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Abstract Book for

**Science and Conservation
of Geomaterials in
Cultural Heritage**



**ASSOCIAZIONE
ITALIANA DI
ARCHEOMETRIA**

G.A.Be.C.



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Abstract Book for 3rd Workshop

Science and Conservation of Geomaterials in Cultural Heritage

The third edition of GABeC Meetings, entitled “Science and Conservation of Geomaterials in Cultural Heritage”, was held on 4-5 December 2025 at the Royal Mineralogical Museum in Naples, bringing together around 80 researchers from diverse scientific disciplines. The event offered a dynamic forum for interdisciplinary dialogue on the latest advances in archaeometry, material characterization, and conservation strategies.

Contributions highlighted the development and application of sustainable materials and eco-friendly conservation techniques, including alkaline-activated products, recycled ceramics, and innovative lime mortars. Other studies focused on material characterization, provenance, and production technologies, exploring ancient mortars, ceramics, pigments, gemstones, and volcanic and obsidian materials, with integrated analytical approaches revealing past practices and trade networks. Environmental and heritage management challenges were also a central theme, with discussions on risk assessment, conservation of hazardous materials, and the impact of environmental and anthropogenic pressures on archaeological and architectural sites.

Together, these contributions underscored the importance of combining advanced analytical methods, material characterization, diagnostics, historical knowledge, and sustainable strategies to inform evidence-based conservation. The workshop demonstrated the fundamental role of Earth Sciences in characterizing, diagnosing, and safeguarding geomaterials of cultural heritage, as well as in advancing their sustainable preservation and valorization.



COVER PHOTOGRAPH: Piergiulio Cappelletti | Monumental Hall of the Royal Mineralogical Museum (Center of Museums of Natural and Physical Sciences - University of Napoli Federico II) | Hyaline quartz in Head of a Satyr (Carrara marble), attributed to Antonio Canova (Center of Museums of Natural and Physical Sciences - University of Napoli Federico II)

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Keynote Lectures

Eco-friendly restoration products: the case of alkaline-activated materials

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In recent years, the research group of the University of Catania has carried out extensive works for the design and development of alkali-activated materials for Cultural Heritage conservation, focusing on the transformation of local aluminosilicate wastes into sustainable and compatible restoration materials. The studied precursors (i.e., volcanic ash, clays, palaeo-soils, pumice, ceramic wastes and basaltic sawing-sludges) undergo alkali activation to form stable aluminosilicate pastes. Their chemical and physical properties can be carefully tuned to design repair mortars and consolidants suitable for historic stones, mortars and ceramic elements. The research integrates laboratory characterization, formulation design and performance testing with conservation-oriented applications. Alkali-activated materials have been assessed on significant Sicilian monuments, including the Odeon and the Benedictine Monastery of Catania, and the cathedrals of Monreale and Cefalù in Palermo, allowing evaluation of their behaviour under real degradation patterns and intervention requirements. These activities were carried out within research projects: Advanced Green Materials for Cultural Heritage (AGM for CuHe, ARS01_00697, CUP E66C18000380005), related to the use of Etnean ashes, ghiara palaeo-soil, Lipari pumice and ceramic residues (Barone et al., 2020); Sicilia Eco Tecnologie Innovative (SETI, PO FESR 2014-2020, Action 1.1.5, CUP G38I18000960007; SI_1_23073), centred on Sicilian clays (Stroschio et al., 2024) and basaltic sludges; and the PNRR project CHANGE - History, Conservation and Restoration of Cultural Heritage (CUP E63C22001960006) still ongoing (Bertino et al., 2025).

Overall, the outcomes demonstrate how alkali-activated materials represent a promising scientific and technological pathway for the conservation of built heritage. Their versatility, sustainability and strong link to local geological resources reinforce the workshop's central topic: the role of geomaterial science in shaping innovative and context-aware strategies for the protection of Cultural Heritage.



Figure 1 Filling gaps in bricks, application of geopolymer mortars based on ceramic waste at Odeon in Catania.

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Keynote Lectures

Roman mortars: Ancient innovation for modern sustainability

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Roman mortars represent one of the most advanced and durable construction materials developed in antiquity and constitute a remarkable example of technological innovation based on natural raw materials and empirical knowledge of their properties. Their outstanding mechanical performance, long-term durability and hydraulic behavior are closely related to a carefully designed mixture of lime binders, volcanic aggregates and, in some cases, recycled ceramic fragments with pozzolanic activity. These characteristics make Roman mortars a valuable reference for modern sustainable construction and circular economy strategies.

This contribution presents a comprehensive overview of the compositional, microstructural and physical features of Roman mortars sampled from key archaeological sites in the Campania region, including the Baia Thermal Complex, *Piscina Mirabilis*, Dragonara Cave, the Temple of Venus and the Flavian Amphitheatre. These sites represent different functional contexts, ranging from hydraulic and thermal structures to monumental architecture, allowing a comparative evaluation of mortar technologies adopted by Roman builders in response to specific structural and environmental requirements.

The analytical approach combines macroscopic observations with petrographic analysis under polarized light microscopy, mineralogical investigations by X-ray powder diffraction, chemical characterization by scanning electron microscopy coupled with EDS microanalysis, thermal analyses and mercury intrusion porosimetry. Attention was paid to minimally invasive sampling, representativeness of the materials and integration of complementary analytical techniques in order to obtain a robust characterization of both binder and aggregate fractions.

Petrographic observations reveal a lime-based binder hosting volcanic aggregates such as pumice and scoriae, often surrounded by well-developed reaction

rims indicative of intense pozzolanic reactions. In several samples, ceramic fragments are also present and show heterogeneous petrographic and mineralogical features, suggesting the use of recycled materials derived from different ceramic productions. Mineralogical analyses indicate the presence of an amorphous fraction related to volcanic glass, together with secondary phases such as calcite, Al-tobermorite, gypsum and halite. The occurrence of Al-tobermorite and C-A-S-H type gels testifies to the high hydraulicity of the mortars and to long-term water-mediated reactions that enhance mechanical strength and durability.

Chemical and thermal data confirm the distinction between natural and artificial pozzolanic mortars, highlighting differences in hydraulic degree related to raw material selection and mix design. Mercury intrusion porosimetry shows clear differences between coating and bedding mortars, with variations in total porosity, pore size distribution and pore radii that reflect functional requirements, construction techniques and performance expectations. Bedding mortars generally exhibit finer pore structures associated with higher hydraulicity, while coating mortars show denser fabrics influenced by the presence of ceramic fragments.

Overall, the results demonstrate that Roman mortar technology was strongly oriented toward quality, durability and sustainability, relying on local geomaterials, recycled components and optimized preparation techniques. The conscious selection of raw materials and the control of mix design anticipated modern concepts of resource efficiency and low-impact construction. The integrated study of mineralogical composition, microstructure and physical properties of Roman mortars provides valuable insights for the development of innovative and sustainable building materials inspired by ancient practices and adapted to contemporary needs.

Keynote Lectures

Recycling in ancient ceramics: The circular economy between past and present

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Recycling is a practice that started since the Palaeolithic, as attested by the reuse and remodelling of broken stone tools. In ceramic production, the reuse of materials can be related practically only to the addition of temper or additives to the base clay, therefore during the clay paste preparation. The most evident attestation of recycling is represented by the use of grog, therefore granules of ceramics obtained from the grinding of previously produced and used pottery (probably from broken objects). This type of practice is well documented in numerous ancient productions, especially in sites located in landscapes characterised by the absence, in the vicinity, of rock outcrops or the availability of sand deposits. But, argillaceous-basis temper or naturally occurring inclusions, such as argillaceous rocks or clay pellets, are often difficult to distinguish from grog, creating misinterpretation, especially when only macroscopic analysis is done. From a chemical point of view, the addition of grog with different compositions than the used clay can affect the bulk composition having important implications when interpreting the provenance of ancient ceramics. Microchemical approaches (SEM-EDS, PIXE) are possible solutions to constrain the provenance of the grog added as well as the ceramic itself (Holmqvist et al., 2018). The

recycling of other artificial materials was, although sporadically, attested, such as glass in crucibles (which determined a high sintering of the ceramic body), metal slags in grater of mills, or byproducts for lead-glazes. More difficult is to prove the recycling of minerals and stones, since the practice of exploiting outcrops to get temper was a very common practice. The reuse of lithic temper derived from previous objects can be proved when the temper is composed of minerals or rocks extraneous to the geology of the region where the ceramic was produced. An example is represented by the reuse of different types of marble and carbonate alabaster from various localities in the Mediterranean basin, as temper in the common ware produced in Veneto region (Maritan et al., 2021). Also, the presence in the same ceramic of rock types geologically consistent with different geological units apart from each other, despite outcropping in the same region where the ceramic was produced, may indicate the recycling of processing wastes related to the production of lithic objects. Among other types of temper of organic origin and being byproducts, plant ash was discriminated from the use of simple plant remains, thanks to the crystal habit of the calcite as observed in this section.

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Keynote Lectures

Defending beauty. The extraordinary plan of the Campi Flegrei Archaeological Park for the bradyseismic emergency

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The Campi Flegrei Archaeological Park is an institute of the Ministry of Culture with the mission of protecting, interpreting, and restoring the value of an extraordinary array of archaeological and monumental sites. It is one of the most important concentrations of tangible and intangible evidence of the memory of ancient cultures in the entire Mediterranean, with the remains of the oldest Greek colony in the Western Mediterranean (Cuma) and the remains of Romanization in the urban and commercial setting of Pozzuoli and the residential context of Baiae. Among the development factors that led to such a concentration of ancient history, is the unique nature of active volcanism and its collateral effects, such as the presence of excellent building materials (tuff, trachyte, pozzolana) and the presence of hydrothermal resources that supported practices widespread in ancient societies, such as the development of thermal baths. This same geological "energy", today represents the most significant risk factor for the preservation of ancient buildings, as most of the monumental contexts are located within the bradyseismic and volcanic risk area of Campi Flegrei. The Campi Flegrei Archaeological Park has placed the utmost emphasis on conservation activities identifying conservation monitoring as a key function for effectively pursuing its institutional tasks and fully developing its mission. From this perspective, it was deemed highly appropriate to build a collaborative network with research institutions capable of supporting the Park in developing a special monitoring plan. The worsening bradyseismic crisis of recent years has prompted the Park to develop a special monitoring plan for the public visitor areas. This plan aims to monitor the conservation status of the structures and ensure continued use of the archaeological areas and monuments open to the public. Drawing on various cataloguing systems and algorithms already tested and proposed in the archaeological field, the project defined ad hoc methodologies for a widespread archaeological site like the Campi Flegrei Archaeological Park. These methods are designed to assess the usability of areas

and locations and enable rapid, hierarchical planning of risk mitigation interventions during the bradyseismic emergency. After a preliminary definition of the site's safety and management requirements, the project proceeded to map the visitor routes and the areas most in need of protection, identifying for each area the structural deficiencies and potential hazards, classifying more than fifteen different vulnerability conditions. This approach led to the successful implementation of minimal restoration and consolidation interventions, which naturally evolved into scheduled maintenance.

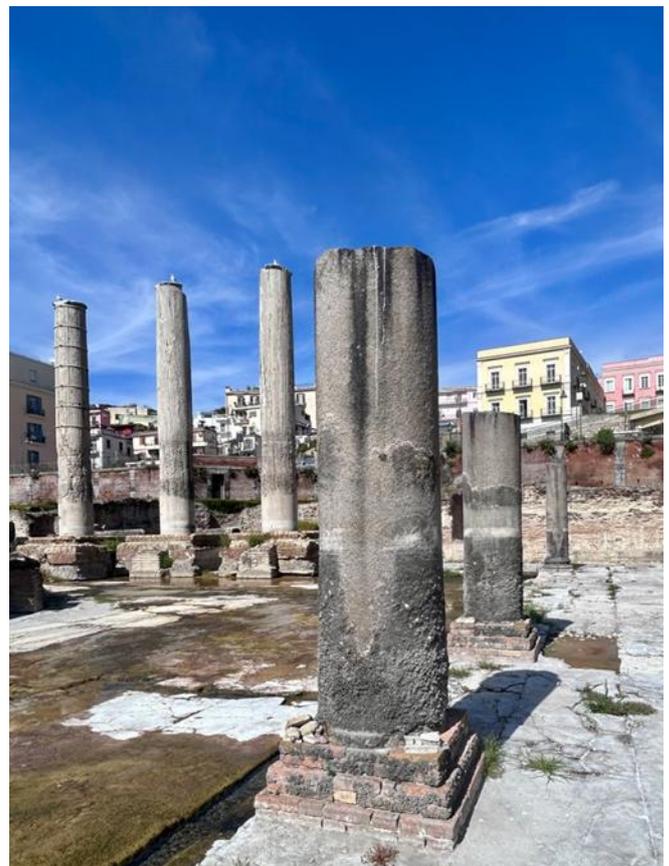


Figure 1 Macellum of Pozzuoli (NA).

Scientific contributions

The iron of the ancient Capua (Campania region, southern Italy): Preliminary archaeometric investigations

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The archaeological site of San Tammaro - Via Cimara, identified only in recent times, is located on the western periphery of the ancient Capua (Caserta province, Campania region, southern Italy), within the avulsion/meandering zone of the Volturno River. In this site, a series of working pits and tanks have been investigated, datable to a period between the 7th and 2nd century BC, some lined with terracotta rings or arches with a diameter of just under one meter.

In one of these pits, dating to the 2nd century BC, in the deepest part and behind the terracotta ring that lined it, a filling made up of soil mixed with iron-rich materials was found. The discovery of several aggregates of spongy materials and likely iron slags, presumably waste products from metalworking, is interesting for the knowledge of utilization of iron-bearing deposits by the peoples of ancient Campania. The site of San Tammaro lies directly above the pedomarker B, only partly outcropping, and has been affected by both ancient and modern human activities. Consequently, the tephra layers related to the post-Neolithic explosive cycles of the Phlegraean Fields are entirely absent, while older volcanoclastic-alluvial successions are visible, showing minor enrichments in oxides. Some of these occurrences are indicated as bog iron.

This study aims to characterize the mineralogical composition of these peculiar Fe-rich deposits, also known as bog iron, and to formulate hypotheses regarding their potential exploitation. The investigated samples (Fig. 1a) consist of dark brown to reddish concretions and crusts, locally with black spots (a few millimeters in size). Preliminary mineralogical analysis (SEM-EDS, XRPD) revealed that they are mainly composed of mixtures of iron+manganese oxides/hydroxides, iron+calcium phosphates and smectite clay minerals (Fig. 1b). XRD analyses also showed a significant amount of amorphous fraction.

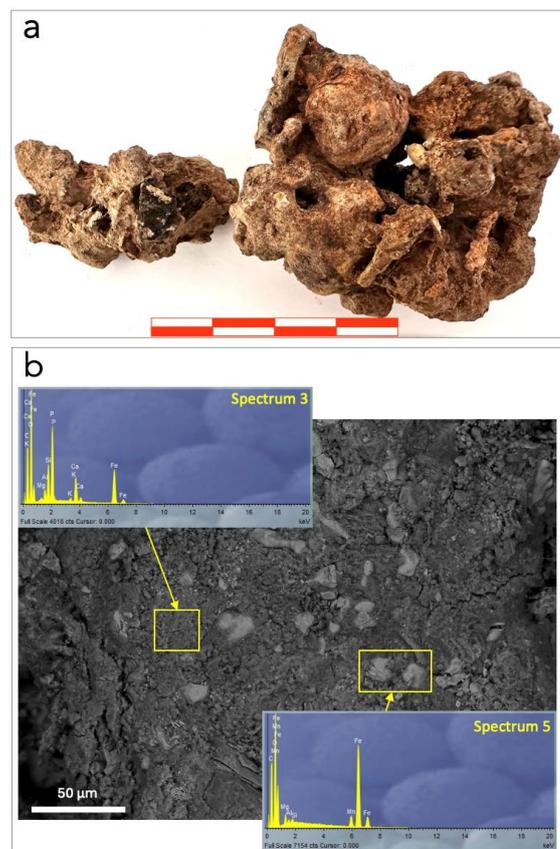


Figure 1 a) Some of the investigated samples (scale bar 5 cm). **b)** Selected SEM image (backscattered electron mode) and EDS spectra of a Fe-rich concretion.

Other occurrences of Fe-rich phosphates concentrations were found at Sant'Agata dei Goti (Benevento province) and identified as vivianite-bearing levels (Balassone et al., 1998). Detailed analyses are in progress on the samples and in the provenance site in order to define the mineralogical and genetic features of these iron deposits, and thereby to clarify their function within the archaeological context.

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Integrated diagnostics and alternative materials for the conservation of Byzantine Mosaics in Sicily

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Recent research carried out within the AGM for CuHe and CHANGES-PNRR projects has combined archaeometric diagnostics and experimental material science to support the sustainable conservation of the Byzantine mosaics of the Monreale and Cefalù Cathedrals (UNESCO World Heritage Sites). A multi-analytical diagnostic approach, including portable X-ray fluorescence (pXRF), Raman spectroscopy and X-ray diffraction (XRD), was employed to characterize the composition, alteration processes and conservation state of glass tesserae, mortars and decorative plasters. The diagnostic results revealed moisture-driven efflorescence and binder degradation at Monreale (Fig. 1), and recycled soda-lime glass tesserae with Fe-, Cu-, Co- and Mn-based chromophores at Cefalù, associated with lime mortars affected by oxalates and chlorides.



Figure 1 Detail of the South aisle wall of Monreale Cathedral involved in the conservation site, with location and photographs of the sampled mortars and salts (from Coccato et al., 2023).

Based on these results, innovative alkali-activated materials were developed as eco-sustainable substitutes for traditional mortars and tesserae. Volcanic ash-based mortars from Mt. Etna showed improved rheology and adhesion thanks to small additions of slaked lime, enabling in situ applications on vertical mosaic surfaces (Fugazzotto et al., 2023; this formulation has been patented). Pigmented geopolymers, obtained from metakaolin and natural pigments (i.e., ochre, green earth and ultramarine blue), exhibited mechanical and chromatic compatibility with the original tesserae and were successfully employed to fill mosaic lacunae in the Cefalù Cathedral apse (Fig. 2). The restoration campaigns were conducted in collaboration with Piacenti S.p.A., ensuring a direct transfer of diagnostic knowledge into sustainable conservation practice to professional conservation practice. These studies highlight the potential of diagnostic-driven, low-impact materials in advancing “green” mosaic restoration.



Figure 2 The main phases of the restoration intervention: **a)** embedding of the basaltic sawing sludge-based bedding mortar; **b)** positioning of the new pigmented geopolymeric tesserae; **c, d)** the restored lacunas (from Bertino et al., 2025).

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Technological memory in ceramic production from the Hyblaeen Plateau: The contribution of archaeometric analyses

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The survey project in the western Hyblaeen region of southeastern Sicily began in 2019. It focuses on the municipalities of Monterosso, Giarratana, and Chiaramonte Gulfi in the province of Ragusa. Due to its diverse environments ranging from upland plateaus to alluvial plains, this area is an ideal case study for investigating ancient Sicilian settlement and road systems from a diachronic perspective.

Analysis of ceramic materials revealed a continuous human presence in the region from prehistory to the modern age, with notable concentrations of sites during the Roman and Byzantine periods. The chronotypological analysis of these materials was complemented by spatial analysis at regional and extra-regional levels. The study determined the production techniques and provenance of the artifacts using archaeometric analyses based on XRF fluorescence instruments and thin-section petrography for selected samples. Local productions, assigned to different chronological periods, seem to share "recipes" that are not entirely dissimilar from one another, probably as an adaptive response to the environment – a form of "ecological knowledge."

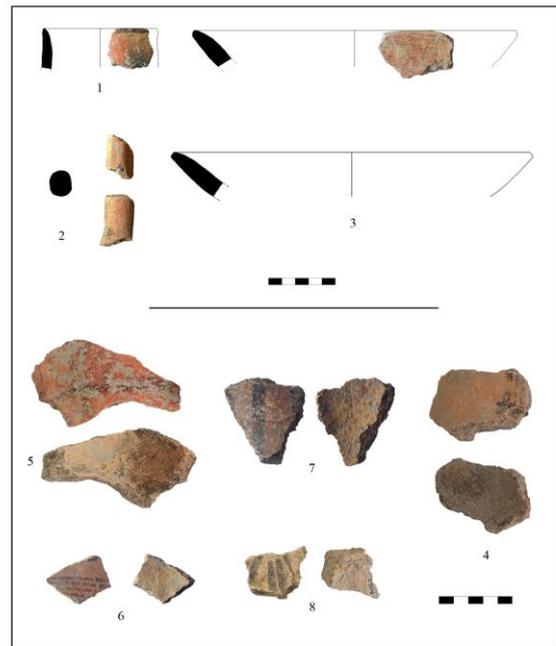


Figure 1 Malpasso-Sant'Ippolito facies: **1** Small jar; **2** Dipper cup; **5** Olla (cooking/storage pot). Castelluccio facies; **3** Stemmed cups; **4** Closed form vessel; **6** Olla; **7-8** Stemmed cup.

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Mineralogical and chemical characterization of Oenotrian pottery (Basilicata region, southern Italy): Constraints on composition and raw material provenance

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The Oenotrian population is a pre-Roman indigenous group inhabiting the southern Apennines (Basilicata, southern Italy). Oenotrian pottery plays a significant role since it reflects the cultural identity of the area, especially through its specific geometric shapes and decorations. Several pottery fragments from three Oenotrian archaeological sites (Anzi, Garaguso and Brindisi di Montagna) have been analyzed by using a multi-analytical approach (XRD, FT-IR, EDX and PCA) which provided information on artifacts production techniques and raw materials provenance. While mineralogical semi-quantitative X-ray diffraction (XRD) showed comparable mineralogical compositions among all pottery fragments, multivariate analysis of FT-IR spectroscopic data and PCA analysis differentiated Anzi sherds from those found at other locations, indicating different raw material sources. Energy-dispersive X-ray (EDX) examination further confirmed compositional diversity among the Anzi, Garaguso, and Brindisi di Montagna samples, suggesting that the raw materials for the Anzi ceramics originated from non-local sources. Further statistical analyses, counting literature data, suggested that raw materials used for Oenotrian pottery in all three archaeological sites likely originated from the Bradanic Trough.

This finding is confirmed by the mineralogical and chemical composition of the sampled Anzi-Calvello basin clays, which is quite different respect artefacts analysed. Finally, the Bradanic Trough seems to be geographically more suitable as raw material source for Oenotrian pottery.

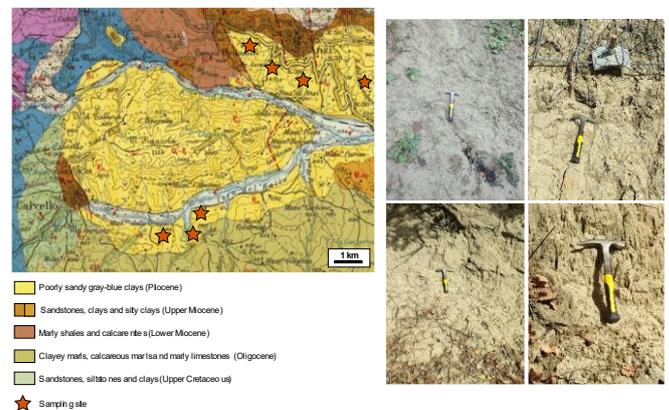


Figure 1 Geological map of the Anzi-Calvello Basin and localization of sampling sites of raw clay materials (Carta Geologica d'Italia - ISPRA, sheet no. 199 "Potenza") with photography of several collected clay samples.

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The archaeological site of the Roman thermal baths of *Teate Marrucinorum* (Chieti, Italy): New insight on ornamental stones and cistern mortars

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An integrated archaeometric approach was applied to the 1st-2nd century AD Roman thermal complex of *Teate Marrucinorum* (modern Chieti, Abruzzo, Italy). The study investigates ornamental marbles, stones and construction mortars by a multi-analytical approach (Fig. 1) to reconstruct their provenance, production technology, and preservation state. This enhances our understanding of Roman material selection and construction methods.

The multi-analytical protocol investigates 56 decorative rock samples by comparative macroscopic observations, transmission optical microscopy (TOM), X-ray powder diffraction (XRPD), micro-Raman spectroscopy, X-ray fluorescence (XRF-EDS) and stable isotope analysis ($\delta^{18}\text{O}$, $\delta^{13}\text{C}$). The identified lithotypes resulted *Marmor Lunense* (Carrara marble from Apuan Alps, Italy), *Marmor Proconnesium* (Proconnesian marble from Marmara Island, Turkey), *Marmor Phrygium* (Pavonazzetto from Afyon region, Turkey), *Marmor Carystium* (Cipollino verde, Euboea, Greece), *Marmor Chium* (Portasanta, Chio Island, Greece), *Marmor Scyreticum* (Breccia di Settebasi, Skyros Island, Greece), and *Greco Scritto* (Ephesus, Turkey), highlighting the wide geographic range of stone procurement and the refined aesthetic choices characterizing this Roman architecture.

Parallely, 3 mortar cylindrical specimens were cored from the outermost to the innermost parts of the walls of the cistern system connected to the baths. They were studied using an integrated 2D-3D approach based on high-resolution scanning (HRS), TOM and electron microscopy (SEM) and X-ray computed microtomography (μ -CT), used to image the outermost portions of 2 cores made of *cocciopesto*.

To segment the 3D volumes, deep-learning models were trained using Dragonfly 2024.1 computer software (Comet Technologies). Image analysis on both 2D and 3D domains allowed the quantification of morpho-textural parameters, including the area and volume fractions (area% and vol.%) of pores, aggregates and cement paste, the size distributions, shapes and orientation of pores and aggregates. Moreover, μ -CT volume analysis enhanced the mortar characterisation by quantifying further parameters, including specific surface area, anisotropy, and connectivity (via Euler characteristic).

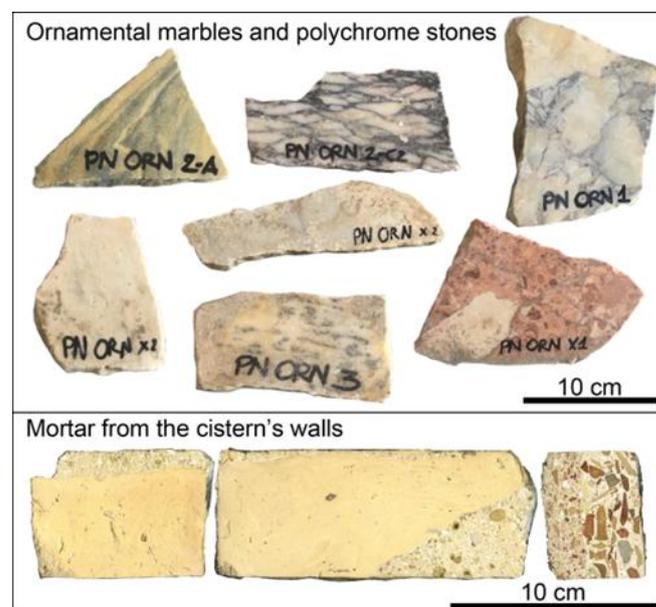


Figure 1 Marbles (top) and mortar (bottom) from *Teate* thermal complex.

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The conservation and restoration challenges of industrial and architectural heritage containing asbestos and other hazardous substances

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Industrial heritage represents a comparatively recent category within heritage studies, encompassing a chronological period closely connected to the present and gaining recognition only in recent decades. Among its defining materials, asbestos stands out as the emblematic substance of the twentieth century, owing to its widespread use in high-tech devices and construction materials. However, the progressive medical evidence of its carcinogenicity – classified as a Group 1 carcinogen by the IARC in 1977 – transformed its status from a valued industrial and geomaterial resource into a major public health concern. Consequently, asbestos and other hazardous substances have emerged as critical cases in the conservation and exhibition of contemporary heritage, where the authenticity of materials comes into tension with the non-negotiable principle of protecting human health.

In this emerging scenario, the heritage of asbestos-containing artefacts is far more extensive than commonly recognised, ranging from everyday objects to industrial complexes and transport infrastructures, and encompassing architectural heritage, industrial archaeology, and works of art that are often undocumented or insufficiently recorded. The current European regulatory framework classifies asbestos as a building material and/or waste, but does not establish specific protocols for cultural heritage artefacts, whether movable or immovable.

The Babcock & Wilcox boiler (1955), housed at the Museu Nacional de la Ciència i de la Tècnica de Catalunya (MNACTEC) in Terrassa, Barcelona (Spain), represents an emblematic case study in contemporary conservation and restoration. The insulating asbestos ropes located at the worn terminations of the superheaters serve both as evidence of the object's technological significance and as a potential source of asbestos fibres dispersion. This case highlights the need to address not only the challenges of conservation but also those of exhibition. A comprehensive conservation management plan should establish clear guidelines for museum

conservators and visitors—defining, for instance, safety distances and circulation paths, containment or localised encapsulation systems, and routine maintenance procedures that ensure public accessibility without increasing risk or compromising the object's integrity.

The main objective for industrial heritage curators is to reframe materials perceived as purely hazardous – and often treated as waste – into artefacts of outstanding universal value, paving the way for the development of *ad hoc* best practices applicable to other complex 20th century materials. Achieving this goal requires the collaboration of interdisciplinary experts and institutions, including cultural heritage professionals (such as museum curators and conservation scientists), prevention and protection services, accredited laboratories specialising in asbestos and hazardous substances, and regulatory agencies, in order to assess potential hazards and guide informed, responsible decision-making.

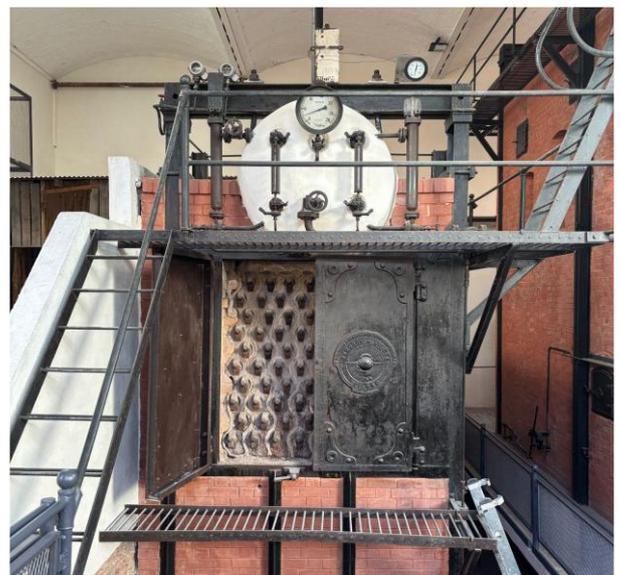


Figure 1 Representative picture of the insulating asbestos system of the Babcock & Wilcox boiler (1955), housed at the MNACTEC in Terrassa, Barcelona (Spain).

The CHANGES Project: Alkali-activated materials for the restoration of the Benedictine Monastery of San Nicolò l'Arena in Catania

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The Monastery of San Nicolò l'Arena in Catania, a UNESCO World Heritage Site, represents an emblematic case of architectural and historical stratification, the result of successive construction phases, functional transformations, and the impact of catastrophic events such as the eruption of 1669 and the earthquake of 1693 (Calogero, 2014). Within the framework of the CHANGES project (PNRR Mission 4, Component 2, Investment 1.3, Spoke 6 - CUP E63C22001960006), an integrated historical-archaeological and scientific study made it possible to deepen the understanding of the conservation state of the monumental complex, thanks also to the use of non-invasive in situ diagnostic analyses. The stratigraphic analysis enabled the identification of numerous masonry and plaster units, reconstructing five main building phases and their related functional transformations. In situ scientific investigations carried out through portable X-ray Fluorescence, Diffuse Reflectance Infrared Spectroscopy, and portable optical microscopy provided valuable information on the chemical and mineralogical composition of mortars and plasters, revealing the use of lime-based binders with variable aggregates, including volcanic clasts, sand, and cocchiopesto. At the same time, the project developed innovative alkali-activated materials designed for the sustainable restoration of the stone materials used in the monument, with

potential application to the wider stone cultural heritage. By mixing aluminosilicate powders with basic solutions, hydraulic binders are obtained with properties similar to those of cement and ceramics (Pachego-Torgal et al., 2014). The resulting products offer numerous advantages in terms of environmental sustainability: the use of natural local raw materials reduces costs and the environmental impact of transportation; the recycling of waste materials, used as secondary raw materials, promotes a circular economy; and the fact that consolidation occurs at room temperature significantly reduces CO₂ emissions associated with traditional production processes. The new formulations were designed for targeted interventions involving the reintegration of mortars and plasters, the consolidation of masonry, and the replacement of damaged decorative elements, using metakaolin, local clays, fly ash and ceramic waste. After laboratory characterization, which focused in particular on the evaluation of chemical stability in water and the study of mineralogical, microstructural, and compressive strength properties, the most high-performing formulations were optimized for on-site applications. Here, fruitful collaboration with craftsmen and restorers is enabling the refinement of the most effective application methods and the development of industrial scale-up processes.

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The Roman palette revealed at Pompeii: From original pigment chemistry to wall painting practice in the *Casa del Tiaso* (Regio IX, Insula 10)

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Reconstructing the technological skills of ancient painters is essential for understanding the material culture and aesthetic sophistication of the Roman world. Pompeii, along with the wider Vesuvian area, offers an unparalleled context where the archaeological integrity and material preservation converge to reveal the complexity of Roman wall painting.

The study of pigments preserved in original ceramic pots from Pompeii (Grifa et al., 2025) offers unique insight into the painters' technical expertise, showing how natural raw materials were transformed through elaborate preparation and mixing procedures to achieve specific optical and chromatic effects.

A multi-analytical approach combining microscopic and spectroscopic techniques demonstrated that pigments were rarely used in pure form but rather as deliberate mixtures of natural and synthetic compounds. The analyses revealed a remarkably sophisticated palette comprising both mineral and organic components. Among the most significant discoveries is a previously unknown light-green pigment composed of baryte and alunite, the earliest evidence of barium sulphate use in the Mediterranean world. These findings expand the known pigment repertoire and highlight the advanced chemical understanding achieved by Roman artists, who exercised precise control over colour saturation, brightness, and durability through calibrated mineral combinations.

The results also underscore the pivotal role of Egyptian blue (*caeruleum*) and red lead (*cerussa usta*) as chromatic modifiers. Egyptian blue was systematically employed to enhance luminosity and spectral balance, contributing to brightness modulation, while red lead acted as a warm-tone regulator, capable of softening or intensifying hues within mixtures. Their consistent occurrence in the pigment pots reflects an empirical yet highly refined methodology rooted in both technical experimentation and aesthetic awareness.

To contextualize these laboratory findings within actual pictorial practice, the analytical focus turned to one of Pompeii's most extraordinary discoveries: the *Casa del Tiaso* (Regio IX, Insula 10). This large domus, excavated between 2023 and 2025, preserves two adjoining rooms of exceptional quality, decorated in the late Second and early Fourth Pompeian styles, respectively.

Non-invasive analyses of the wall paintings revealed a chromatic palette closely corresponding to that identified in the pigment pots. The Blue Room, a small *sacrarium* whose central register was painted in blue—an aesthetic hallmark of elite domestic contexts—shows extensive use of Egyptian blue combined with Fe-, Pb-, and As-bearing pigments, black carbon, and Ca-carbonates. These mixtures produced a luminous and optically balanced surface in which *caeruleum* played a fundamental role in modulating hue and brightness.

The adjoining Red Room, corresponding to an *oecus corinthius*, is decorated with a Dionysiac megalography of the Second Style, one of the most remarkable pictorial cycles unearthed in recent decades. Its deep red background, dominated by large areas painted in bright cinnabar red and iron-based reddish hues, is enriched with the same pigment typologies observed in the Blue Room. This produces an intense yet harmonious interplay of chromatic depth and luminosity.

Although differing in function and chronology, the two rooms share a consistent technological and aesthetic framework coherent with the chemical data from the Pompeian pigment pots. The *Casa del Tiaso* thus stands as an exemplary context in which analytical chemistry and art-historical interpretation converge, illuminating the advanced material knowledge that underpinned the visual language of Roman wall painting.

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Preliminary multidisciplinary evaluation of marine-coastal impacts on ancient Calabrian watchtowers (southern Calabria, Italy) and hazard mapping using QGIS

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Calabria's coastal watchtowers, built between the XIII and XVI centuries, played a key role in observation and defense, particularly during the Viceroyalty of Charles V. Of the historically documented 130 towers, around 70 remain, many underutilized and neglected (Donato, 1992).

This study applies multidisciplinary methods to catalogue, assess, and promote these heritage structures, focusing on five watchtowers located in two provinces of southern Calabria: Saracena (Palmi), Ruggero (Bagnara), and Cavallaro (Marina di Gioiosa Ionica) in Reggio Calabria; and La Rocchetta (Briatico) and Marrana (Ricadi) in Vibo Valentia. Preliminary observations identified building materials and degradation forms, including saline efflorescence, alveolization, *flos tectorii*, and biological colonization. Minero-petrographic analyses using Polarized Optical Microscopy (POM), X-ray Diffraction (XRD), X-ray Fluorescence (XRF), Ion Chromatography (IC), and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) will provide a more detailed

characterization of these materials and their degradation patterns (La Russa & Ruffolo, 2021).

Drone-based photogrammetry will generate accurate 3D models, integrated into H-BIM and 3D GIS for continuous monitoring and environmental risk assessment (Colucci et al., 2020). A QGIS-based digital map contains data on the towers' materials, conservation status, and restorations, integrated with information on coastal erosion, landslides, and seismic hazards. Hazard mapping shows that Palmi and Bagnara (Reggio Calabria province) are exposed to the highest risk class according to national maps by the Southern Apennines District Basin Authority. Finally, innovative tools such as Augmented Reality (AR) will enhance public engagement, making the towers' historical and scientific value more accessible. By combining traditional and digital methods, this research offers a replicable framework for the preservation, monitoring, and sustainable valorization of Calabria's coastal watchtowers, while highlighting the environmental risks they face.

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Scientific approaches to archaeogemmology: Investigating ancient gemstones in Cultural Heritages

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Archaeogemmology represents a crucial scientific approach for reconstructing historical, artistic, and cultural frameworks of ancient goldworks (Lüle, 2012). Advances in non-invasive and non-destructive analytical methodologies, along with the emergence of portable instrumentation has revolutionized the field by enabling direct, *in situ* characterization of these valuable materials without removing the artifacts from their preservation context (Karampelas et al., 2020).



Figure 1 Gemmologist and art historian, geologist, and physicist collaborating during fieldwork, illustrating the transdisciplinary approach required for the study and interpretation of historical goldworks. Museo Diocesano, Arezzo, Italy.

A comprehensive understanding of these artworks requires the combined contributions of gemmology, art history, and advanced analytical techniques. This integrative perspective – supported by documentary research, study of goldsmithing and compositional methods, and analysis of provenance, gem cutting, and enhancement practices – offers critical insights into the identification and reattribution of gem materials, the dating of gemstones, and the reconstruction of ancient exchange networks.

Together, these approaches establish a coherent interpretive framework that deepens knowledge of the artifacts' provenance, context, and technological significance (Martiniello et al., 2023).

This study highlights the scientific and cultural value of such analytical practices and underscores the necessity of a transdisciplinary framework. Focusing on unique Byzantine and Medieval goldworks preserved in central Italy – mainly sacred artifacts such as reliquaries and staurothekes – the combined archaeogemmological and analytical approach demonstrates its capacity to connect the materiality and appearance of these remarkable works of art, providing insights into the nature of the gems and metals while revealing symbolic meanings and history of technology.



Figure 2 Selection of gems from Byzantine and Medieval goldworks, showcasing variations in symbolism, treatment techniques, provenance, cutting practices, and reuse.

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The path of Phlegraean pozzolana: From Puteoli to the whole Mediterranean basin

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The Phlegraean pozzolana, referred to as pulvis puteolana by Vitruvius in his famous *De Architectura* (1st century BC; Book II, Chapter VI) book, played an important role in the production of Roman hydraulic mortars, capable of enhancing mechanical strength even in underwater conditions, making it particularly suitable for its use in works intended for predominantly maritime use such as *thermae* and port infrastructures. This geomaterial was widely employed by the Romans as it has been found in several Roman sites throughout the Mediterranean basin (Oleson et al., 2004).

Literature studies refer to *pozzolana sensu stricto* as the unconsolidated facies of the Neapolitan Yellow Tuff eruption (NYT) (~15,000 years ago), the second largest eruption occurred in the Campi Flegrei volcanic field. The aim of this study is to demonstrate that other incoherent deposits, belonging to post-NYT eruptions, were also employed as pozzolanic aggregates for the production of Roman hydraulic mortars and were exported all along the Mediterranean basin. To this end, three *pozzolana* samples collected from three quarries in the Campi Flegrei area, historically known to be used by Romans, were compared with pozzolanic aggregates found in Roman hydraulic mortars from both Campanian archaeological structures (e.g., Baia Thermae, Dragonara Cave, Anfiteatro Flavio, Mausoleo di Porta Mediana in Cuma, Piscina Mirabilis, Villa del Capo and Villa del Pezzolo) and extra-regional sites, such as the wall of a Roman cistern in Venice (Dilaria et al., 2024), the Roman Theatre of Aquileia (Dilaria et al., 2023) and the remains of the ancient roman city of Hippo Regius in Algeria.

The *pozzolana* samples were analyzed using a multi-analytical approach to obtain chemical and mineral-petrographic information through Polarized Optical

Microscopy (POM), X-ray Powder Diffraction (XRPD), X-ray Fluorescence (XRF), Field Emission Scanning Electron Microscopy with Energy Dispersive Spectroscopy (FESEM-EDS) and pozzolanic activity test. In addition, a physical characterization of the samples was performed by laser granulometry.

This research aims to establish a first reference database on Phlegraean *pozzolana* to further our knowledge of ancient Roman technology. By comparing mineralogical and chemical results of the analyzed *pozzolana* samples with the literature data from ancient mortars, the preliminary results aim to determine if there was a preferential choice of a specific *pozzolana* deposit and the linked eruption.

The study seeks to demonstrate that not only the *pozzolana* of NYT, but also from other pyroclastic deposits post-NYT became an important traded commodity, widely exported across the Roman Empire.

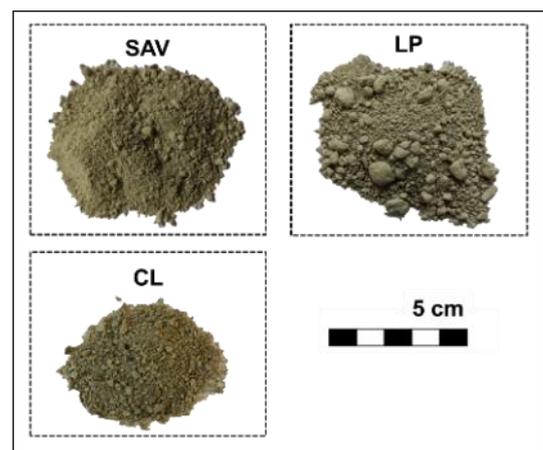


Figure 1 Three phlegraean pozzolana samples (SAV, LP, CL) analyzed in this study.

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The origin of the blue color of Bronze Age vitreous materials: A spectroscopic approach

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An X-ray Absorption Spectroscopy (XAS) and Electron Paramagnetic Resonance (EPR) investigation of protohistoric blue vitreous materials was undertaken, aimed at ascertaining the valence state speciation of Cu and Co suspected to play a role in the colour origin.

Five different glass artefacts coming from Paduli (Colli sul Velino, Rieti, Italy) were investigated. A bichrome blue and white vessel fragment represents the only *Natron glass*. The other four beads, instead, are *LMHK glass*. A relevant question deals with concentration, distribution and valence states of the transition elements Cu and Co. Two out of the five coloured objects, in fact, contain only Cu, whilst the others exhibit both Cu and Co.

A sample holder was specifically designed to ensure minimal invasiveness during XAS measurements. Multiple spots of measurements (up to six) were

performed for each sample at Cu and/or Co edges to check for sample homogeneity. Fragments of the samples, when available, were investigated by EPR without manipulation, to further characterise the Cu^{II} aliquot in the materials.

The XAS spectra provided significant information confirming the presence of the Co^{II} chromophore, in the samples where this species is chemically more abundant, and identifying and quantifying the presence of the Cu^{II} chromophore. Cu^{II}, as revealed by EPR, appears in a distorted (4+2)-fold coordination and partly clustered to form pairs.

This spectroscopic approach, combining XAS and EPR techniques, reveals to be successful in characterization of Co- and Cu-based blue colours in the glasses of Bronze Age, highlighting the high skill reached in the production.

A multi-technique archaeometric study of Montelupo Fiorentino maiolica (14th-18th centuries CE)

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Maiolica (i.e., tin-glazed ceramics) were highly valued in Europe during the Middle Ages and quickly became among the most traded goods in the Mediterranean region.

The technique, of Islamic origin, arrived in Italy in the 13th century CE through trade and cultural exchanges with the Iberian Peninsula (Giorgio, 2018). This led to the emergence of numerous production centres in the 13th and 14th centuries CE. Among these, Montelupo Fiorentino (Florence, Italy) stands out as a key centre, known for its variety and quantity of maiolica artifacts traded, with a production history spanning from the 14th century to the present.

This study employs a multi-technique archaeometric approach to analyse 30 maiolica sherds from Montelupo Fiorentino, dating from the late 14th century to the 18th century CE. The multi-technique investigation combines scanning electron microscopy with energy dispersion X-ray spectrometry (SEM-EDS) and backscattered electron imaging to examine the stratigraphy, microstructure, and chemical composition of the ceramic samples, alongside thermal ionisation mass spectrometry (TIMS) used to determine the lead isotopic signature, providing insights into the origin and commercial dynamics of lead, a key raw material in tin glaze production. Additionally, hyperspectral imaging (HSI) analysis was conducted on the glazes and colours of 50 maiolica sherds from Montelupo to identify the main chromophores and create a reference for the colours used in tin-glazed ceramics prior to the Industrial Revolution.

The glazes are of the lead-alkali type (Tite, 2009). Changes in recipes and microstructure can be observed in the different centuries of production, coinciding with those found in other Italian productions examined by Tite in his review of Italian maiolica (Tite, 2009).

Lead isotope analysis revealed that the lead used in Montelupo maiolica did not originate from local Italian deposits, indicating the use of lead sourced from long-distance trade. The samples matched the isotopic signatures of German deposits, aligning with the proverb reported by Cipriano Piccolpasso in his treatise on maiolica (1557), which mentions "German lead". Additionally, ore deposits from Bulgaria, England, France, and Switzerland also show isotopic consistency with the analysed glazes and remain potential sources, even without supporting historical records. HSI analysis identifies the main chromophores of the Montelupo maiolica palette, demonstrating a suitable and effective method for non-invasive characterisation of tin-glazed pottery preserved in museum environments. The dataset assembled in this study can serve as a reference for this application in future.

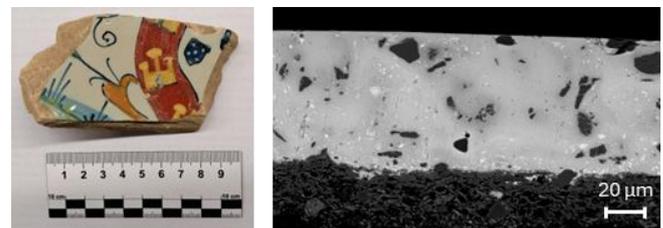


Figure 1 Example of Montelupo maiolica observed at SEM in backscattered electron imaging, 200x magnification.

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Geochemical modelling: A promising method for studying stone weathering in Cultural Heritage

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Cultural heritage assets are continuously exposed to environmental factors (Sesana et al., 2021). Materials interact with the surrounding environment in an ongoing process aimed at maintaining a dynamic equilibrium. Throughout this process, they inevitably undergo transformations, ageing, and various forms of deterioration (Camuffo, 2019). In this context, climate change represents an increasingly significant threat because it accelerates existing degradation processes and can trigger new forms of decay (Sesana et al., 2021). Consequently, increasing research efforts are focused on understanding the effects of various climate-related stressors on materials used in cultural heritage. This research project aims to apply geochemical modelling in cultural heritage, proposing an innovative method that could support and increase scientific knowledge on the impact of climate change on cultural heritage.

Modelling is a geochemical tool that utilizes specialized software to quantitatively simulate mineral formation and dissolution processes, phase composition transformations, and the distribution of chemical species within geological systems (Helgeson et al., 1970). Geochemical modelling applied in cultural heritage could represent a promising tool for studying the reactions involved in the interaction between stone materials and specific environmental conditions (Fig. 1). The research plan included: *i*) the selection of four cultural sites in Calabria (Italy), characterized by granitoid and carbonate lithologies located in urban and non-urban environment; *ii*) the collection of environmental data from local

monitoring stations; *iii*) the characterization of the lithotypes to define the solid phase for geochemical simulations.

An initial simulation was focused on the dissolution of calcite in a selected pilot site characterized by limestone lithology, taking into account the site-specific environmental data. To this end, PhreeqC software is used, entering input data regarding monthly atmospheric CO₂ data, the pilot-site's mineralogical composition, and historical monthly average temperatures. The models provide the amount of calcite dissolved as a result of geochemical interactions. This value is then normalized using the monthly mean precipitation for the site, resulting in a final output expressed as the amount of calcite dissolved per square meter of exposed surface. Preliminary results demonstrate the applicability of geochemical modelling in cultural heritage and suggest its potential for predicting weathering under future environmental conditions.

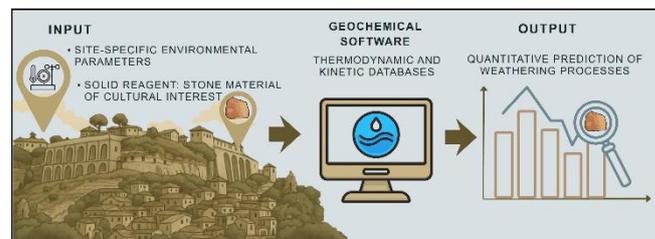


Figure 1 Graphical representation of the geochemical modeling approach used to study weathering processes in cultural heritage materials.

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Asbestos as a geomaterial in Cultural Heritage: From historical use to risk assessment and conservation management

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Asbestos fibres, appreciated since antiquity for their exceptional technological properties such as non-flammability, chemical resistance, flexibility, and binder capacity, have long served as a key geomaterial in both industrial and artistic production. Their use across time and cultures reflects a remarkable intersection between material science and cultural practice.

The earliest asbestos use dates to the Neolithic period, when fibres were mixed into ceramic pastes throughout Eurasia, from Scandinavia to the Japanese Archipelago. In the Greek and Roman productions, asbestos was employed for weaving fabrics, cremation shrouds, and candlewicks, as described by ancient authors and confirmed by archaeological evidence. These traditions persisted in some regions into the Middle Ages.

The large-scale use of asbestos intensified in the 20th century, particularly during the Second World War, and peaked between the 1960s and 1980s with the widespread production of asbestos-cement roofing and panels (e.g., Eternit®). However, growing medical evidence revealed its carcinogenic effects upon inhalation. Following its classification as a Group 1 carcinogen (IARC, 1977), asbestos was progressively banned in many countries, transforming it from a valued industrial resource into a major public health concern.

In the field of cultural heritage, asbestos poses a dual challenge: protecting the health and safety of workers and visitors while ensuring the preservation of asbestos-containing artefacts as material and cultural assets. Although existing regulations focus on the presence of asbestos in buildings and construction materials, the management of movable and immovable heritage objects remains largely underexplored and insufficiently regulated.

Asbestos may occur as a primary or secondary component in a wide range of artefacts, including ceramics, decorative plasters, theatre curtains, musical instruments, electrical devices, modern furniture, and artistic installations. Intervention on these materials, through handling, cleaning, restoration, or exhibition, may lead to the potential release of asbestos fibres into the air, posing health risks to conservators, museum personnel, and the public.

This project outlines a comprehensive overview of asbestos as a geomaterial within cultural heritage, emphasising its historical and geographical diffusion and material properties. It further proposes guidelines for identifying, documenting, and safely managing asbestos-containing artefacts during conservation, transport, and display, contributing to a more integrated and responsible approach to heritage protection.

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The contribution of igneous petrology to unraveling the lava millstones trade in ancient times

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Volcanic rocks (lavas) were widely used in ancient times to produce millstones due to their good physical-mechanical properties for grinding cereals. One of the main aims of the archaeometric studies on volcanic millstones is to recognize provenance and manufacturing areas of the raw material (volcanoes or volcanic regions). Following classical methods of the igneous petrology, before proceeding to the use of major-trace elements magmatic signatures, compatibility of the millstone samples with the volcanic source areas has to be established through thin section modal mineralogy and chemical classification (e.g., Total Alkali vs. Silica diagram).

Based on their widespread use in antiquity, lava millstones also provide evidence for the technological evolution of grinding techniques through time: Archaic saddle quern, Greek hopper-rubber (Olynthian type), composite Delian type, small to medium size rotary device (Morgantina type) and large hourglass rotary millstone (Pompeian type). Typologies of grinding tools coexisted in different periods, even if some technological developments marked transitions between cultures (Fig. 1). Literature data on the provenance of the lava millstones from the Protohistoric period to the Roman Empire are abundant throughout the Mediterranean. Literature data of the last four decades (e.g. Williams-Thorpe, 1988; Williams-Thorpe & Thorpe, 1993; Santi et al., 2021) point out several Italian areas of provenance: the Roman Volcanic Province such as the Vulcini Volcanic Complex (a strongly exploited leucite phonolite quarrying site near Orvieto) and Vesuvius; the Tuscan Volcanic Province (e.g., Radicofani neck); Vulture Volcano; Etna and Hyblaean Mountains in Sicily; Sardinia Volcanic Province (Mulargia site); volcanic islands of the Sicilian Channel (Pantelleria) and the Southern Tyrrhenian Sea (Aeolian Archipelago and Ustica Island). By contrast, lavas from the Levant Area (Lebanon, Israel, Jordan and Syria), Morocco (Middle Atlas), Libya (e.g., Gharyan area), Northeast Spain and France (e.g. Olot and Gerona; Massif Central, Agde), were mainly used as millstones

for local use and not transported by long sea-trade throughout the Mediterranean. Besides millstones investigated in famous terrestrial archaeological sites (e.g., Morgantina and Megara Hyblaea), grinding stones found in shipwrecked cargoes (e.g. Xlendi Bay, Gozo, Maltese Islands) contributed to exactly trace the trade networks in the Central-Western Mediterranean, from the volcano/volcanic area of provenance to the final destinations.

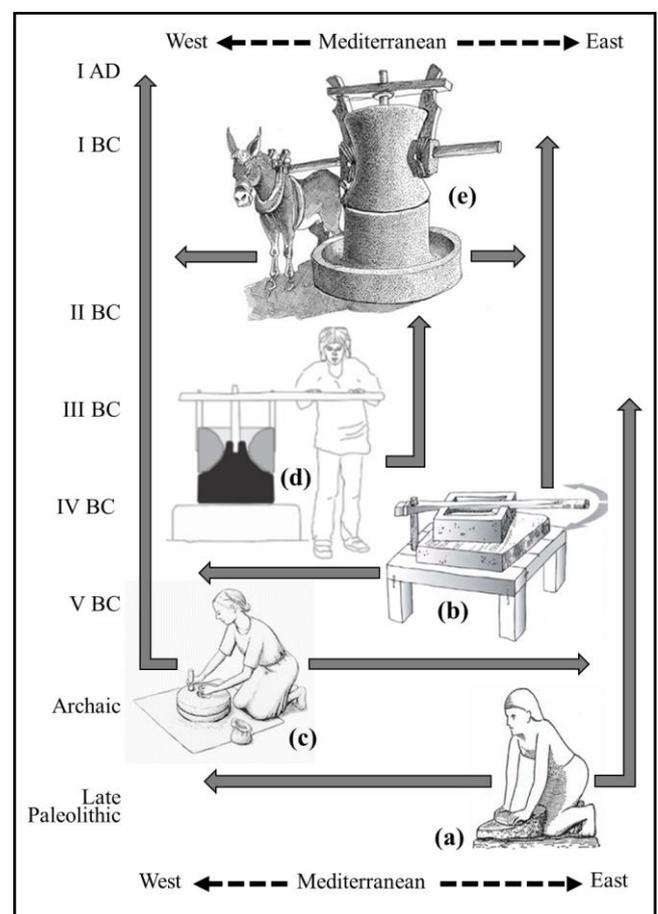


Figure 1 Evolutionary sketch of chronological and areal distribution of the grinding techniques in antiquity. **a)** saddle quern; **b)** hopper-rubber millstone; **c)** small rotary hand-mill; **d)** Morgantina type rotary millstone; **e)** Pompeian type millstone (from Santi et al., 2021 and references therein).

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Archeometric characterization of obsidian tesserae in the medieval floor mosaics of Otranto and Trani Cathedrals [12th Century, Apulia, Italy]

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The contribution, proposed for GABeC 2025 CONFERENCE - SCIENCE AND CONSERVATION OF GOMATERIALS IN CULTURAL HERITAGE, describes the first chemical-analytical study conducted on obsidian tesserae present in the medieval floor mosaics (12th century AD) of the Cathedrals of Otranto (LE) and Trani (BAT). Both mosaic works, of great historical and artistic relevance, are mainly composed of polychrome limestones or marbles; however, in some areas of major liturgical relevance and in several scenes with high symbolic value, tesserae of coloured artificial glass and of obsidian are present. Mainly natural glass is particularly used in anthropomorphic and zoomorphic figures to represent the eyes. The characterisation of the obsidian tesserae was performed *in situ*, at the two cathedrals, using portable X-ray fluorescence spectrometer (pXRF) (Fig. 1). Using the same instrument, pXRF spectra were acquired from obsidian samples of known provenance from the main Mediterranean sources (Monte Arci, Pantelleria, Palmarola, Lipari - Italy - and Melos and Gyalis - Greece). Although pXRF determination performed in air does not allow for the measurement of all elements, particularly those with a low atomic number (Na, Mg and Al), the observed elemental composition, which varies according to the magma of origin and its formation conditions, confirms a variability consistent with the data acquired from the known samples. Furthermore, two obsidian samples, collected during previous restoration works from the apsidal area of the Otranto Cathedral, were also analyzed using scanning electron microscopy coupled with energy dispersive microanalysis (SEM-EDS). The compositional characterization of the glassy matrix, along with the presence of microphenocrysts, suggests Lipari Island (ME) as the most probable area of provenance. Considering the limitations of *in situ* analysis and the overall variability of the spectra, the data were compared using an unsupervised statistical analysis technique. Specifically, Principal Component Analysis (PCA) was applied to suitably pre-treated pXRF spectra. The results in the scatter plots, with an

explained variance of 99% and two components, delineate two distinct clusters: the first associates the data relating to the obsidian tesserae from Otranto with those from the Lipari source; the second links the obsidian samples present in the mosaic pavement of the Trani Cathedral with those related to samples originating from Pantelleria.

The identification of the source area of obsidian artefacts is very important because it can provide information about trade routes active in middle age as well as interactions between patrons and artisans.

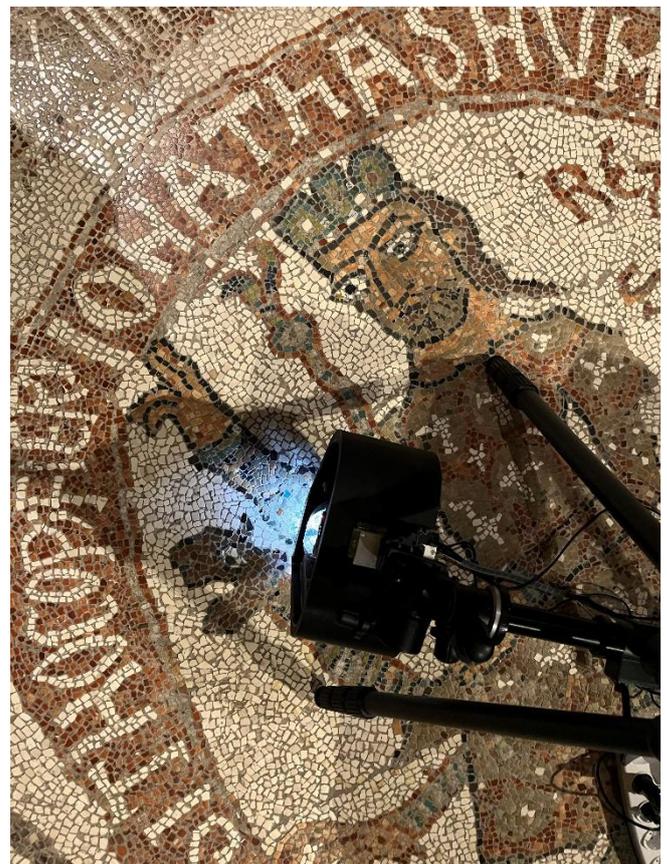


Figure 1 On-site analysis campaign, pXRF analysis, representation of King Solomon, 12th century, presbyterial area, Cathedral of Santa Maria Annunziata, Otranto (LE).

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Powdered Olive Stone (POS) in lime mortars for the conservation of Cultural Heritage

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The building industry plays a major role in influencing environmental conditions, mainly because it depends heavily on natural resources (Alengaram & Muhit, 2013). Continuous extraction of these materials leads to serious environmental degradation and resource depletion. As the global demand for building materials continues to rise, the sector must move toward more sustainable practices. Using alternative raw materials and reducing the consumption of non-renewable resources are essential steps to minimize the industry's ecological impact and protect natural reserves (Firoozi et al., 2024).

This research explores the potential use of Powdered Olive Stone (POS), an agricultural residue, as a partial substitute for quartz sand in lime-based mortars employed in the restoration and preservation of historical buildings. In this study, various mortar mixes were formulated by replacing natural quartz aggregates with POS at proportions of 5%, 10%, and 15%. Furthermore, the impact of nano-silica addition in such mixtures was assessed as well.

After the curing phase, the samples were subjected to an extensive series of tests and measures to evaluate their mechanical and physical behavior which include colorimetric assessment, capillary water absorption test, ultrasonic pulse velocity measurements, bulk density determination, salt crystallization resistance and mechanical testing for compressive and flexural strength. In addition, optical and scanning electron microscopy investigations were conducted.

The findings reveal that incorporating POS notably alters the physical and mechanical characteristics of lime mortars, allowing such properties to be adjusted to satisfy specific demands of conservation interventions.

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