennines, Italy)

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Keywords: magma emplacement, granite exhumation, Gavorrano pluton.

Granites emplaced in the upper crust during Neogene-Quaternary, and now exposed at the surface, bear witness to fast or rapid exhumation and can provide insights to understand the relationship between magmatism and exhumation. Unravelling the depth and timing of their emplacement and the processes favoring their exhumation, has become worthwhile. Recent chronological constraints on cooling histories indicate that extremely high rates of tectonic exhumation are feasible, particularly during late orogenic extension when crustal anatexis, detachment faults and thermo-rheological perturbation produced by the granitic intrusions are active. The Gavorrano pluton, one of the Neogene granites of the Tuscan Magmatic Province (Italy) emplaced in the inner Northern Apennines during the Neogene extensional tectonics, is well suited to determine and quantify the exhumation process. Integration of petrological and geochronological (Zircon U-Pb) data revealed that the Gavorrano granite was emplaced at 4.9±0.2 Ma ago, before the end of the earliest Pliocene (Zanclean), under a minimum crustal pressure of 120 MPa corresponding to a minimum depth of c. 4.5 km. On the other hand, Apatite (U-Th)/He thermochronological data indicate an exhumation age of 4.21±0.46 Ma for the pluton representing the time of cooling below the established closure temperature in response to exhumation. Even before the ascent and emplacement of the Gavorrano granite, the region must have been characterized by a high thermal gradient due to the lithospheric thinning that affected the northern Tyrrhenian domain. After the emplacement of the granitic magma, this high thermal gradient is further increased. Given an exhumation timing of c. 1.35 Myr, the minimum estimate of the average exhumation rate for the Gavorrano pluton is 2.6 mm/yr down to 1 km below the surface. The emplacement and exhumation of the granite was driven by the interplay between the SW–NE striking left–lateral regional transfer zone and top–to–the ENE and WSW low–to middle–angle normal faults. The near vertical permeability favored by the transfer zone allowed the magma to be emplaced, while the normal faults favored the condition for uplift and exhumation.

Miracles needed. Climate changes and the physical limits of the Earth

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Keywords: energy transition, global warming, critical minerals.

The energy transition is one of the hottest topics both in the scientific world and in social media and coffee shop discussions. Despite this important nature, unfortunately the approach adopted is generally superficial. When the reasoning is instead based on scientific argumentations, it is easy to see how it is based on unrealistic to easily refutable hypotheses. The arguments can be grouped in two main reasoning styles. One is of conspiracy-type, and considers the possibility of moving to a decarbonized world immediately as a real thing, hindered only by oil lobbies and old-style oil industrialists (e.g., Jacobson, 2023). The other considers, with a greater dose of realism, that the energy transition is extremely difficult, very expensive and certainly impossible to achieve except in a few decades of gradual adaptation (e.g. Smil, 2022).

The transition to a decarbonized society is certainly possible, but only if we accept a long-lasting and very painful degradation of our life styles. Developing countries would significantly delay the transition to better living conditions, as instead envisaged by the United Nations' Sustainable Development Goals. We certainly could not ask them to make the sacrifices that OECD countries will have to face. Rich countries, even in light of the immeasurable wealth they have accumulated especially since the Second World War due to the easy access to immense energy source exemplified by fossil fuels, will be called upon to make the greatest contribution to change their socio-economic models. This possibility, even if spread over a few decades, will be hardly accepted by society and very few political parties will be willing to set their communication strategies in this direction.

Society is not well aware of what a transition to a completely decarbonized world or to a world with net zero CO_2 emissions could imply (a topic that is still very poorly defined, as no valid industrial-scale options for neutralizing or safely confining CO_2 are yet available). The first step to follow would be to limit consumption, and immediately after start thinking about how to diversify energy sources to continue obtaining goods for our well-being. Renewable sources will never be able to satisfy the lifestyles of rich countries in any way because they are intermittent, inconstant and have poor energy density expressed per unit of surface area or unit of volume. Indeed, the problem of modern societies is not the availability of energy, considering that solar radiation alone could satisfy all current energy requirements by many hundreds of times. The fundamental problems we will face are of two types: the availability of energy when we need it, not when it is most abundant, and the availability of matter, which will be transformed through renewable energy into the objects of our desires.

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Smil V. (2022) - How the world really works - A Scientist's Guide to Our Past, Present and Futur. Viking Press, 336 pp.

Sedimentological analysis of the Jurassic pelagic "oolites" (Buccheri Formation, Western Sicily): paleoenvironmental and paleogeogra phic implications

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Keywords: Jurassic, oolites, paleoenvironment.

The sedimentological analysis of the Jurassic limestones outcropping in Western Sicily provided new data on a lithofacies containing pelagic "oolites" whose genetic origin is still debated.

The pelagic "oolites" (Jenkyns, 1972) is a lithofacies of the Buccheri Formation, informally known as "Rosso Ammonitico", a condensed pelagic succession that was deposited at the top of the drowned carbonate platforms of Western Tethys during the Early-Middle Jurassic. This formation exhibits differences in terms of texture, fossil content and geometry documenting variation in the sedimentation processes.

The pelagic "oolites" facies usually occurs along the lower (e.g. Monte San Calogero area, Sciacca, southwestern Sicily) or the upper member (e.g. Monte Maranfusa, central-western Sicily) of the Buccheri Formation and sometimes reaches thickness up to 25 m. It is represented by packstone/grainstone, with small spheroidal ooids, exhibiting a diameter always < 0.4 mm, planktonic foraminifera (*Globuligerina* sp.), crinoid fragments and rare benthic foraminifera (*Lenticulina* sp.). The "ooids" (or "microonkolites"; Jenkyns, 1972) sometimes exhibit a well-preserved tangential micritic lamination and the nucleus is in some cases represented by *Globuligerina* sp. The lower boundary is often sharp on the underlying lithofacies represented by a thin-shelled bivalves (*Bositra* sp.) packstone or by crinoidal packstone/grainstone. The upper boundary is transitional to the ammonitic-rich limestone or to *Saccocoma* limestone.

As regard the genetic origin, the presence of planktonic foraminifera included at the nuclei may indicates that they have formed by particle adherence, meanwhile the preserved concentric lamination is consistent with a genetic origin linked to sediment trapping by algae, as suggested by Jenkyns (1972). The *Globuligerina* sp. probably acted as nuclei around which those ooids grew. The presence of pelagic faunal elements indicates that they were primarily formed on top of submarine paleotopographic high. Sometimes, the "pelagic oolites" exhibit downlap termination, for the first time observed along the Western Sicily successions, on the underlying lithofacies (Monte San Calogero area) suggesting the occurrence of reworking and risedimentation processes, probably related to bottom current activity, that determined their redeposition. These features represent a useful tool in paleogeographic and paleoenvironmental reconstructions.

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Magnetite nanoparticles dissolution in simulated biological fluids

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Keywords: magnetite, reactive oxygen species, simulated biological fluids.

Biogenic magnetite nanoparticles (NPs) have been found in the human brain (Kirschink et al., 1992). At the same time, exogenous ferrimagnetic NPs have also been detected in the human brain, mainly derived from anthropogenic activities such as combustion processes (Maher et al., 2016). After inhalation, exogenous NPs or pathological biogenic NPs can accumulate in several organs, including the brain. Bioaccumulation of ferrimagnetic NPs can cause an overproduction of reactive oxygen species (ROS). Indeed, ferrimagnetic NPs can produce ROS in several ways, such as the release of metal ions, adsorption of metals or compounds, interaction with carbon dioxide, water, or molecular oxygen, or by cellular inflammation. ROS can lead to various toxic effects, including cancer (Schoonen et al., 2006). The listed ROS production mechanisms are all influenced by the ferrimagnetic NP mineralogical phase. To examine in depth the pathways with which ferrimagnetic NPs can produce ROS in humans, it is crucial to investigate the evolution of the physicochemical state of these minerals and their possible transformations while present in different body compartments. In this regard, simulated biological fluids (SBFs) are useful in studying the dissolution kinetics and ROS formation processes of ferrimagnetic NPs inside the human brain.

The presented research aims to investigate the interaction between magnetite NPs and SBFs (a phosphate buffer saline solution - PBS) and related physiochemical transformation of NPs. The experiments were thus divided into three main steps. First, we characterized magnetite NPs (50-100 nm) through the following techniques: XRPD for identifying all mineral phases, SEM to determine the dimensional distribution of NP aggregates, HR STEM to collect morphological and crystallochemical information on single NPs and perform dimensional measurements, Dual-EELS for determining the Fe-valence state, and 4D STEM to identify any local inhomogeneities in the NPs. Secondly, following the initial characterization, magnetite NPs were placed in PBS at various concentrations (0, 50, 100, 200, 300, 400, 600 µg/ml), and then sampled at different times (0.5, 1, 12, 24, 48, 96, and 168 hours). ICP-MS was used to analyze filtered PBS to detect Fe released into the PBS solution. Lastly, magnetite NPs retrieved from the solution after 168 hours of interaction were subjected to the same characterization as the starting material. Preliminary results indicate no significant differences in morphology, dimensions, and crystallochemistry of both individual NP surfaces and NP aggregates, and ICP-MS revealed no release of Fe to the PBS. These first results suggest that Fe cations may be locally released from the NPs after interaction with SBFs, but these cations rapidly precipitate and rearrange on the surface of the NPs.

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Organobentonites as perspective adsorbents for nonsteroidal anti-inflammatory drug - diclofenac sodium

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Keywords: clays-surfactant composites, diclofenac, adsorption.

Various chemical substances found in natural water sources and wastewater are considered as emerging contaminants since they exhibit resistance to traditional water treatment methods and persist in treated effluents. Of particular concern are pharmaceuticals, given to their widespread use and potential adverse effects on human health, especially when they contaminate drinking water (Rivera-Utrilla et al., 2013). Nonsteroidal anti-inflammatory drugs (NSAIDs), such as diclofenac, ibuprofen, and naproxen, commonly used in both human and veterinary medicine for pain relief, are frequently detected in various water bodies, raising concerns about their environmental impact. Diclofenac has attracted global attention as an emerging contaminant, especially after its veterinary use was linked to the decline of scavenger bird populations. Additionally, studies have emphasized the adverse effects of diclofenac on aquatic organisms, further highlighting its environmental significance (Lonappan et al., 2016). Different methods have been explored for removal of emerging contaminants from water sources, including advanced oxidation processes, activated sludge, adsorption, membrane filtration, and others (Rivera-Utrilla et al., 2013). Among the techniques for effective removal of NSAIDs from polluted water, adsorption onto different materials such as activated carbons, clays, and zeolites is a promising approach (Smiljanić et al., 2020; Obradović et al., 2022).

This research aims to investigate the potential of modified bentonite in the removal of diclofenac from water solution. The natural bentonite from the Šipovo deposit in Bosnia and Herzegovina underwent modification using dodecylamine - an aliphatic primary amine, and di(hydrogenated tallow)dimethylammonium chloride - a quaternary ammonium salt known under a tradename Arquad®2HT-75. Both surfactants were used in quantities equivalent to 50% and 100% of the bentonite's cationic exchange capacity. Analysis of the prepared samples via Fourier-transform infrared spectroscopy and simultaneous thermal analysis confirmed the presence of the surfactant in the modified bentonites. Adsorption isotherms demonstrated that the adsorption of diclofenac increased with the increase of surfactant amount, as well as with the increase of the initial pharmaceutical concentrations. The highest adsorption of the drug occurred with bentonite containing the highest surfactant concentration, with slightly higher adsorption reported for composites with Arquad®2HT-75. Considering that natural bentonite exhibits minimal affinity for diclofenac removal, these findings indicate that organobentonites have significant potential as effective adsorbents for eliminating diclofenac from contaminated water sources.

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Synthesis and structural characterization of a new high-pressure and high-temperature $CaSiO_3$ polymorph

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Keywords: CaSiO3, Multianvil, single-crystal diffraction.

The $CaSiO_3$ system represents one of the most abundant pure calcium silicates on the Earth and the third most abundant phase in the Earth's mantle, after bridgmanite and Fe-periclase. Despite having such a simple chemical composition, its phase diagram is characterized by a wide number of different polymorphs and polytypes in the pressure interval 0-9 GPa (Mazzucato & Gualtieri, 2000; Milani et al., 2021). At pressures lower than ~3 GPa, this system exhibits a Si-tetrahedra chain structure, corresponding to the minerals wollastonite and parawollastonite. The high temperature polymorph pseudowollastonite (ps-woll), commonly found in cements, has a 3-fold rings configuration. At mantle conditions another 3-fold structure named breyite, is stable and it is widely found as inclusion in diamonds (Brenker et al., 2021).

In the low-temperature stability field of breyite, a single study (Chatterjee et al., 1984) reported a potential new polymorph with unknown structure, named wollastonite-IIm (woll-IIm), further increasing the complexity of the system.

In this study, we conducted multianvil syntheses in the PT stability field of the new polymorph to stabilize single crystals and obtain structural information. The first synthesis was performed at 4 GPa and 700°C and resulted in sub-micrometric crystals not suitable for standard X-ray diffraction. 3D electron diffraction allowed the determination of a triclinic unit cell with parameters compatible with woll-IIm, but no structural information could be obtained due to nanometric scale twinning and strong streaking in diffraction. Consequently, a second synthesis has been conducted at higher temperature conditions (4.5 GPa, 800°C) and additional water content as fluxant, to increase the kinetics of crystal growth. Crystal grains with 50x50x50µm3 dimension suitable for single crystal X-ray diffraction were successfully isolated and their diffraction were indexed thanks to the unit cell determined by 3D ED.

Structural resolution confirmed the triclinic symmetry with space group $P\bar{1}$ and unit cell parameters a=8.1911(10) Å, b=9.3441(9)Å, c=10.4604(10)Å, α=73.901(8)°, β=89.814(9)°, γ=77.513(9)°. Woll-IIm is characterized by a 3-fold rings tetrahedra configuration with different tetrahedra orientation with respect to the breyite structure.

To compare the thermo-elastic behaviour of the two high pressure ring-structures, PV and VT equation of state for woll-IIm have been determined through in-situ single crystal X-ray diffraction. We observed that there is no direct structural relationship between woll-IIm and breyite, being the latter quenchable, further suggesting that the natural occurrence of one of the two ring structures could provide insights on the temperature conditions of its formation. To assess the possibility of discriminating between the two polymorphs in mineral inclusions, we also present the first Raman spectrum of woll-IIm.

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