
# REMTECH EXPO 2024

Ferrara (Italy)
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## Stati generali delle miniere in Italia

Proceedings Poster Session:
(Short papers and Abstracts)

*Coltivazione e recupero di materie prime critiche da aree di cava e da aree minerarie anche in un'ottica di economia circolare e di valorizzazione del patrimonio di conoscenze dell'arte mineraria*

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**Volume unico: 79 pagine**

# *Indice*



## *Short papers*

# *Abstracts*

# *Prefazione*

*Si prevede che entro il 2050 la domanda di materie prime strategiche nell'Unione Europea raddoppierà e che, per tale ragione, la diversificazione dell'approvvigionamento delle stesse sarà un obiettivo essenziale da perseguire.*
*Nel solco di questa riflessione, l'11 aprile2024 viene emanato il regolamento EU 2024/1252 "Critical Raw Material Act" recepito poi in Italia con il D.Lgs 84 del 25/6/2024.*

*La conoscenza e la corretta valutazione delle risorse minerarie dell'UE e la fattibilità del loro sfruttamento diventa pertanto una questione chiave nel dibattito internazionale attualmente in corso, inerente la sicurezza e l'approvvigionamento delle materie prime strategiche per lo sviluppo dell'economia dell'Europa e la mitigazione dei relativi potenziali rischi.*

*Gli "Stati Generali sulle Miniere", organizzati dal Politecnico di Torino, dall'Università di Ferrara e dal Consiglio Nazionale dei Geologi in collaborazione ed all'interno della XVIII edizione di RemTech Expo 2024 (www.remtechexpo.com) a Ferrara, si propongono l'avvio di un percorso stabile, con la finalità di focalizzare l'attenzione sulle prossime sfide, di natura tecnica, tecnologica, ambientale e sociale, connesse ai nuovi impulsi generati dal dibattito sulle attività minerarie - prospezione, estrazione, trasformazione, recupero di risorse minerarie dai rifiuti estrattivi - ma anche di riunire al tavolo del confronto, proficuo e permanente, i principali attori coinvolti, quali, enti governativi, enti territoriali, aziende, università, professionisti, esperti tutti, cittadini.*

*La sessione plenaria degli Stati Generali di Ferrara è stata ulteriormente arricchita mediante l'allestimento di una importante Sessione Poster, totalmente fruibile durante i tre giorni della manifestazione, dal 18 al 20 Settembre, sul tema della "Coltivazione e recupero di materie prime critiche da aree di cava e da aree minerarie anche in un'ottica di economia circolare e di valorizzazione del patrimonio di conoscenze dell'arte mineraria" di cui ai Conveners Stefano Columbu (columbus@unica.it, Università di Cagliari), Rosalda Punturo (rosalda.punturo@unict.it, Università di Catania).*

*L'obiettivo progettuale finale è quello di definire un appuntamento annuale permanente a Ferrara, nell'ambito di RemTech, di proseguire l'approfondimento dei temi di interesse mediante incontri periodici ed operando di prossimità sui territori in occasione di appuntamenti che saranno via via definiti durante l'anno nella piena sinergia tra le Parti coinvolte e nel massimo rispetto dei ruoli e delle competenze di ciascuno, cercando di offrire un supporto concreto e fattivo al Paese e all'Europa.*

***Silvia Paparella***

*Consigliere Delegato Ferrara Expo*
*General Manager RemTech Expo*

# Industrial waste silico-aluminate ashes as raw material for the sustainable production of construction mortars

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## Abstract

*The recovery of waste materials, especially fly ash from coal combustion, is growing with a view to more sustainable production and reduction of industrial waste. Ash, widely produced by thermal power plants, is mainly composed of silicon, aluminium, iron and calcium oxides and can be reused as pozzolanic material in mortars. This approach not only reduces the environmental impact of disposal, but also improves the mechanical properties of building materials. In this study, different types of ash produced in about ten years by a thermal power plant were examined. The ashes were used as pozzolans in the production of environmentally friendly mortars, using silica sand as aggregate and hydrated lime or natural hydraulic lime as binder. Petrographic and mineralogical analyses were conducted through light microscopy, X-ray diffraction (XRD) and scanning electron microscopy (SEM-EDS). The mortar samples were then subjected to mechanical and physical tests, including the Uniaxial Compressive Strength Test and the Point Load Test. The results show that the addition of ash significantly improves the physical-mechanical properties of the mortars, with increased compressive strength and durability. Mortars with hydraulic lime showed higher mechanical strengths than those with hydrated lime, suggesting that fly ash may be an excellent pozzolanic material for the construction industry. The reuse of fly ash not only optimises the performance of construction products, but also contributes to environmental sustainability by reducing CO2 emissions and landfill waste.*

**Keywords**: flyash, sustainability, pozzolan, mortars, industrial waste.

## 1. Introduction

Waste ashes from thermal power stations is the solid particulate matter collected by the dedusting systems of coal combustion flue gas for electricity production. It consists of amorphous, micrometre-sized, spheroidal particles, resulting from the melting in the boiler and subsequent recondensation along the flue gas path of the inert silico-aluminous fraction present in the coal dust used for steam generation.

Coal combustion ashes, whose production in Italy has been in recent years even about 1 Mt/y and in Europe about 40 Mt/y, represent today an important resource for their possible use in construction materials. According to modalities specified by precise technical standards and in compliance with the regulations on the re-use of non-hazardous waste, they can be re-used in the construction sector for the production of cement-based premixes, mortars and concretes, where they play the role of an addition as a pozzolanic additive / aggregate-filler, improving the resistance and durability characteristics to atmospheric agents of the final products.

The opportunity to fully reuse this industrial waste, making it more and more valuable also from an economic point of view, in full compliance with stringent quality control specifications, is increasingly pushing the ash management methods towards those typical of a "product".


***Figure 1****. Location of the Sulcis coal basin.*

### *1.1. Aims of research*

The aim of this research is to test a series of ashes, produced by thermal power station over a period of about 10 years, as pozzolanic filler in the production of mortars with low environmental impact, using a silicate sand as aggregate and slaked lime (NL) or natural hydraulic lime (NHL) as binders.

## 2. Materials and methods

Four samples were chosen to produce mortars based on both air binder (hydrated lime) and hydraulic lime: P03, P09, P13, MC01. Before being used in the production of the mortars, the ashes were placed in an oven at 90°C for 48 hours and then ground to a fine grain size (<0.063 mm) using the colloidal mill with agate jars. Once the samples P02, P09, P13, MC01 were ground, they were ready to be mixed and kneaded with hydraulic lime in one case and with slaked lime in the second case, adding sand as an aggregate. Two main mixes were made, named 'A' and 'B', containing ash, and a third mix, named 'C', without ash, containing only slaked lime or hydraulic lime and sand, according to the volumetric proportions shown in Table 1.

| Mortar mixture | Ash samples (P02, P09, P13, MC01) | Hydraulic lime or lime (grassello) | Sand aggregate |
|---|---|---|---|
| A | 2 | 2 | 1 |
| B | 1 | 2 | 2 |
| C | 0 | 2 | 3 |

***Table 1****. Mortar types and volumetric proportions.*

The mortars were placed in centimetric plastic containers, each consisting of a total of twelve moulds into which six samples of the 'A' mixture and six samples of the 'B' mixture were poured, making a total of eight containers divided according to the addition of hydraulic lime or slaked lime. The ninth container containing body 'C' was made by dividing it into two, whereby six moulds are with hydraulic lime and six moulds with slaked lime. The mortar moulds were left to dry. After one week and one month, two cubes were taken from each container and subjected to physical-mechanical tests to assess their main characteristics (porosity, real and apparent density, mechanical strength). Thin sections were made and studied under the light of a polarising microscope to assess the textural characteristics.

## 3. Results

### *3.1. Microscopic features of mortars*

On microscopic analysis of the MCM01 lime mortar in figure 2 with parallel niches, a brown matrix is observed in which an aggregate consisting of silicate phases (mainly quartz and feldspars) is present, covering approximately 50 per cent of the cross-section. The 1.8 mm mineral is an aggregate of quartz and plagioclase. Figure 3 shows the ash particles used in the slurry, which are irregular in shape and generally around 0.3 mm in size; the part of the ash matrix is almost always extinct and no reaction edges with the carbonate binder are observed. The presence of pores of varying size (often around 0.1-0.4 mm) induced by the preparation of the mortar or the processing of the section itself is also observed.

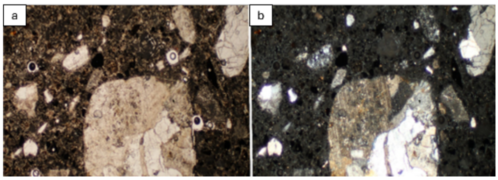


***Figure 2****. Photomicrographs of MCM01 lime mortar in nicols // (a) and nicols X (b) (2.5x). Detail of the silicate aggregate (quartz and feldspar).*

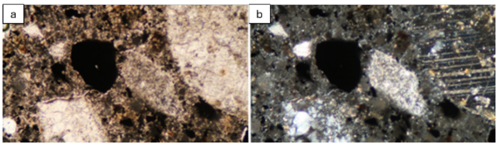


***Figure** 3. Photomicrographs of MCM01 lime mortar in nicols // (a) and nicols X (b) (10x). Detail of ash particles used in the mix.*

Observation of the section of MCM01 mortar using hydraulic lime as binder under the microscope (Figure 4a) reveals many aggregates covering the section at a rate of 50-60%. They are mainly quartz and feldspars ranging in size from 1 mm to 0.2 mm, homogeneously distributed with an irregular shape. Figures 4c and 4d show in detail the ash particles used with an ellipsoidal shape that has no reaction edges with the hydraulic binder. In the matrix, looking at figure 4d, pseudo-crystalline phases with high interference colours can be seen and it is assumed that they may be partly C-S-H and C-A-H phases and partly calcite formed by carbonation of C-H from hydration of hydraulic lime.

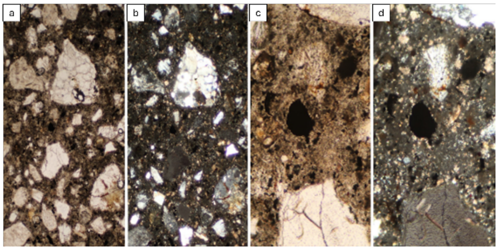


***Figure** 4. Photomicrographs of the MCM01 hydraulic lime mortar in nicols // (a) and nicols X (b)(2.5x). (c) and (d) show in detail the ash particles used with an ellipsoidal shape.*

### *3.2. Physical-mechanical features of mortars*

To verify their improvement and to understand their physical-mechanical behaviour, some main physical properties were compared (porosity, density, water absorption, saturation) in addition to the mechanical resistance, which certainly remains one of the key properties for defining the hydraulicity degree and consolidation of pozzolanic mortars.

As shown in figure 5 Natural Hydraulic Lime mortars (NHL), as might be expected, exhibit a lower porosity (around 42-46%) and a correspondingly higher bulk density (around 1.35 g/cm$^3$).

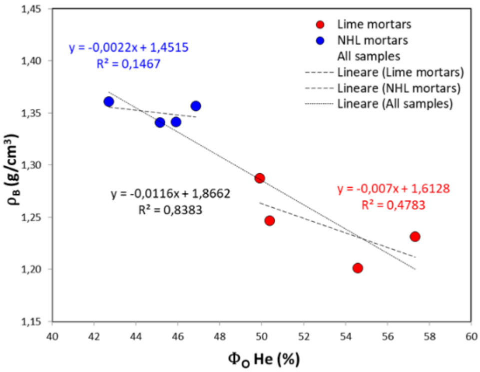


***Figure** 5. Helium open porosity against bulk density.*

Figure 6 shows the helium open porosity (close to the total porosity of the sample, i.e. interconnected open porosity and closed porosity) against the puncture resistance index $Is_{(50)}$ calculated through the PLT test. The graph shows a clear negative correlation between the two parameters, with a correlation index $R^2$ of 0.70 in the case of 7-day broken samples and 0.89 in the case of 28-day broken samples.

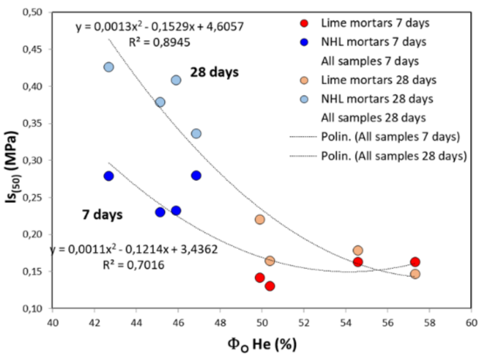


***Figure** 6 Helium open porosity against puncture resistance index $Is_{(50)}$.*

It clearly shows the different physical-mechanical behaviour between the two types of mortars which, due to a very different binder, show very different strength index values: around 0.25 MPa for the hydraulic mortars versus 0.15 for the air lime mortars for the samples broken at 7 days, and 0.40 MPa versus 0.18 MPa after 28 days of curing.

The graph in figure 7 shows the bulk density, inversely correlated with porosity, against the puncture resistance index $Is_{(50)}$ calculated through the PLT test. The graph shows an even stronger positive correlation between the two parameters, with an $R^2$ correlation index of 0.97 in the case of 7-day broken samples and 0.91 in the case of 28-day broken samples.

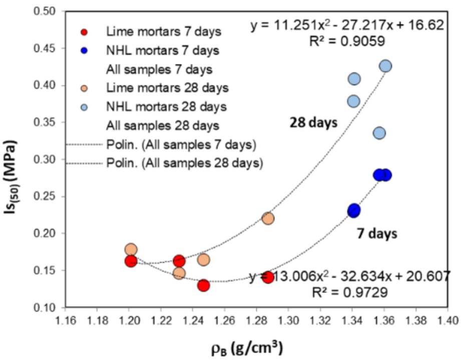


***Figure** 7. Bulk density against puncture resistance index $Is_{(50)}$.*

## 4. Conclusions

The results concerning the puncture resistance $Is_{(50)}$ calculated through the PLT test clearly highlight the different physical-mechanical behaviour between the two types of mortars (with air lime and with hydraulic lime). The strength index values are understandably different: around 0.25 MPa for hydraulic mortars versus 0.15 for air lime mortars for the 7-day cracked samples, and 0.40 MPa versus 0.18 MPa after 28 days of curing.

The increase in the case of hydraulic mortars is decidedly greater than in the case of airborne mortars, due to the greater presence of the C-S-H and C-A-H phases in the former. However, while in the former case a further curing time would not substantially improve the mechanical behaviour, in the case of airborne mortars the following months would lead to an undoubted increase in resistance values which could even double after 9 months. In any case, already the time of approx. 1 month has led to an increase in the mechanical strength of pozzolanic lime putty mortars, albeit not so clearly.

At the conclusion of the study, therefore, we can affirm that the ashes analysed and studied deriving from the waste products of coal combustion can be used as pozzolanic material for the hydraulicisation of mortars to be used in the building industry, either as bedding mortars in the case of hydraulic limes, or as plastering mortars or low mechanical strength in the case of pozzolanic limes made with a hydrated lime binder.

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# Preliminary study on the possibility of concentrating REEs minerals from Granite EW in Sardinia (Italy)

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## Abstract

*The recently enacted Critical Raw Materials (CRM) Act establishes that CRM utilized within European Union should be derived from recycling. In the context of a circular economy, evaluating the resource potential of unconventional deposits, such as extractive wastes, is of significant importance.*

*This research specifically examines a granite quarry in the Budduso-Alà dei Sardi extractive district (Sardinia, Italy), which was identified by the LIFE REGs II and NOP ESF REACT-EU (F71B21005760007) projects. The aim of the study is to investigate the qualitative and quantitative presence of Rare Earth Elements (REE) in waste generated from ornamental granite quarrying. In this area the Sardinian Batholith was a source of substantial amount of granite extractive waste, as Sardinia has historically been a global leader in the production of ornamental granite.*

*Preliminary results from SEM-EDS investigations on granite waste thin-sections and a processing approach for the recycling of granite waste, including gravity and magnetic separations, highlighted the potential of this material as a possible source of REE, due to presence of allanite, a LREE-epidote.*

**Keywords**: Critical Raw Materials, REE, Sardinia, Granite Waste, Recycling.

## 1. Introduction

The "CRM Act" outlines benchmark parameters across the value chain of strategic raw materials and for EU supply diversification. These include requirements such as: at least 10% of annual consumption is derived from extraction, at least 40% from processing, and at least 25% from recycling. Additionally, it aims to limit the EU's reliance on a single third-country source to no more than 65% of its annual consumption (European Commission, 2023; The European Parliament and The Council of the European Union, 2024)

Because of the similar chemical properties that characterize Rare Earth Elements (REE) among themselves, there are few effectively exploitable deposits in the world. Predominantly in carbonatite complexes and pegmatitic granitoid bodies, the subtle variations in the properties of REE allow significant fractionation and economically exploitable enrichment of small intrusive bodies and/or intrusive veins consisting of one or more REE minerals, such as allanite, REE oxides, apatites, and carbonates.

Sardinia's ornamental granite quarries have in the past generated high concentrations of unmarketable waste (Figure 1), mostly pegmatite bodies and veins with REE-enriched late- magmatic and deuteric mineralogical phases).

The huge amount of these waste accumulations has resulted in high land consumption and landscape distortions, but with the increased REE demand they now represent an important resource, as they can contribute to the implementation of the EU "CRM Act".

### *1.1 Aims of research*

This research specifically examines a granite quarry in the Budduso-Alà dei Sardi extractive district (Sardinia, Italy), which was identified by the LIFE REGs II and NOP ESF REACT-EU (F71B21005760007) projects., where granite from

Corsica-Sardinia batholith had been extracted for a long time. This study reports the results of observations and microanalysis performed using Scanning Electron Microscope (SEM) on thin section of granite waste samples from the test site. These observations were conducted in order to identify potential REE-bearing minerals and characterize their composition.

***Figure 1.*** *Examples of granite waste within the quarry.*

Furthermore, the preliminary results of a processing method aimed at evaluating the feasibility of obtaining REE-bearing mineral-enriched fractions are presented.

## 2. Materials and Methods

### *2.1 SEM-EDS observations*

Thin sections for petrographic observation were obtained from granite waste samples from the quarry under study. Ten of these thin sections were subjected to observations using a Zeiss EVO MA 15 SEM (Carl Zeiss, Oberkochen, Germany), coupled with an X-Max 50N energy-dispersive X-ray spectroscopy (EDS) detector (Oxford Instruments, Abingdon, U.K.).

### *2.2 Processing of granite waste*

Nine samples were subjected to a processing procedure involving crushing and sieving to retain material within the particle size range of 0.125–0.850 mm. The processed material was then subjected to gravity separation using a Gemini Masa G-150 wet shaking table (Onur Makina, Eskisehir, Turkey). This procedure resulted in the separation of three distinct fractions: the light fraction (lower specific gravity), the intermediate fraction (higher specific gravity than the light fraction), and the heavy fraction (highest specific gravity).

Each fraction was dried at 105 °C for 24 hours, after which ferromagnetic minerals were removed using a magnet. The fractions were then subjected to magnetic separation using an isodynamic magnetic separator L-1 (S.G. Frantz Co., Tullytown, U.S.). This process was carried out in two steps: a first low-intensity separation to isolate the highly paramagnetic minerals, resulting in three distinct fractions (light, intermediate, heavy). A second separation, conducted at high intensity, was used to separate the weakly paramagnetic minerals, yielding three additional fractions (light, intermediate, heavy). For the analytical phase, after grinding, the resulting powders were then subjected to Loss On Ignition (L.O.I.) analysis. For the determination of major oxides and trace elements compositions, the WD-XRF (Wavelength Dispersive X-ray Fluorescence) technique was used. Each powdered sample was pressed into pellets using a hydraulic press on a boric acid support. These pressed pellets were then analyzed with a Thermo ARL Advant'XP+ Wavelength Dispersive X-ray Fluorescence Spectrometer (Thermo Scientific, Waltham, MA, USA). The accuracy of the analyses, evaluated based on results obtained from international geological sample standards, and the precision, expressed as the standard deviation of repeated analyses, ranged between 2% and 5%. The processing of the acquired intensities and the correction of matrix effects were carried out according to the model proposed by Lachance and Trail (1966).

## 3. Results and discussion

### *3.1 SEM-EDS observation*

The presence of numerous REE-bearing minerals was observed. These minerals were characterized by euhedral to subhedral morphology and compositional zoning.

This zoning consistently exhibited a higher concentration of REEs in the core, which decreased towards the mineral boundaries (Figure 2). From a compositional standpoint, these minerals displayed calcium content ranging from 7–11 wt.%.

They also exhibited elevated concentrations of light REEs (6–11 wt.% Ce, 3–6 wt.% La, 3–4 wt.% Nd, etc.). Additionally, minerals with higher Fe content (>11.5 wt.%) and minerals with lower Fe content (<11.5 wt.%) were identified.

Based on these observations, it is hypothesized that these minerals may be associated with allanite, a REE-rich epidote (Giere and Sorensen, 2004), whose presence is well-documented in the granites of this region of Sardinia (Soorajal, 2017).

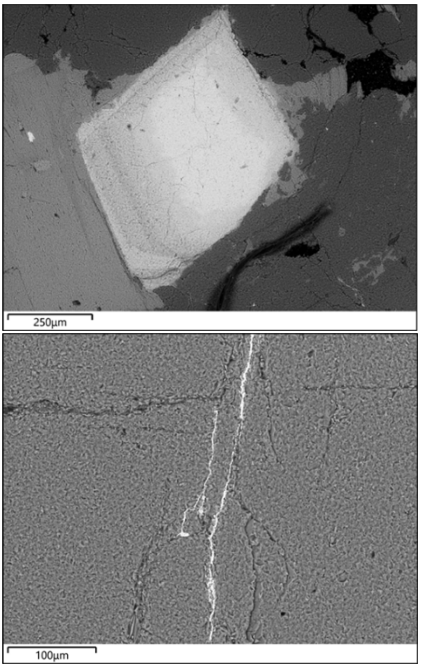


***Figure 2**. Examples of SEM-EDS backscattered electron images related to REE-bearing minerals found in extractive granite waste.*

Additionally, of significant interest was the identification of numerous minerals that appeared to fill fractures or cavities (Figure 2), ranging in length from a few hundred micrometers to a few micrometers in thickness, predominantly composed of light REE oxides, particularly Ce and La.

These minerals displayed very low Fe content (< 2 wt.%). They were found in direct contact with the previously identified allanites or in very close proximity to them.

*3.2 Processing of granite waste*

Regarding the highly paramagnetic fraction, analytical results revealed (Figure 3) that the heavy fraction exhibited the highest concentrations of Ce (> 2600 ppm), La (> 900 ppm), and Nd (> 980 ppm). Similarly, this fraction also showed the highest Th content (> 380 ppm). The intermediate fraction also displayed relatively high values for these elements (> 1600 ppm, > 500 ppm, > 660 ppm, and > 280 ppm, respectively).

In contrast, the light fraction showed significantly lower concentrations compared to the aforementioned values.

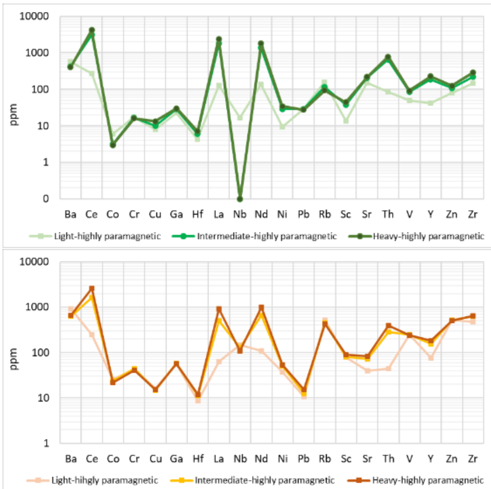


***Figure 3.** Line diagram illustrating the concentration of trace elements , obtained through WD-XRF analyses. (top) highly paramagnetic fractions; (bottom) weakly-paramagnetic fractions.*

Regarding the weakly paramagnetic fractions, slightly different behaviours were observed compared to the previous results (Figure 3).

Specifically, no significant differences in LREE concentrations were found between the heavy and intermediate fractions, as both exhibited similar levels of these elements.

Notably, these samples were characterized by very high contents of Ce (approximately 4000 ppm), La (approximately 2400 ppm), and Nd (approximately 1800 ppm). The Th content was higher (781 ppm) compared to the highly paramagnetic fractions. Additionally, these two samples were distinguished by the near-total absence of Nb. In contrast, the light fraction consistently displayed significantly lower concentrations of these elements compared to the other two. Based on these results, it appears that the combination of gravity and magnetic separation is also effective in concentrating allanite, generating two equivalent fractions (heavy and intermediate).

Based on the results obtained from SEM-EDS observations, it appears that the varying iron concentrations may indeed have influenced the performance of allanite during magnetic separation. Specifically, allanite with higher iron content likely exhibited highly paramagnetic behaviour, while those with lower iron content displayed weakly paramagnetic behavior.

## 4. Conclusions

The results obtained in this study suggest that the granite extractive waste from the Buddusò-Alà dei Sardi quarrying district has the potential for the extraction of REEs. This is attributed to the presence of allanite, a LREE-epidote, which exhibits significant concentrations of Ce, La, and Nd. By applying a processing method involving gravity separation and magnetic separation, it is possible to obtain fractions where the concentration of these elements reaches several thousand ppm. These findings underscore the need for further investigation, such as exploring the potential of this process through semi-industrial scale tests. Additionally, it is essential to examine the subsequent steps in this process to determine the percentage of REEs that can be recovered from the obtained fractions and to assess the overall costs of the entire procedure. Utilizing this waste as a source of REEs could bring multiple benefits to the area under study, such as landscape rehabilitation, the creation of new jobs, and the revitalization of the extractive industry. Furthermore, it could actively contribute to achieving the goals set forth by the "CRM Act."

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# Mineralogical and petrographic analysis of the serpentinites in the Pollino Massif quarries (Southern Apennines)

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## Abstract

*The serpentinites of the Pollino ophiolite Massif have been extensively studied for their mineralogical, petrographic, and chemical characteristics, revealing significant insights into their impact on environmental and human health. The mineralogical and petrographic analysis identified the presence of lizardite, antigorite, chrysotile, chlorite, magnetite, tremolite, actinolite, pyroxene, calcite, dolomite, aragonite, and talc, with various polymorphs of serpentine being the most common. Capturing atmospheric $CO_2$ and storing it in natural rock systems through carbonation reactions is a promising approach for greenhouse gas mitigation. This research relies on the use of hydrated ultramafic rocks, which are prevalent in orogenic belts worldwide. Integrating petrographic and mineralogical studies of serpentinites in Southern Italy's ophiolites could serve as a foundation for examining natural materials that may be utilized for $CO_2$ storage and sequestration. Special attention should be given to the carbonate phases produced by carbonation processes to evaluate the potential of the Pollino Massif serpentinites for induced mineral Carbon Capture Storage (CCS). If proven effective, this technique and the Pollino Massif serpentinites could play a crucial role in protecting our planet's climate health.*

**Keywords**: Serpentinites; health risk; $CO_2$ storage and sequestration; mineralogy and petrography; Pollino Massif; ophiolites.

## 1. Introduction and aim

Carbon dioxide ($CO_2$) is a greenhouse gas that significantly impacts Earth's temperature and global warming patterns. Its atmospheric concentration has increased notably over recent decades (Figure 1). Carbon management involves capturing, storing, transporting, and utilizing $CO_2$ emissions, as well as removing it from the atmosphere. The EU Industrial Carbon Management Strategy aims to develop these technologies and their regulatory and investment framework, focusing on i) Capture and storage of CO2 (CCS); ii) Capture and utilization of $CO_2$ (CCU); iii) Removal of $CO_2$ from the atmosphere.

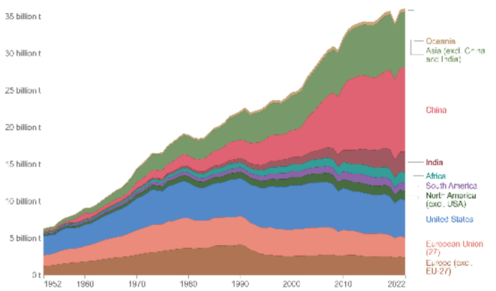


***Figure 1***. *Annual $CO_2$ emissions by world region modified after Global Carbon Budget (2023).*

Mineral carbonation is a process where $CO_2$ reacts with minerals to form stable solid carbonates, representing an environmentally and geologically stable method for carbon disposal. Studies on the Pollino mafic-ultramafic massif in Calabria have shown that serpentinites, due to their highly fractured texture, are particularly suitable for carbonation. Future research could focus on these rocks to determine their effectiveness as a site for induced mineral Carbon Capture Storage (CCS), contributing to international climate change mitigation efforts. Recent studies have also documented the presence of asbestos minerals in the area, which is significant for environmental and human health. This research aims to provide a mineralogical and petrographic characterization of the Pietrapica quarry serpentinites in the Pollino Massif (southern Apennine; Figure 2) and the potential future use of these rocks for $CO_2$ capture. Serpentinites of the Pollino mafic–ultramafic massif have been widely studied for their mineralogical, petrographic, and chemical characteristics, which also provided relevant findings on their impact on environmental and human health (Bloise et al., 2019; Dichicco et al., 2018, 2019; Punturo et al., 2023a, b; Rizzo et al., 2016, 2018;2024; Paternoster et al., 2021).

## 2. Geology of the studied area

The Pollino Massif in the Southern Apennines (Italy) is located within the continental convergence zone between Eurasia and Africa and is composed mainly of Mesozoic and Tertiary magmatic and sedimentary rocks derived from the Ligurian ocean basin and the African passive margin. These oceanic and continental crustal rocks are overlain by Pliocene – Pleistocene terrestrial deposits (Figure 2; Cello and Mazzoli, 1999). The Pollino Massif and the continental crustal rocks make up the Liguride Complex of the Apennines and the Calabria region (Knott, 1994; Monaco and Tortorici, 1995; Stampfli et al., 2002). The Pollino Massif (Jurassic Palaeo – oceanic lithosphere) is part of the Frido tectonic unit, which includes a metasedimentary sequence (phyllite, meta-arenite, quartzite, and blocks of calcschist and metapelite; (Monaco and Tortorici, 1994) and a Hess-type, incomplete ophiolite, composed of serpentinite, metabasalt, metagabbro, metapillow lavas, and dismembered metadolerite dikes (Spadea, 1982). The Pollino massif likely represents a fossil ocean–continent transition zone or a continental margin ophiolite (Dilek and Furnes, 2014), reminiscent of the modern Western Iberia rifted margin (Pinheiro et al., 1996). The second major tectonic entity in the Frido Unit is a non-metamorphic Calabro-Lucano Flysch or the North Calabrian Unit. The Pollino Massif tectonically overlies the North Calabrian Unit and forms the structurally highest tectonic unit in the Liguride Complex.

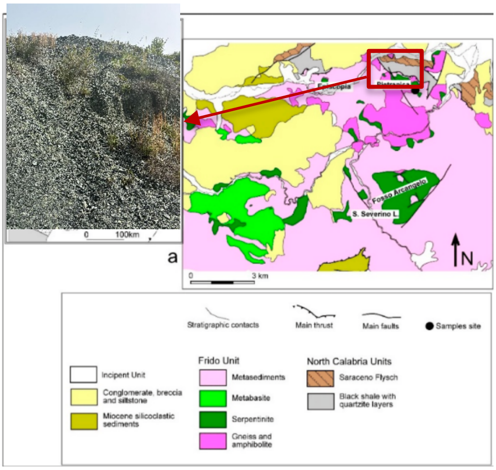


***Figure 2**. Localization and geology of the studied area. Modified after Rizzo et al., 2020.*

## 3. Materials and methods

Petrographic analysis was carried out by using a Nikon Alphaphot-2 YS2 optical microscope on thin sections of rock samples. Semi-quantitative mineralogical analyses were performed on randomly oriented powder by using a Philips X’Pert 3040PW with CuKα radiation, 40 kV and 40 mA, 1 s per step, and step scan of 0.01 °2θ, in the Department of Sciences at University of Basilicata. Raman analyses were performed at the Department of Sciences, University of Basilicata. The used spectrometer, a Horiba Jobin-Yvon LabRam HR800, is equipped with a HeNe laser source with a wavelength of 633 nm. The detector operated at

−70 °C with an edge filter excluding the detection shift below 150 cm$^{-1}$. The evaluation of the calibration of the instrument was made by checking the position of the Si band at ±520.7 cm$^{-1}$. The measurements were performed using optical microscope Olympus with objective of 10×, 50× and 100× and the Raman spectra were collected in the spectral ranges of 200–1200 cm$^{-1}$ and 3200–3800 cm$^{-1}$ with an average of 5 acquisitions of 10 s. Micromorphological analysis was undertaken by using Scanning Electron Microscopy (ESEM) at the Microscopy Laboratory of the Department of Basic and Applied Sciences, University of Basilicata, Italy. SEM-EDS investigation was carried out on serpentinite representative fragments with a Tescan-Vega\\LMU scanning electron microscope (SEM), equipped with an energy-dispersive X-ray spectrometer (EDS) Edax Neptune XM4 60 (SEM laboratory, Department of Biological, Geological, Environmental Sciences, University of Catania.

## 4. Results

Petrographic analysis revealed that the Pollino Massif serpentinites are characterised by pseudomorphic and vein textures (Figure 3a,3b). The pseudomorphic texture is represented by a mesh texture in which serpentine and magnetite phases statically replaced olivine grains whereas yellow brown bastite replaced orthopyroxene.

The vein texture is represented by different sub-millimetric veins intersecting each other and cross crossing the pseudomorphic texture. Scanning Electron Microscope micromorphological analysis revealed either the typical lamellar habit of serpentine polymorphs such as antigorite and lizardite; furthermore, Fe-oxides mineral phases have been also observed (Figure 3c,3d).

In the studied serpentinites, the protolith minerals are olivine, pyroxenes and spinel, whereas the secondary minerals are serpentine, chlorite, magnetite, prehnite, and amphibole. The results of the semi-quantitative XRPD X-ray diffraction analysis revealed that the mineralogical phases of the serpentinite samples mainly include serpentine (i.e. lizardite, antigorite and chrysotile), chlorite, magnetite, tremolite, actinolite, pyroxene, and calcite.

The most abundant minerals are polymorphs of serpentine including lizardite (d = 7.27 Å), chrysotile (d = 7.32 Å), and antigorite (d = 7.23 Å) and amphibole minerals such as actinolite (d = 8.31 Å) and tremolite (d = 2.94 Å) (Figure 4a).

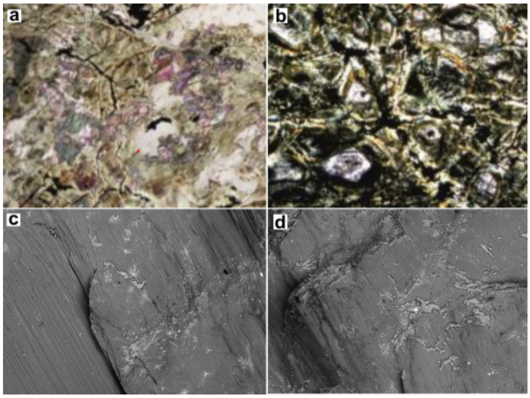


***Figure 3.*** *a) pseudomorphic textures, lower polarizer; b) mesh texture with relicts of olivine crystals, crossed nicols; c, d) SEM images showing the matrix details of the selected serpentinite samples.*

Raman spectroscopy identified the main mineralogical phases which are serpentine, chrysotile, lizardite and antigorite. Serpentine showed the main peaks at 696 cm$^{-1}$, 394 cm$^{-1}$, 236 cm$^{-1}$ at low wavenumbers, regarding the high wavenumbers we identified peaks at 3704 cm$^{-1}$ and 3693 cm$^{-1}$. The chrysotile has the main low wavenumber peaks at 694 cm$^{-1}$, 388 cm$^{-1}$, 235 cm$^{-1}$ while the high wavenumber peak was identified at 3699 cm$^{-1}$. The main low wavenumber peaks of lizardite were observed at 698 cm$^{-1}$, 389 cm$^{-1}$, 233 cm$^{-1}$ while the main high wavenumber peak was identified at 3685 cm$^{-1}$. Finally, regarding the low wavenumbers in the Raman spectra, antigorite showed the main peaks at 689 cm$^{-1}$, 378 cm$^{-1}$, 230 cm$^{-1}$ whereas the main high wavenumber peaks were identified at 3701 cm$^{-1}$ and 3672 cm$^{-1}$ (Figure 4b).

## 5. Conclusions

The petrographic and mineralogical study of serpentinites from the Frido Unit cropping out in the Pietrapica quarry indicates that Mg-silicates, predominantly serpentine and, to a lesser extent, olivine, are viable for carbonation purposes.

Utilizing serpentine rocks for $CO_2$ storage is an emerging technique in the carbon capture and storage (CCS) field. This technology aims to capture $CO_2$ produced by industries and power plants, storing it underground, thus reducing greenhouse gas emissions.

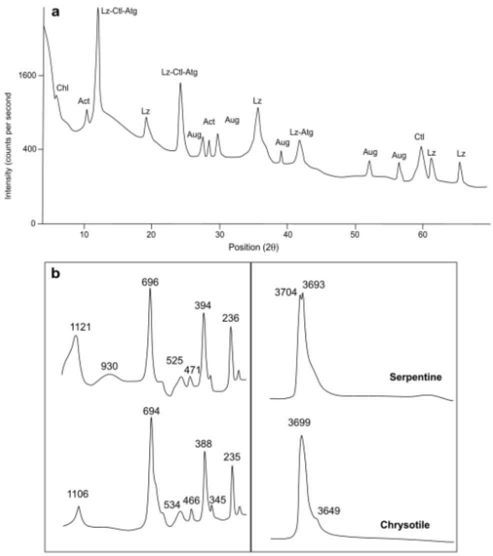


***Figure 4.*** *a) XRPD diffraction peak of selected sample; b) Raman spectra at low and high wavenumbers of selected sample.*

This paper also proposes exploring the suitability of natural analogue systems using different approaches across various sites in the Pollino area (Southern Apennines). The large-scale application of mineral sequestration holds significant potential for remediating mine sites and reducing greenhouse gas emissions. This technique could enhance the characterization of many tailings materials and quantify $CO_2$ sequestration. Recent studies, such as those by Lavikko et al. (2016), highlight the importance of mineralogical and petrographic studies in optimizing the mineral carbonation process.

Furthermore, recent research has demonstrated that lizardite, amphiboles, and pyroxenes are suitable for mineral carbonation (Sjöblom and Eklund, 2014; Byggmästar, 2011). In the works which deal with carbonation processes, it is important to consider the mineralogical structure, parent rock, and subsequent rock transformation through metamorphosis. These integrated studies can help select potential injection sites on a field scale and identify additives or pre-treatment strategies to optimize carbonation reactions of Mg-silicate minerals.

Therefore, a multi-analytical study regarding the petrographic and mineralogical study of naturally occurring serpentinite rocks in ophiolites cropping out in the southern Apennines can be useful for researching natural materials suitable for $CO_2$ capture and storage. Extensive research in this area is crucial to develop more efficient and sustainable methods for reducing carbon emissions and mitigating climate change.

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# Recovery of quarry waste as a pozzolanic additive in mortars

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## Abstract

*The recovery of quarry waste is a crucial issue for the sustainable management of natural resources. Extractive activities generate large amounts of waste materials, which in the past were often disposed of in landfills, leading to negative environmental and economic consequences. Thanks to new technologies and increased ecological awareness, these materials are now increasingly being reused in various sectors, such as construction and environmental restoration. This approach promotes a circular economy, reducing environmental impact and optimizing resource use. In a specific study, the use of waste from a perlite quarry in Monte Arci, Sardinia, was evaluated as a pozzolanic material for lime-based mortars. The perlites, silicate and vitreous rocks, were ground into powder and mixed with lime and sand, using both quicklime and lime putty. The samples were tested at time intervals (from one week to two years) to verify their physical and mechanical properties. The results showed a progressive improvement in mechanical strength, with values increasing from 4-6 kg/cm² after one week to 18-25 kg/cm² after two years. Porosity initially increases due to water evaporation, but later stabilizes with carbonation. Vapor permeability tests revealed good breathability, making these mortars suitable for humid environments. The good water-repellent characteristics and the quality of perlites as a pozzolanic additive make them ideal to produce plasters, both for internal and external use.*

**Keywords**: recovery, sustainability, pozzolan, perlite quarry.

## 1. Introduction

Pozzolanic mortars are a type of building material named after the city of Pozzuoli, located near Naples, where in ancient times a particular volcanic rock called pozzolana was quarried. These types of rock, when finely ground and mixed with lime, produce a mortar with remarkable strength and durability properties. The ancient Romans were among the first to exploit the properties of pozzolana in the construction of civil works, such as roads, bridges or aqueducts, as this formulation allowed for stronger and more durable structures than traditional mortars. Their ability to harden even in the presence of water made them particularly suitable for constructions exposed to weather and humidity. Today, the research and development of these geomaterials has become a topic of central importance in the building industry. First, compared to traditional modern mortars, they have a low energy impact in their production, as the reaction that produces the waterproofing phases (C-S-H and C-A-H) takes place cold. Furthermore, their use as mortars for the restoration of ancient buildings is increasingly common, given the similarity of physical-mechanical characteristics between them and the geo-materials with which they were built.

***Figure 1****. Packaging of cylindrical mortar specimens.*

### *1.1. Aims of research*

The research aims to study the physical and mechanical characteristics of various pozzolanic mortar formulations and to understand the reactivity relationships between lime and pozzolan. Various types of volcanic rocks of rhyolitic composition from various parts of Sardinia were used as MAP (Materials with Pozzolanic Activity).

## 2. Materials and methods

The pozzolanic mortars (Fig. 1) studied were produced from five different MAPs (Cpz1, Cpz5, Cpz11a, Cpz8 and RyMs), volcanic rocks of rhyolitic composition. The MAPs used come from two different volcanic complexes in Sardinia. The pozzolans Cpz1, Cpz5, Cpz8 and RyMs are part of the Monte Arci volcanic complex, formed during the Plio-Quaternary cycle (3.8-2.6 Ma) (Montanini et al., 1994). The pozzolan Cpz11a was extracted from the Pietra Dacia Quarry located in the municipality of Fordongianus; different types of volcanic rocks, such as dacites and rhyodacites, outcropped in this area, which were placed there during the Oligo-Miocene volcanic cycle (Assorgia et al., 1998). A quartz-feldspathic sand consisting of crystal-clasts and fragments of granitoid rocks, crushed with a grain size of less than 2 mm, was chosen as aggregate. The binders used were hydrated lime (slaked lime, $Ca(OH)_2$) and quicklime (CaO), which was subsequently slaked during the mixing process. The mortars were manufactured according to the mix: 60% aggregate -15% pozzolan -25% binder. In the mortars produced with the pozzolans Cpz8 and RyMs, both quicklime and slaked lime were used as binders, while the remaining mortars (Cpz1, Cpz5, Cpz11a) were manufactured using slaked lime only.

The mortars were studied, after packing and curing, by means of optical microscope observation, XRD and SEM-EDS analysis, as well as a series of analyses aimed at understanding their physical-mechanical characteristics (compressive strength, porosity, density).

## 3. Results and discussion

From a compositional point of view, these Map are rhyolites that differ in genesis and emplacement. They all have in common a large percentage of amorphous material (about 90%) and the mineralogical composition of phenocrysts, albeit in different quantities: Plagioclase, K-feldspar, quartz, pyroxene, biotite and opaque (Fig. 2).

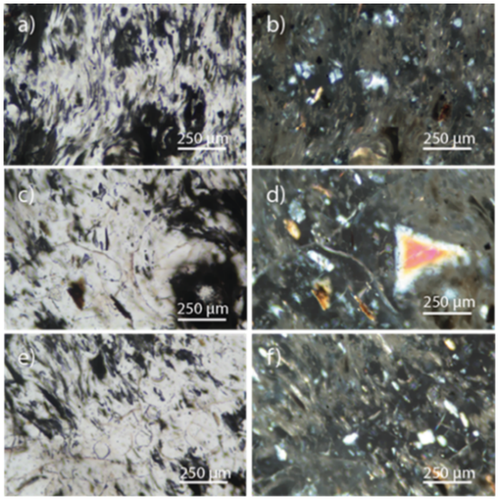


***Figure 2****. Light microscopy analysis of pozzolan CPZ 8. In the images at nicols // (a, c, e) the pearlitic structures, common in these rock types, are visible. At nicols x (b, d, f) the phenocrysts of quartz, orthoclase and plagioclase immersed in the glassy ground paste can be seen*

The pozzolans showed, as evidenced by the Chapelle test, a good chemical reactivity to hydrated lime with values that were substantially very similar.

Under light microscopy, the minerals forming part of the aggregate used and a homogenous structure can be recognised in mortars. By means of XRD analysis, it was possible to recognise Portlandite ($Ca(OH)_2$) up to two years (Fig. 3).

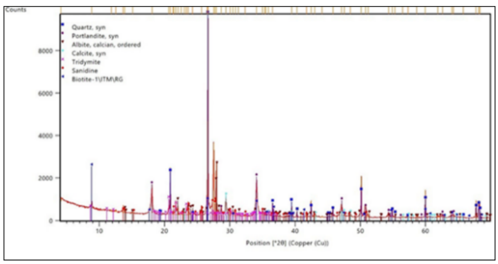


***Figure 3****. XRD pattern of CPZ5 sample.*

The simple compressive strength, measured at 1 week, 1 and 2 months and 2 years, tended to increase over time, with higher values in the pozzolanic mortars than in the control samples formulated with only aggregate and binder. Furthermore, this resistance benefited from a series of immersion cycles in water, both at room temperature and heated to 70°C, as shown in the histogram (Fig. 4).

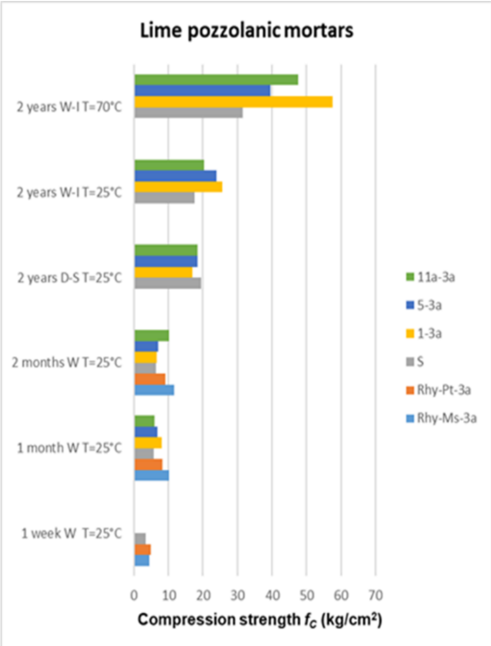


***Figure 4****. Histogram of the evolution of the mechanical strengths of the mortars produced.*

The reaction between lime and pozzolan is made possible by the interaction between the former and the Si and Al present in the latter. In particular, the pozzolans finding themselves in a state of physical-chemical non-equilibrium, release these elements that will bond with the lime, forming silicates and calcium aluminate hydrates (C-S-H and C-A-H). These new phases improve various characteristics of the final product: they increase compressive strength, decrease porosity and make them more impermeable. Through the studies carried out using optical microscopy and XRD, during the observation times (2 months and 2 years), it was not possible to detect these phases, most likely because they formed in small sizes and quantities. However, using SEM, it was possible to detect an increase in these elements within the calcitic binder, particularly in mortars subjected to water immersion cycles (Figs. 5-6).

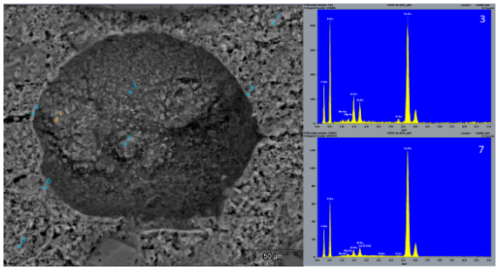

***Figure 5****. SEM-EDS analysis of CPZ5-1a mortar at two years of curing after 4 months of water absorption cycles. Detail of a void due to the loss of a pozzolan fragment.*

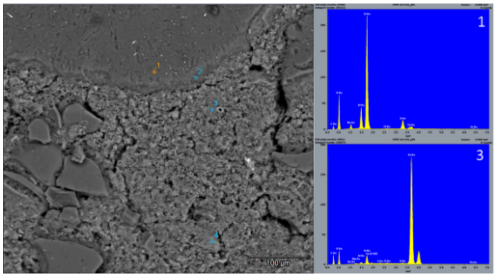

***Figure 6****. SEM-EDS analysis of CPZ5-1a mortar at two years of curing after 4 months of water absorption cycles.*

## 4. Conclusions

The study confirmed that there are numerous volcanic lithologies in Sardinia that can be exploited as MAP. The various Chapelle tests and mechanical strength tests carried out show a good reactivity of these geomaterials with lime, increasing several performance aspects. XRD analyses show that the carbonation process of calcium hydroxide continues two years after the mortars were made, given its presence in the analyses carried out. SEM-EDS analyses carried out two years after packing show the presence of Si and Al within the binder, as a result of an evident chemical exchange between lime and pozzolan. Therefore, the increase in mechanical strength is reflected in the newly formed hydraulic phases (C-S-H and C-A-H) highlighted by the SEM analyses and the carbonation process still underway.

The physical-mechanical and mineralogical characteristics of pozzolanic mortars, coupled with their low energy and cost impact in the production phase, make them an ideal material for use as plasters, and given their strength values, subordinately also to produce bedding mortars for low-to-medium physical-mechanical load-bearing masonry. Finally, their low environmental impact and chemical-physical affinity with the materials with which many cultural heritage sites have been built, make them ideal as restoration mortars.

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# Mining waste characterization for optimised management by multidisciplinary approach: case study of Sidi Bou Azzouz mine in Morocco

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## Abstract

*A smart economy aims to minimize waste from mining activities and repurpose it as a valuable resource, working toward a near-zero waste society. This study introduces an integrated, multidisciplinary methodology for optimizing mining waste management. The Sidi Bou Azzouz mine in Morocco serves as the test site. Mining waste from the site was collected and analysed using X-Ray Powder Diffraction, X-Ray Fluorescence, SEM-EDS, and spectral signature techniques to determine its mineralogical, chemical, and spectral properties. Finally, the classified Sentinel-2A satellite imagery was used to create a map of characterized mining waste to support sustainable resource recovery.*

**Keywords**: Sentinel-2, chemical, mineralogical, and spectral characterization, satellite map.

## 1. Introduction

Mining and mineral processing activities generate some of the most substantial and persistent waste streams globally, presenting significant environmental and resource management challenges. Defined as *"waste products originating, accumulating, and present at mine sites, which are unwanted and have no current economic value"* (Lottermoser, 2010), mining waste represents a vast and underutilized resource.

The environmental implications of mining waste disposal are severe, ranging from ecological degradation to landscape transformations such as stockpiled waste rock, subsidence basins, and open pits (Hudson-Edwards, et al. 2011). These impacts are compounded by the continuous demand for raw materials (RMs) to sustain economic activities, underscoring the need for innovative strategies to manage waste while minimizing environmental harm and protecting human health.

In recent years, increasing resource depletion, rising metal prices, and growing environmental concerns have highlighted the importance of recovering critical raw materials (CRMs) from unconventional sources, such as low-grade ores, steelworks by-products, and industrial waste. Advances in technologies and market dynamics have revealed the potential of past mining wastes as valuable repositories of raw materials (European Environment Agency, 2019).

Accurate mapping and characterization of mining waste are critical for unlocking its potential. Remote sensing techniques, particularly those utilizing multi- and hyperspectral imaging, have emerged as powerful tools for non-invasive and cost-effective waste management. These methods leverage the spectral properties of materials, enabling the identification and mapping of minerals within waste deposits (Guglietta et al., 2022). The increasing availability of open-access satellite data, such as Sentinel imagery, has further fostered the use of remote sensing in geological and mining applications. However, the integration of satellite data with mineralogical and chemical analyses remains a challenge. Field sampling plays a crucial role in validating remote observations and creating spectral signature databases for long-term monitoring and management of mining waste. By leveraging advanced technologies and adopting circular economy principles, mining waste can be transformed from an environmental liability into a valuable resource, contributing to sustainable development and reducing the pressure on primary extraction.

### *1.1. Aims of research*

At the time of the opening of Sidi Bou Azzouz mine (Morocco), the chemical and mineralogical composition of the waste was ignored or considered below the cut-off level. Advances in technology mean that past waste deposits can be used as sources of economically strategic resources.

The aim of the project is to develop an approach that integrates advanced spectral, chemical and mineralogical characterisation techniques, and satellite mapping to optimise the management of mining waste in the abandoned and closed mine of Sidi Bou Azzouz (Morocco).

To this end, mining waste mapping is a useful tool for mine management, and remote sensing is a valuable, fast, low-cost, and environmentally non-invasive technique for optimising in-situ sampling strategies, characterising exploitable resources, and managing waste as mineral resources for future use.

## 2. Materials and methods

The methodology presented in this study integrates diverse analytical and imaging techniques to characterize and map mining waste effectively. Key steps include:

1- **Collection of Mining Waste**: Samples were collected from the Sidi Bou Azzouz mine to ensure a representative analysis of the waste materials.

2- **Laboratory Analyses**: Advanced techniques, such as X-Ray Powder Diffraction (XRPD), Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS), and FieldSpec FR3 PRO hyperspectral spectrometer (350–2500 nm), were employed to determine the mineralogical, chemical, and spectral properties of the samples.

3- **Remote Sensing and Mapping**: Sentinel-2 satellite imagery was utilized to classify and map the spatial distribution of mining waste within the study area.

These integrated methods enable a holistic understanding of the waste materials, supporting their valorisation as potential resources for various applications.

### *2.1. In situ sampling campaign*

The Sidi Bou Azzouz mine, currently closed and abandoned, is situated in the southern Rehamna region of Morocco. It represents a significant geological and economic resource, having been actively exploited for tungsten ore extraction during the 1980s. In May 2022, during the in-situ sampling campaign, a total of 14 samples were collected from the study area for subsequent characterization analyses (Fig. 1).

For each sampling site, GPS coordinates, photographs, and a brief description were recorded and summarized in datasheets.

The sub-sampling method, specifically coning and quartering, was applied to the mining waste samples to obtain a representative sample from a larger bulk material (sampling area). A portion of these samples was used for chemical and mineralogical analyses.

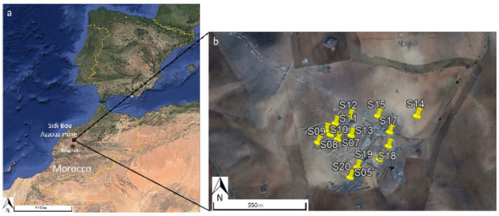


***Figure 1****. The closed and abandoned Sidi Bou Azzouz mine in Morocco (a), with samples collected during the in-situ sampling campaign in May 2022 (b) (Google Earth screenshots from February 2022).*

### *2.2. Mineralogical, chemical and spectral characterization analyses*

XRPD analysis was conducted using a Bruker D2 PHASER with Cu–Kα1 X-radiation (1.54 Å, 40 kV, 20 mA), and data were processed with DIFFRAC.EVA software and the Crystallography Open Database (COD). XRF analysis was performed with a SPECTRO XEPOS ED-XRF analyzer, optimized for heavy elements, and calibration curves were constructed using international standards. Back-scattered electron (BSE) images, energy dispersive X-ray (EDS) spectra, and X-ray maps were acquired with a ZEISS EVO MA10 SEM and an Oxford X-Max EDS detector, operating at 20 kV. These analyses allowed for high-quality imaging and semi-quantitative elemental analysis of the samples.

Spectral signatures of mining waste samples were recorded using a FieldSpec FR3 PRO hyperspectral spectrometer (350–2500 nm) to cover the visible, near-infrared, and short-wave infrared ranges. The system used a 25° field-of-view sensor, and measurements were taken from a 10 cm distance, with a white Spectralon® panel as a reference for reflectance calculations. Multiple measurements (four or more) were taken per sample, rotating it to reduce shadow effects, and spectra were averaged. To ensure accuracy, the reference panel was measured before and after each session, with an error of about 2%. The spectra were resampled to align with Sentinel-2 spectral bands for remote sensing analysis.

### *2.3. Sentinel-2 satellite image processing*

The Sentinel missions provide routine observations for Copernicus services, ensuring continuity of data from ERS, ENVISAT, and multispectral missions like SPOT, Landsat, and Aster. The Sentinel-2 satellite, equipped with a multispectral instrument, operates in a sun-synchronous orbit at 786 km altitude, covering land surfaces and coastal waters from 56° to +84° latitude, with a 290 km swath and a 10-day revisit cycle at the equator. Primarily designed for global land coverage and change detection mapping, Sentinel-2 images have also been used for geological applications, including mapping surface mineralogy. On February 10, 2022, a Sentinel-2A image was acquired over the mine area. The sampling sites were identified on the georeferenced image, and their spectral signatures were extracted and compared to laboratory spectra. A Spectral Angle Mapper (SAM) classifier was used to process the data, based on spectral similarity to identify mineral classes.

## 3. Results and discussion

The comparison with the results of characterization analyses allowed to identify 5 different classes of mining waste. Each class is represented by different spectral, chemical and mineralogical features. The Sentinel spectra of each identified group were used as a training set to classify the Sentinel-2A image. The results of the SAM classification were presented in a map of mining waste deposits, illustrating the spatial distribution of different waste classes (Fig. 2).

This map helps identify areas with varying spectral, mineralogical, and chemical compositions of waste. Given the potential for the reuse of mining waste over large areas, the waste deposits map serves as a fundamental tool for detecting homogenous waste deposits based on mineralogical composition. It also supports the optimization of future planning and management of mining waste storage in the Sidi Bou Azzouz mine area.

These waste deposits could be valorised and considered as new orebodies, as their exact location and mineral content can be further exploited.

Moreover, the collected data could contribute to unlocking potential raw materials for reuse and recycling, reducing the environmental impact of accumulated mine waste.

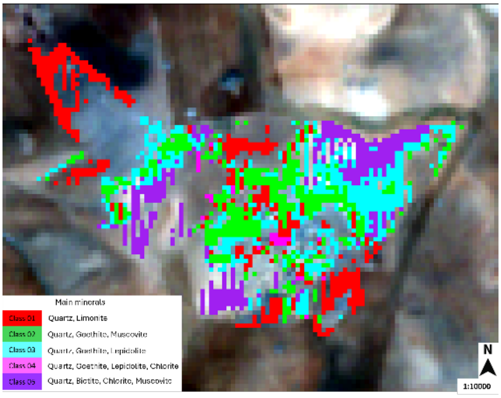


***Figure 2***. *Map of closed and abandoned Sidi Bou Azzouz mine in Morocco (Sentinel-2 image overlaid SAM classification. R=Band 04; G=Band 03; B= Band 02).*

## 4. Conclusions

A smart economy minimizes waste and promotes its reuse as resources for industrial processes, aiming for a near-zero waste society with reduced environmental impact and improved quality of life. Recycling and reusing mining waste is crucial to reduce mining’s environmental footprint, protect health, and find cost-effective solutions. Research focuses on the characteristics and reuse potential of mine wastes. As larger deposits of lower-grade ores are increasingly exploited, sustainable management of mining waste is vital.

Remote sensing offers a cost-effective way to map large areas and identify resources, compared to traditional field methods. The ESA Copernicus Program, through the Sentinel-2 satellite launched in 2015, provides free multispectral images to locate high-concentration reusable waste areas and optimize storage in homogeneous zones.

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# Studio del comportamento meccanico di terreni misti granulari sottoposti a prove in situ e di laboratorio

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## Abstract

*Questo articolo tratta della Vita Infinita dei materiali da costruzione, che dopo la demolizione e il riutilizzo edilizio possono reiterare quasi all'infinito questo processo, finendo con prestazioni migliori e un ridotto utilizzo di materiali naturali di scavo.*
*Nella moderna tecnica costruttiva di opere antropiche quali rilevati stradali, rilevati ferroviari, aree di stoccaggio o per gli usi più svariati, vengono sempre più utilizzati materiali di recupero, siano essi primari o provenienti da scavi in suolo naturale (vedi Allegato 5 al D.Lgs. 161 /2012 e successive modifiche), secondario o già utilizzato per edifici, successivamente demolito e i materiali nuovamente riutilizzati, avviando così una sorta di "moto perpetuo" di uso e riuso.*
*In particolare in questo articolo si tratta di materiali granulari che possono essere caratterizzati mediamente da un D50 ovvero da un diametro corrispondente al 50% del peso del materiale di ¾ o un pollice con diametro massimo anche superiore a 3 pollici ed una finezza non superiore al 30%.*
*Materiali di questo tipo sono soggetti a "lunga durata" proprio in funzione della notevole percentuale di elementi grossolani che, anche se sottoposti (in virtù della lavorazione) ad una riduzione di diametro ad ogni riutilizzo, mantengono comunque la dimensione media grossolana.*

**Parole chiave**: riciclato, test, materiali granulari, test in situ

## 1. Introduzione

Nella moderna tecnica delle costruzioni di opere antropiche come rilevati stradali, ferroviari, aree di deposito o per i più svariati usi, vengono sempre più utilizzati materiali di riciclo sia primario ovvero provenienti da scavi in terreno naturale (cfr. Allegato 5 al d.lgs. 161/2012 e s.m.i), che secondario ovvero già utilizzati per le costruzioni, successivamente demolite e i materiali reimpiegati di nuovo, avviando così una sorta di "moto perpetuo" di uso e riutilizzo.

In questo articolo vengono in particolare trattati materiali granulari mediamente caratterizzabili da un D50 ovvero da un diametro corrispondente al 50% in peso del materiale di ¾ o un pollice con diametro massimo anche superiore ai 3 pollici e fine non superiore al 30 %.

Materiali di questo tipo sono soggetti a "lunga vita" proprio in funzione della considerevole percentuale di elementi grossolani che ancor quando soggetti (in virtù delle lavorazioni) ad una riduzione di diametro ad ogni riutilizzo, mantengono pur sempre grossolana la pezzatura media.

### *1.1. Obiettivi dello studio*

Oggetto della odierna discussione era un progetto integrato di utilizzo e riutilizzo di materiale estratto da terreno naturale e/o reperito da impianti di riciclo per la realizzazione di alcune opere che consistevano in:

- Piazzali aeroportuali
- Sottofondi strutturali di aree di stoccaggio materiali inerti e di rifiuto
- Piste stradali di prova

Nel caso 1 l’attività era finalizzata alla conoscenza del sottosuolo in primis e poi nello studio del miglior reimpiego e trattamento del materiale.

Nel caso 2 si studiava il raggiungimento di determinate caratteristiche di resistenza di materiali riciclati e di cava, tramite prove di laboratorio su Macro-Campioni.

Nel caso 3 invece si verificava la prestazione del materiale proveniente da scavi diversi, in condizioni di esercizio estreme come quelle richieste da una pista di prova ad elevata domanda prestazionale


***Figure 1**. Area di scavo in terreno vergine e pozzetti esplorativi e lo studio dei sottofondi strutturali per aree di stoccaggio materiali.*

## 2. Materiali e metodi

Il programma di prove studiato per questi progetti integrati di scavo realizzazione e recupero è stato il vero perno portante di tutto il lavoro, accorpando prove di semplice identificazione con prove meccaniche difficilmente eseguibili su materiali che ad una matrice fine a volta argillosa e di plasticità elevata, contrapponevano la presenza cospicua di frazione grossolana e addirittura ciottoli “oversize”.

In situ sono state eseguite nella fattispecie:

• N 4 prove di carico su piastra da 30 cm di diametro spinte sino a 250 KPa in pozzi di escavazione

• N 20 Prove di carico su piastra sempre da 30 cm di diametro spinte sino a 350 KPa sulla superficie compattata delle piste

• N 260 Prove di carico su Piastra Dinamiche e correlate perfettamente con le statiche sulle stesse superfici

• N 4 Prove CBR in situ in pozzetto esplorativo

• N 20 prove di Densità in Sito eseguite a norma ASTM D 1556 per sostituzione con sabbia ma utilizzando un cono da ben 30 cm di diametro

In Laboratorio PANGEA di Milano sono state invece eseguite:

• N 4 Prove CBR in Laboratorio eseguite a varie percentuali crescenti di cemento per la stabilizzazione

• N 4 prove di compressione e rottura su cilindri di materiale stabilizzato a cemento

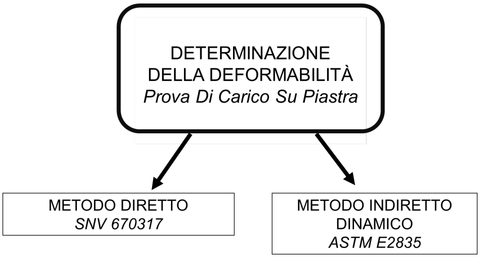
• N 4 prove di trazione indiretta “brasiliana” su altrettanti cilindri di materiale stabilizzato a cemento come sopra

• N. 10 prove di TAGLIO DIRETTO su macro campioni da 30 x 30 cm

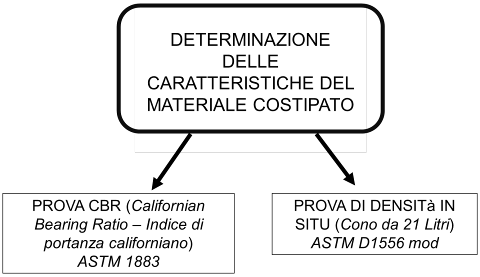
• N 2 Prove di compressione TRIASSIALE su provini di grande diametro per la misura in condizioni drenate di deformabilità angolo di attrito e coesione apparente

Va da sé che le prove prescelte si sono dimostrate le più opportune per unire al contempo una sufficiente rappresentatività dei campioni senza inficiare i principi base di funzionamento ed efficacia delle prove, cercando quindi di minimizzare il rapporto φ Provino Min. / φ Clasto Max pur garantendo l’affidabilità dei risultati. Allo scopo comunque di accertare la corretta definizione dei vari parametri le prove sono stati incrociate con differente metodologia, curando che i risultati non si discostassero in dipendenza del metodo di prova.

E cosi partendo dall’indagine in situ le prove di carico su piastra tradizionali eseguite in ossequio alla normativa SNV 670317 ad incrementi di carico sono state confrontate con le prove Dinamiche in ossequio alla normativa ASTM E2835.

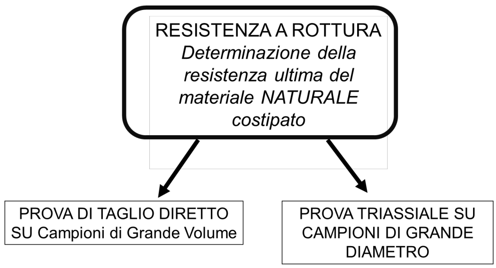


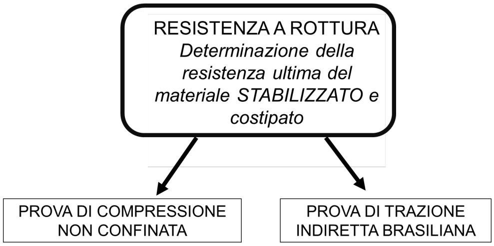

Le Prove CBR invece sono state eseguite sul materiale compattato e la cui densità è stata determinata in situ.




Infine la resistenza meccanica del materiale a rottura è stato determinata sia con prove di taglio di tipo diretto su Macro-campioni (di oltre 27.000 cm3) che più tradizionalmente con prove di compressione triassiale su campioni di relativamente grande diametro.

Sui campioni stabilizzati a cemento (in proporzioni variabili tra il 2 ed il 3.5 %) infine sempre allo scopo di esaminare nel dettaglio la resistenza a rottura sono state poi eseguite sia prove di compressione sui provini delle dimensioni CBR che di trazione indiretta brasiliana.



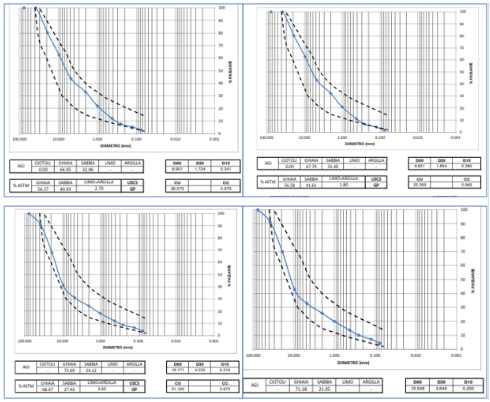



***Figure 2.*** *Curve granulometriche rappresentative dei materiali di sottofondo.*

***Figure 3.*** *Prove Triassiali sui materiali grossolani destinati a sottofondi strutturali.*

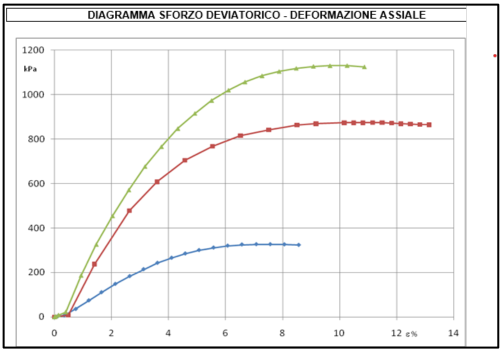
## 3. Analisi comparative

L'analisi comparata delle varie tipologie di indagine ha restituito una sorprendente ripetibilità.

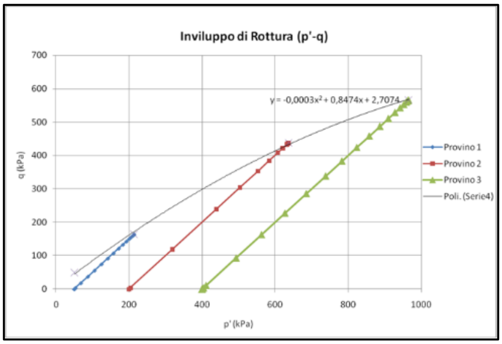
Nella fattispecie le indagini in situ (prevalentemente le prove di carico su piastra eseguite con le due differenti metodologie) hanno confermato che il rapporto previsto di resistenza misurata attraverso l’attrezzatura dinamica e quella statica in identiche condizioni di locazione umidità e costipamento del terreno previsto in 1,2 (dove il maggiore è per la piastra statica) è stato spesso confermato e la media è stata addirittura maggiore attestandosi oltre1,3.

Questo valore fa sì che le misurazioni eseguite con piastra dinamica siano sempre molto a favore di sicurezza in confronto a quelle statiche. in nessun caso infatti il rapporto tra le due tipologie è sceso sotto 1.2 sul campione di oltre 260 prove effettuate nello stesso luogo e con lo stesso materiali a parità di identiche condizioni di temperatura pressione ed umidità.

D’altro canto le prove di resistenza a rottura effettuate su campioni aventi un diametro medio superiore ai 2 cm eseguite con attrezzature speciali hanno ribadito quanto le prove di taglio diretto ancorché eseguite su provini macroscopici atti a simulare la scala reale hanno palesato valori molto bassi in confronto alle prove eseguite in cella triassiale con provini di largo diametro, che vengono illustrate nel seguito:




| | | tg | arcsen | gradi |
|---|---|---|---|---|
| Φ | 0,646 | 0,754 | 0,854 | 48,93 |
| a | | | | 25,53 |
| coesione | 48,93 | 0,854 | 0,657 | 38,86 |




Si noti come la linearità assoluta delle curve (acquisite automaticamente con attrezzatura digitale) abbia suggerito l’interpretazione con inviluppo curvilineo e non lineare e quindi valido per specifici campi di tensioni verticali.

L’interpretazione di un angolo di oltre 48° con una coesione di oltre 38 KN/m2 sembra conferire al materiale resistenze straordinarie che smentiscono in parte i valori già comunque accettabili e coerentemente elevati mostrate dalle prove di taglio su provini di grande area.

Le prove invece su materiale naturale e stabilizzato a cemento hanno consentito di verificare le condizioni a seguire:

- I valori di CBR raddoppiano repentinamente anche con basse percentuali di cemento (2%) mentre non aumentano considerevolmente al crescere della percentuale

- La resistenza è sensibile alla maturazione nella prima settimana a percentuali elevate resta piuttosto stabile

- La resistenza a trazione dei provini stabilizzati pare influire nella misura del 10-15% della resistenza a compressione (totale) del materiale

## 4. Conclusioni

Le sperimentazioni effettuate hanno permesso innanzitutto di evidenziare al di là di ogni ragionevole dubbio come le prestazioni dei materiali riciclati non risentono della “fatica” apparentemente derivante da svariati cicli di utilizzo, consentendo quindi in prospettiva il loro riutilizzo pressoché all'infinito, migliorando le prestazioni ultime.

Prova di tale conclusione è il raffronto tra svariati materiali sia vergini che riutilizzati più volte impiegati in questi campi sperimentali.

Le prove tradizionali di controllo e di ricerca dei parametri di resistenza sia in termini di rottura che deformabilità possono essere:

• Ottimizzate in termini di massima efficienza ed efficacia Tempi/Risultati come dimostrato dalle prove di piastra dinamiche strettamente raffrontate alle tradizionali statiche

• Impiegate invece largamente anche in una vasta gamma di materiali, scegliendo sapientemente le modalità di preparazione selezione del materiale ed esecuzione delle stesse.

Eclatante davvero in questo studio è il raffronto tra prove di taglio eseguite su macro campioni di ben 300 mm di lato e prove eseguite in cella triassiale con diametro di 70 mm ma su materiale selezionato.

Conclusione che ne deriva è che è sempre il fine a dover essere preso in considerazione per la resistenza e non la frazione grossolana. Anzi la presenza di clasti grossolani o ciottoli non contribuisce ipso facto ad aumentare l'attrito ma addirittura laddove si instaura una iso-orientazione si ha la creazione di una superficie preferenziale che abbatte di fatto la resistenza. In questo caso il triassiale tradizionale esibisce valori ben più elevati e più simili a quelli reali.

L'impiego di stabilizzanti e leganti ad ausilio del miglioramento delle caratteristiche ultime di resistenza dei materiali ha un grande effetto anche in percentuali minime di impiego e le prove di controllo sia tradizionali che di raro utilizzo (vedi brasiliana effettuata su provini CBR) evidenziano una evidente riproducibilità della scala reale, costanza e coerenza dei risultati.

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# Managing and recovering critical raw materials: a sustainable approach in Italy and Europe

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## Abstract

*In Europe, critical and strategic raw materials (CRMs and SRMs) are vital for industrial policy and economic security, especially for the energy and technological transition. The European Union heavily imports materials like rare earth elements, lithium, and cobalt. The European Commission has updated a list of CRMs, emphasising diversification of supply sources, recycling, and sustainability.*

*Italy's recently enacted Decree-Law 84/2024 aims to enhance the management of these resources. It introduces measures to secure supplies of CRMs and SRMs, promote investment in research and development, encourage recycling, and support the development of internal supply chains. This aligns with EU goals of reducing import dependency and fostering a resilient and sustainable economy.*

*A project developed by the Economic Geology group of the University of Cagliari (UNICA) focuses on classifying and mapping 70 million cubic meters of mining waste across Sardinia, potentially a source of CRMs and base metals. Preliminary findings indicate the presence of Rare Earth Elements in the Fluminese-Arbùrese district, Tungsten in Sulcis skarns, and Lead and Zinc in the Iglesiente district.*

*Reprocessing some mining waste could provide significant economic benefits through the sale of contained materials and metals. This process would also address site contamination, complying with Legislative Decree 152/2006. The resulting purified material could be used for mine refilling, mitigating sinkhole risks, or as material for road subbases, reducing land use and consumption.*

**Keywords**: Sardinia, Sustainable Economy, Mining wastes, Reprocessing, Recycling.

## 1. Introduction

The European Union's strategic initiatives emphasise reducing import dependency and fostering sustainable practices in managing critical and strategic raw materials (CRMs and SRMs), which are essential for industrial competitiveness, economic stability, and the energy transition. These goals are particularly pressing given the increasing demand for these materials in sectors such as renewable energy, electric mobility, and advanced technologies. To face these challenges, adopting the Critical Raw Material Act (European Commission, 2023) at the EU level, alongside Italy's Legislative Decree 84/2024, represents a decisive step forward. These legislative measures aim to enhance the security of supply chains by promoting innovative approaches to material recovery, scaling up recycling processes, and strengthening the role of local resource exploration and utilisation.

Moreover, they encourage targeted investment in research and development to support the discovery of sustainable extraction and reprocessing technologies while fostering partnerships between industry, academia, and government institutions to build a resilient and circular economic framework for raw materials. By integrating these multifaceted strategies, the EU and Italy seek not only to reduce dependence on external sources but also to contribute to global sustainability goals and decarbonisation.

### *1.1. Aims of research*

The project led by the University of Cagliari capitalises on Sardinia's unique mining heritage, which spans millennia. Mining activities on the island date back to the Nuragic era, a legacy of the region's rich geological resources and its historical role in extracting valuable metals such as lead, zinc, silver, and copper.

This long-standing tradition continued through the Roman, Medieval, and modern industrial periods, each era contributing distinct methodologies for mineral extraction and processing. Over time, these activities have resulted in approximately 70 million cubic meters of mining waste distributed across the island (RAS, 2003). The highest part of these mining wastes is in the Sulcis-Iglesiente area, about 60% of them.

These extensive deposits, which originate from various extraction and treatment techniques, now represent a potential source of CRMs that are essential for modern technological and industrial applications (Das et al., 2024). The University of Cagliari project seeks to study this latent potential, to transform mining waste into valuable resources while addressing environmental concerns.

The study has three main goals:

- **Mapping and classification of mining waste in Sardinia**: This involves a systematic analysis of historical mining sites and their waste deposits, creating a comprehensive inventory of the materials and their locations. The aim is to establish a clear understanding of the scale and composition of these resources, essential for sustainable planning.
- **Identification and quantification of critical raw materials**: Preliminary studies have highlighted the presence of rare earth elements, tungsten, lead, and zinc within the waste. These results have been obtained utilising advanced geochemical and mineralogical techniques to accurately quantify their concentrations.
- **Development of reprocessing methodologies**: Drawing on Sardinia's historical expertise in mining, the project will evaluate innovative processes for reprocessing these materials. These methodologies could integrate environmental remediations, such as the removal of contaminants and stabilisation of waste sites, with the eventual recovery of valuable CRMs. This dual approach ensures that reprocessing not only generates economic benefits but also contributes to environmental restoration.

By leveraging Sardinia's extensive mining legacy and its accumulated waste materials, the project aligns with Italy's commitment to the EU's sustainability goals. It exemplifies a circular economy approach, turning historical by-products of extraction into critical inputs for the future while mitigating the environmental impact of past activities (Fig.1).

## 2. Materials and methods

The investigation focuses on the analysis of mining waste accumulated in Sardinia, originating from centuries of extractive activities in the Fluminese-Arbùrese, Sulcis, and Iglesiente mining districts.

Sardinia's mining history spans from the Nuragic era through the Roman, Medieval, and modern industrial periods, employing diverse extraction and processing techniques such as crushing and flotation to extract metals like lead, zinc, silver and copper. These activities have produced approximately 70 million cubic meters of mining waste (Fig.2), a significant volume that could represent a potential source of CRMs and SRMs. (RAS,2003)

***Figure 1***. *The interaction between the waters and the mining wastes located in the Montevecchio mine.*

The methodological approach adopted by the project includes:

- **Mapping and classification of mining waste**: Using GIS systems and geological surveys, a detailed inventory of mining waste sites was created, documenting the distribution, composition, granulometric and mineralogical characteristics of the waste materials.

- **Sampling and geochemical and mineralogical analysis**: Waste samples were analysed to determine their elemental and mineral composition using advanced techniques such as P-XRF (Portable X-ray Fluorescence), ICP-MS (Inductively Coupled Plasma Mass Spectrometry), SEM-EDS (Scanning Electron Microscope-Energy Dispersive X-ray Spectroscopy) and XRD (X-ray diffraction).

- **Development of reuse methodologies**: useful studies are being conducted to evaluate the feasibility of reprocessing these materials, optimising the recovery of metals while addressing any residual contamination.

This integrated approach aims to transform mining waste into valuable resources while adhering to environmental regulations and promoting sustainable practices.

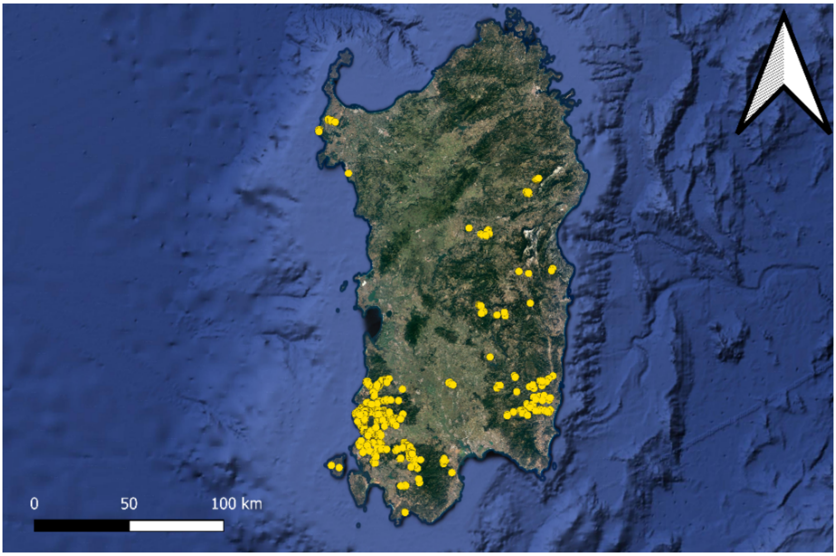


***Figure 2****. The distribution of mining wastes in Sardinia. Every yellow dot identifies a mining dump.*

## 3. Results and discussion

Preliminary results highlight the significant potential of Sardinian mining waste as a source of critical raw materials:

- Rare Earth Elements (REEs): Found in the waste of the Fluminese-Arbùrese district (Sedda et al., 2024), they show promising concentrations that can be evaluated as a source of raw materials for various technological applications, including permanent magnets and electronic components.

- Tungsten: Identified in the skarn deposits of Sulcis, tungsten could represent an opportunity for strategic sectors such as aerospace and defence.

- Lead and Zinc: Present in the waste from the Iglesiente district, these metals have substantial economic significance for the metallurgical industry.

Recovery methodologies suggest that a combination of physical methods (e.g., gravity separation) and chemical methods (e.g., hydrometallurgy) could optimise the extraction of target elements. Furthermore, the remediation of disposal sites offers environmental improvement opportunities, reducing contamination and repurposing purified by-products for:

- Mine refilling: Mitigating the risk of sinkholes (Manca et al., 2014).

- Construction materials: Use in road subbases, reducing the consumption of new natural resources (Kong et al., 2024).

These efforts support a circular economy model, where waste becomes a resource and environmental impacts are minimised. Compliance with Legislative Decree 152/2006 reinforces the project’s sustainability framework.

## 4. Conclusions

The sustainable management and recovery of CRMs and SRMs are essential for the economic and environmental resilience of Italy and Europe. The project led by the University of Cagliari demonstrates the feasibility of transforming historical mining waste into strategic resources, contributing to enhanced raw material security and reduced import dependency.

The project delivers multiple benefits:
1. Economic value creation: The recovery of critical materials can offer significant market opportunities.
2. Environmental improvement: The remediation of waste sites reduces contamination and promotes land regeneration.
3. Support for sustainability: The developed methodologies must be aligned with the EU's goals for ecological transition and decarbonisation.

Future research efforts should focus on scaling up the developed technologies to support industrial applications and replicating these solutions in other geological contexts across Europe.

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# The underground quarries of Cutrofiano. Project strategies for recovery

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**Abstract**
*It is not difficult to ascribe the Apulian quarry landscapes to the heritage system, both from an environmental, landscape, historical, cultural, anthropological, geological and mining point of view. The objective is to address the intrinsic environmental, geological and spatial problems, in particular relating to the tunnel system of Cutrofiano (LE), strategically outlining three design approaches for environmental recovery, protection and enhancement of the territorial context: each of these places in a dialogue and a multidisciplinary relationship for the safety of the site and the new intended use at the conclusion of the plan. The first is a modeling of the terrain, to determine new areas for agricultural use and for the construction of lamination tanks for the mitigation of the hydrogeological risk of flooding; the second as an energy park for the production of sustainable electricity; the third as an adaptive reuse project for the creation of recreational places for citizens (among these, a disco). Specifically, finally, one of these solutions will be examined, to detail the technical and design characteristics. It also intends to outline principles and methods for living below the ground line, identifying qualifying opportunities for reconnection between the anthropic landscape and nature.*

**Keywords**: Mining sites, Hypogeum, Lithic, Landscape, Recovery.

## 1. Introduction

The quarries in Puglia represent a significant aspect of the regional landscape, both from a geological and historical, natural and cultural point of view. The Apulian territory is in fact characterized by a geological framework of particular interest: the deposits of calcarenites and compact limestones of the Miocene have constituted a precious resource (both in economic terms and in those of aesthetic and technological value) for the growth of inhabited places and the production of stone artefacts since ancient times, contributing significantly to the architectural richness of the region, used for the construction of monumental and heritage buildings.

Among the most widespread and appreciated stones, reference should be made to Pietra Leccese (a light-coloured and easily workable calcarenite, used for the construction of the Palazzo dei Celestini, and the churches of Santa Croce and Santa Chiara in Lecce); to the Pietra di Trani (a limestone rock that is formed mainly from marine sediments and fossils, giving the stone a natural beauty and a notable resistance to compression, known for its compact consistency and its color that varies from white to cream, with veins thin gray or pinkish); or to the Ostuni Stone (typically white and characterized by a predominantly limestone composition, it is a sedimentary rock that intensely reflects sunlight, giving the buildings the typical appearance of the urban landscape of the "White City").

The value and exceptional quality of Apulian stones have led to the opening of numerous cultivation and extraction sites for stone material, leading to rapid urban and economic growth, as well as the appearance of some inhabited centers near the lithological deposits to be cultivated, carrying forward a homothetic parallelism between the activities relating to the subsoil and those above ground.

### *1.1. Aims of research*

The intensive mining activity in Puglia (388 active quarries and 2,552 abandoned) has had significant consequences on the landscape and the local environment, both in terms of land consumption and in terms of disposal of debris deriving from stone processing, generating serious impacts on water resources and geological stability, increasing the risk of soil erosion, alteration of water flows and loss of biodiversity. Furthermore, at the end of the life cycle and use of the extraction basins, although local administrations have made every effort to formulate recovery plans for abandoned extraction sites, the redevelopment practices of the same are very little explored and moreover relegated to the practices of greening and revegetation of the beds (seeding) or to environmental rehabilitation, if not to the establishment of open-air geological museums, which sometimes lose an opportunity for social and cultural growth and development, as well as reconnection between the environment built and nature.

This contribution intends to outline innovative strategies for recovery in terms of environmental rehabilitation and heritage use.

## 2. Materials and methods

The design solutions reported below were formulated following the preliminary study of the geomorphological and hydraulic risk characteristics of the territory and the evaluation of the potential deriving from the urban structure (infrastructure and planning) and the safety and mitigation operations of the hydrogeological risk aimed at a productive relaunch of the territory. To formulate the recovery strategies, we made use of environmental and geological monitoring data (open source and acquired in the quarry), survey tools (in situ and from drone) and the return of a three-dimensional model starting from the acquisition of a point cloud (Fig. 1).

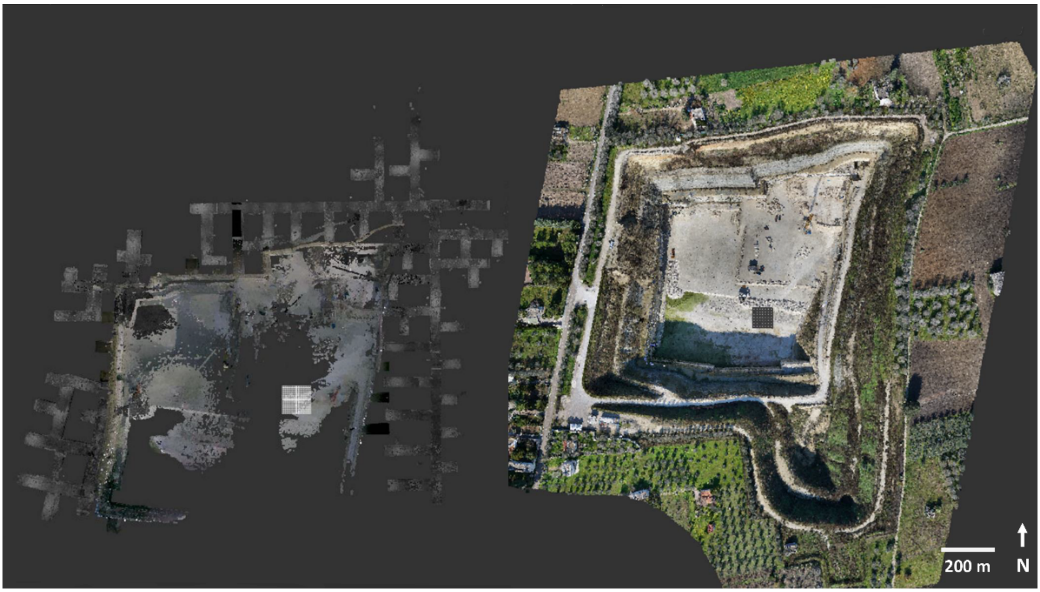


***Figure 1**. Photogrammetric survey of the site under examination.(A. Reina., A.Ganazzoli, 2024)*

*2.1. Materials*

The underground quarries of Cutrofiano, located in the province of Lecce, represent an historical, cultural and natural heritage of significant importance for the Salento area from a landscape, historical and anthropological point of view. The stone extracted here is a fossiliferous calcarenite formed during the Miocene period, composed mainly of calcite granules and fossil fragments, which give it its distinctive appearance. Due to the extreme workability of the stone and its lightness - a condition which is particularly advantageous for transport - Cutrofiano calcarenite is a high quality material, widely used (even today) for local construction. The particular geological conformation of the territory did not allow, until recently, the cultivation of open-air quarries, since, before being able to reach the calcarenitic layer, banks of sand and clay with thicknesses sometimes greater than 10 m would have had to be removed, resulting in enormous costs to be borne, combined with the difficulty of finding suitable areas for the disposal of the removed clay, making the large surrounding agricultural area unusable. The extraction techniques used until the second half of the 20$^{th}$ century were exclusively manual: the quarrymen (called "cavanonti"), descending along deep circular wells which also served to raise the extracted material (small ashlars widely used in Salento construction), they attacked the calcarenitic rock with sledgehammers and pickaxes, creating a fracture around the main block, so as to leave enormous pillars of rock in the middle, which also had the purpose of giving structural stability to the quarry itself. This extraction process, conducted in more recent times also through the use of mechanical tools, has generated an intricate system of tunnels with a great sculptural effect. A particularly interesting case is that of the pit quarry located south of the town of Cutrofiano, between the provincial road 362 and the provincial road 198. In fact, the recent extraction operations of the carbonate stone material, by means of modern tools and techniques, during the demolition phase, intercepted the ancient tunnels that extended underground, giving rise to an exceptional condition in which, on the quarry, large access portals stand out to the underground tunnels, once accessible only through the shafts.

*2.2. Sampling and methods*

Starting from the study of the characteristics of Danger and Risk, it follows that one of the main problems associated with hydrogeological instability is linked to the management of groundwater. The extraction of calcarenites has compromised the local hydrogeological stability, negatively influencing the water regime underground. This phenomenon has led to significant variations in the recharge of the aquifers and phenomena of land subsidence, with consequent risk of subsidence and collapse of the underground cavities.

Therefore, in order to contain and mitigate the environmentally risk characteristics, the project involves the conversion of the quarry into a rolling basin, taking the form of a soil modeling project, through the excavation of a portion of the bed and the redefinition of the quarry, in order to intervene for the consolidation and stabilization of the same, as well as for the definition of clear shapes, legible at different depths: this allows the immediate identification of the level reached by the water in the event of a flood, becoming the quarry itself, the measuring instrument, and also constituting a water supply basin for the use of the adjacent city and the countryside surrounding. Furthermore, the tower that rises from the bottom contains a mechanical device to lay the keel of small boats directly on the surface of the water, giving rise to the possibility for visitors to carry out some guided excursions inside the quarry which becomes a museum of itself, revealing itself from time to time, depending on the level at which the water is found (Fig. 2).

## 3. Conclusions

The environmental and landscape redevelopment of the quarry territory must start from the knowledge and analysis of the historical and cultural contexts and from the interpretation of the intrinsic spatial relationships for the identification of principles and design strategies in an integrative key between the conservation of the historical-cultural heritage and environmental and adaptation to contemporary issues; thus establishing new mechanisms of habitability and use of now abandoned places. In fact, if the City is understood overall as a physical, social and productive structure that overlaps with natural spaces in terms of soils, lands, vegetation areas, water resources and intangible resources (air, visibility, brightness), it is impossible not to identify the caveal systems as pertaining to the city.

The becomes a tool and opportunity for reconnecting a dialogic relationship between nature and artifice, mending the wounds left by man on the ground, and acting as an accelerator of the dynamics of renaturalization. The ways of using the cave systems are multiple depending on the formal expression that the project can give back to the interpretation of the places: the cave can become a museum of itself, or express an intense dialogue between the natural kingdoms, it can deal with elements of new construction in an integrative manner, or in an antithetical manner. Ultimately, the project tool becomes the strategic means to convert waste landscapes into accessible, attractive and functioning places, which enhance the geological and landscape peculiarities of the quarries themselves and act as drivers of social, economic and cultural development, as well as in terms of tourist attractiveness, promoting sustainable and coherent development that defines new balances between the built environment and the landscape.

***Figure 2****. Photorealistic meaningful view. (A. Reina., A.Ganazzoli, 2024).*

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# Exploring the use of ornamental granitoid quarry waste for supplying raw materials to the ceramic and glass industry

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## Abstract

*Feldspars, designated as critical raw materials (CRMs) in 2023, are vital for the glass and ceramics industries but face supply risks due to growing import dependence. Granite waste, rich in K-feldspar and Na-plagioclase, offers a promising alternative resource while mitigating environmental degradation caused by quarrying. In Sardinia, the decline of the granite industry since the 2000s has left significant waste accumulations, contributing to environmental degradation and landscape disruption. This work aims to identify, through the application of physical (gravity and magnetic) separations, possible solutions for the valorisation, in terms of raw material supply, these white-granite extraction waste. Suitable quartz-feldspars enriched fraction obtained by these processes revealed compositional features that can make the obtained materials potentially usable in ceramic and glass mixtures. The valorisation of these landfills could play an important role in the recovery of the ornamental extraction sector in Sardinia, which is experiencing a period of crisis. that has hit the territory, leading to the abandonment of the quarries, to strong landscape impact. In addition, this could contribute to the restoration of the landscape in Sardinia, which has been defaced by numerous extractive waste dumps.*

**Keywords**: Feldspars, Granite waste, Recycling, Sardinia

## 1. Introduction

Since 2023, feldspars have been designated as critical raw materials (CRM) due to their growing supply risk. This risk is primarily attributed to increasing dependency on imports, with Turkey now accounting for 51% of the EU's feldspar demand—a doubling of its previous contribution (European Commission, 2023; Grohol and Veeh, 2023**)**. Feldspars play a crucial role in the glass and ceramics industries and are extracted from diverse geological sources: 37% from albitites, 24% from pegmatites and aplites, 16% from granitoids, 11% from feldspathic arenites, 6.5% from nepheline syenites, 2.5% from rhyolites and porphyries, and 3% from rocks affected by metamorphic and epithermal processes (SCRREEN, 2023).
Granite waste, due to the nature of its parent rock, contains substantial amounts of K-feldspar and Na-plagioclase, with average concentrations of 28.5% and 39.7%, respectively, making it a promising feldspar source (Gougazeh et al., 2018; Silva et al., 2019). As highlighted by Dino et al. (2012), granite quarry waste serves as a viable alternative and complementary resource, reducing the need for virgin material extraction from primary quartz and feldspar deposits. Moreover, utilizing quarry waste can aid in environmental restoration and stabilize waste-affected slopes. Nonetheless, the authors stress the importance of thorough evaluations to determine the material's volume, size distribution, and mineralogical and chemical properties for optimal exploitation. Beneficiation techniques, including gravity and magnetic separations, can efficiently recover quartz and feldspars while minimizing the presence of colored impurities like micas, iron oxides, and other mafic minerals (El-Omla and Shata, 2008).
In this context, the island of Sardinia (Italy) was, for several years, among the leading global producers of ornamental granite. However, starting in the 2000s, this industry in Sardinia began to decline due

to infrastructural challenges and the emergence of new international competitors. Today, clear evidence of this period remains across the island, as numerous granite quarries house large piles of granite waste. These accumulations represent a significant factor of landscape degradation, as they are visible from kilometers away and, together with the quarries themselves, disrupt the natural scenery and contribute to soil depletion. Furthermore, these waste piles may pose environmental risks due to the presence of metallic minerals capable of leaching into the hydrosphere and biosphere, as well as safety concerns related to the stability of such waste heaps (Careddu and Sanciu, 2008; Lokeshwari and Jagadish, 2016).

### *1.1. Aims of research*

This research aims to identify possible solutions for the recycling of granite waste present within a granite quarry located in the municipality of Buddusò (Province of Sassari, Italy). In this quarry, which has been in operation for more than 40 years, substantial quantities of granite waste have accumulated, forming clearly distinguishable heaps even from several kilometers away (**Figure** 4). This work presents the results of applying a processing method on granite waste, involving gravity and magnetic separation techniques, with the aim of obtaining quartz-feldspar enriched fractions, and to assess their potential applications within the context of ceramic industry.

## 2. Materials and methods

Eighteen granite waste samples were collected from various disposal points within the quarry, each weighing between 3 and 7 kg. Of these, nine samples underwent a processing procedure that included crushing and sieving to retain material within the particle size range of 0.125–0.850 mm. The processed material was then subjected to gravity separation using a Gemini Masa G-150 wet shaking table (Onur Makina, Eskisehir, Turkey). This procedure yielded three distinct fractions: light fraction (lower specific gravity), intermediate fraction (higher specific gravity than the light fraction), and heavy fraction (highest specific gravity).


***Figure 4.*** *The quarry under investigation. Top left: a satellite image of the quarry. Bottom: an example of a granite waste pile.*

Each fraction was dried at 105 °C for 24 hours, after which ferromagnetic minerals were removed using a magnet. Subsequently, the fractions were subjected to magnetic separation using an isodynamic magnetic separator L-1 (S.G. Frantz Co., Tullytown, U.S.). This process resulted in diamagnetic fractions devoid of ferromagnetic and paramagnetic minerals, categorized as Light-diamagnetic, Intermediate-diamagnetic, and Heavy-diamagnetic fractions.

For the analytical phase, the samples were first ground into a fine, impalpable powder using an electronic mortar equipped with an agate jar and pestle. The resulting material was then subjected to Loss On Ignition (L.O.I.) analysis as follows: approximately 0.6 g of each powdered sample was weighed into ceramic crucibles and placed in an oven at 105 °C to remove any residual moisture. After drying, the crucibles were weighed and subsequently transferred to a muffle furnace, where they were heated at a rate of 3 °C/min to 1000 °C. This temperature was maintained for 6 hours. The crucibles were allowed to cool gradually within the muffle furnace before being placed in a desiccator to complete the cooling process. Finally, the crucibles were re-weighed, and the percentage L.O.I. was calculated.

Subsequently, analyses were carried out to determine the major oxide and trace elements composition using the WD-XRF (Wavelength Dispersive X-ray Fluorescence) analytical technique. Each powdered sample was pressed into tablets using a hydraulic press on a boric acid support. These pressed powder tablets were then analyzed with a Thermo ARL Advant'XP+ Wavelength Dispersive X-ray Fluorescence Spectrometer (Thermo Scientific, Waltham, MA, USA). The accuracy of the instrument, evaluated based on results obtained from international geological sample standards, and theprecision, expressed as the standard deviation of repeated analyses, ranged between 2% and 5%, with a detection limit of 0.01%. The processing of the acquired intensities and the correction of matrix effects effects were conducted following the model proposed by Lachance and Trail (1966).

## 3. Results and discussion

From the perspective of major oxides, the diamagnetic fractions appearead to be relatively homogeneous. They were characterized by a high content of $SiO_2$ (77.76–78.05 wt.%) and $Al_2O_3$ (12.06–12.16 wt.%). The combined $Na_2O$ + $K_2O$ content ranged from 7.57–7.80 wt.%. The CaO content varied between 1.44–1.51 wt.%, while the L.O.I. values ranged from 0.31–0.37 wt.%. Additionally, the diamagnetic fractions were notable for their low concentrations of $Fe_2O_3$ (0.33–0.34 wt.%), $TiO_2$ (<0.02 wt.%), MgO (<0.1 wt.%), and MnO (<0.01 wt.%) (Figure 5).

Regarding trace elements (Figure 5), the effects of gravity separation were mildly evident and involved elements such as Nd, Th, Y, Zn, and Zr. The differences were observed in their concentrations, which were highest in the Heavy-diamagnetic samples and decreased progressively to reach the lowest values in the Light-diamagnetic samples. Nevertheless, for most of these elements, the concentrations were generally below 10 ppm despite the observed variations. The only notable exception was Zr, which exhibited significantly higher concentrations in the Heavy-diamagnetic sample (>100 ppm), compared to 30 ppm in the Intermediate-diamagnetic sample and 21 ppm in the Light-diamagnetic sample. No differences were observed for the other investigated elements. Specifically, their concentrations were distributed as follows: Ba (approximately 600 ppm), Rb and Sr (90–100 ppm), Pb (around 25 ppm), Cr and Ce (approximately 10 ppm), and Co, Cu, Ga, Ni (<10 ppm). Hf, La, and Sc were found in concentrations below 1 ppm.

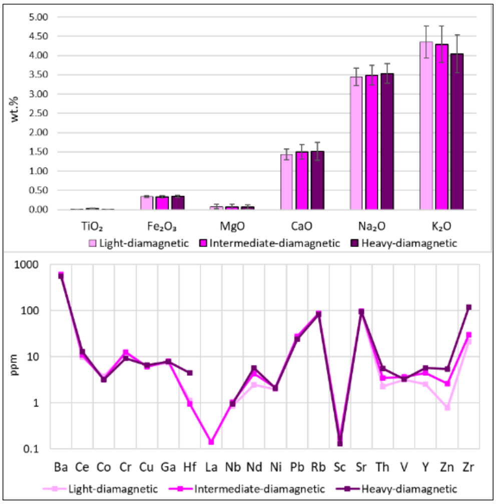


**Figure 5.** WD—XRF *analytical results: Major Oxides and Trace Elements (results of analyses conducted on 9 Light-diamagnetic samples, 9 Intermediate-diamagnetic samples, and 9 Heavy-diamagnetic samples).Top: bar chart displaying the concentrations of selected major oxides. Bottom: line graph illustrating the concentrations of trace elements across the three sample types.*

The composition of the diamagnetic phases was compared to that of quartz-feldspar sands used as supplementary raw materials for ceramic tile production, as suggested by Fabbri & Fiori (1985). This comparison showed that the diamagnetic phases under study had compositions closely resembling those proposed by Fabbri and Fiori (Fig. 4). Therefore, it would be beneficial to conduct further investigations on the obtained material to assess its potential suitability for use in ceramic tile production.

Furthermore, Nordala et al. (2014) demonstrated the potential of using granite waste, with an $Fe_2O_3$ content of 2.52 wt.%, as a fluxing agent in ceramic paste formulations consisting of 50 wt.% granite waste and 50 wt.% ball clays, resulting in excellent outcomes. El-Maghraby et al. (2011), replaced both aggregates and feldspars with natural granite in ceramic body formulations. They used granite with an $Fe_2O_3$ content of 2.5 wt.% in paste formulations ranging from 20 wt.% to 35 wt.%, achieving excellent results, particularly in terms of color, as the product was compatible with white single-fired tiles. Given the very low iron content observed in the diamagnetic fractions obtained in this study, it is plausible that these materials hold significant potential for use in the ceramic industry, including the production of high-quality products. For this reason, further studies are necessary to evaluate the feasibility of utilizing these materials in the formulation of ceramic bodies.

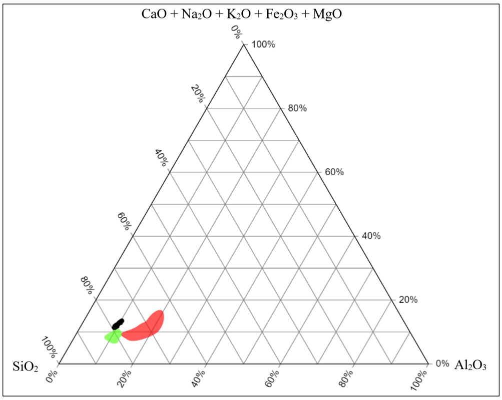


***Figure 6.*** *Ternary diagram comparing the compositions of the complementary raw materials for the production of ceramic tiles, by Fabbri & Fiori (1985) with those of the diamagnetic fractions under investigation in this study. Red: feldspars and feldspars rocks; green: quartz-feldspars sands; black: diamagnetic fractions of this study.*

## 4. Conclusions

The supply of raw materials, the excessive accumulation of waste, soil depletion, the preservation of natural landscapes, and the granite industry are deeply interconnected issues within the Sardinia region. Ensuring a sustainable CRM supply necessitates waste recycling, and in the context of Sardinia's granite industry, the accumulated waste represents a significant challenge stemming from the region's long history of extraction activities.

This study revealed that in the Buddusò area, processing granite waste through crushing, sieving, gravity separation, and magnetic separation can yield diamagnetic fractions significantly depleted in components such as Fe, Ti, Mg, and Mn, while being highly enriched in Si, K, and Na. These fractions exhibit considerable potential for application in the ceramic industry. Therefore, further studies are needed to evaluate their suitability for such uses.

Repurposing these waste materials would enable soil reclamation and the restoration of its ecological functions while rejuvenating the natural landscape, which has been heavily impacted by the proliferation of quarries. Moreover, reframing these waste materials as valuable resources rather than mere byproducts, and directing research efforts toward identifying optimal recycling and reuse strategies, could contribute the sustain the granite industry in Sardinia. This approach holds particular promise given the substantial volumes of granite waste in Sardinia.

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# Mineral Exploration utilizing remote sensing techniques and ground-based data

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## Abstract

*This contribution illustrates the starting activities of the Horizon Europe MINEYE Project (GA: 101138456, 2024-2027) designed to contribute to increasing access to critical and strategic metals and minerals on European territories. MINEYE intends to develop and integrate non-invasive investigation methods (including: geophysical measurements, remote sensing and Earth Observation) within the mining value chain, through an Interfacing, Programming and Optimization Platform (IPOP). The technology will be demonstrated and validated in three pilot sites: (i) the mining areas of Tharsis (Spain) with massive sulphide deposits; (ii) Norrbotten County (Sweden) with rare earth element potential; and (iii) the SO.RI.CO.M. mine (Albania) with deposits of chromite. This contribution focuses on the case study of the Albanian mine and in particular on the first analyses carried out and on the field visit conducted by the research group.*

**Keywords**: mineral exploration, mining engineering, remote sensing, mining value chain, chromite mine.

## 1. Introduction

Europe nowadays is in urgent need of reactivating and empowering its mining sector (Bertet et al., 2024). The Critical Raw Materials act was approved in 2024, providing clear exploration and mining strategies, with special reference to the “critical” minerals, those whose scarcity can seriously endanger the European Economy (EU, 2024). Among the ongoing projects in the sector, MINEYE aims to integrate non-invasive methods within the entire mining value chain, to enhance efficiency of exploration, to improve the mine management and to verify the environmental compatibility in mining operations.

***Table 1***. *Project Consortium and specific competences applied to MINEYE*

| N° | Partner Name | Specific Sector |
|---|---|---|
| 1 | Stiftelsen Geotekniske Institutt | Research – Mineral Exploration |
| 2 | Luleå Tekniska Universitet | University – Mineral Exploration and Remote Sensing |
| 3 | Università di Bologna | University – Mining Engineering, Geostatistics and Remote Sensing |
| 4 | Terranigma Solutions GMBH | Industry – Mineral Exploration |
| 5 | ETAM SA | Industry – Communication and Dissemination |
| 6 | Ceska Geologicka Sluzba | Research – Geological Survey |
| 7 | Innsight SRL | Industry – Environmental services |
| 8 | Spacebel SA | Industry – Software house |
| 9 | Tharsis Mining Sociedad Limitada | Industry – Mining Company |
| 10 | TRE Altamira SRL | Industry – Remote Sensing |
| 11 | Planet Labs Germany GMBH | Industry – Remote Sensing |
| 12 | Spectral Industries BV | Industry - Sensoring |
| 13 | SO.RI.CO.M. Società Ricerche Coltivazioni Mineraria SRL | Industry – Mining Company |

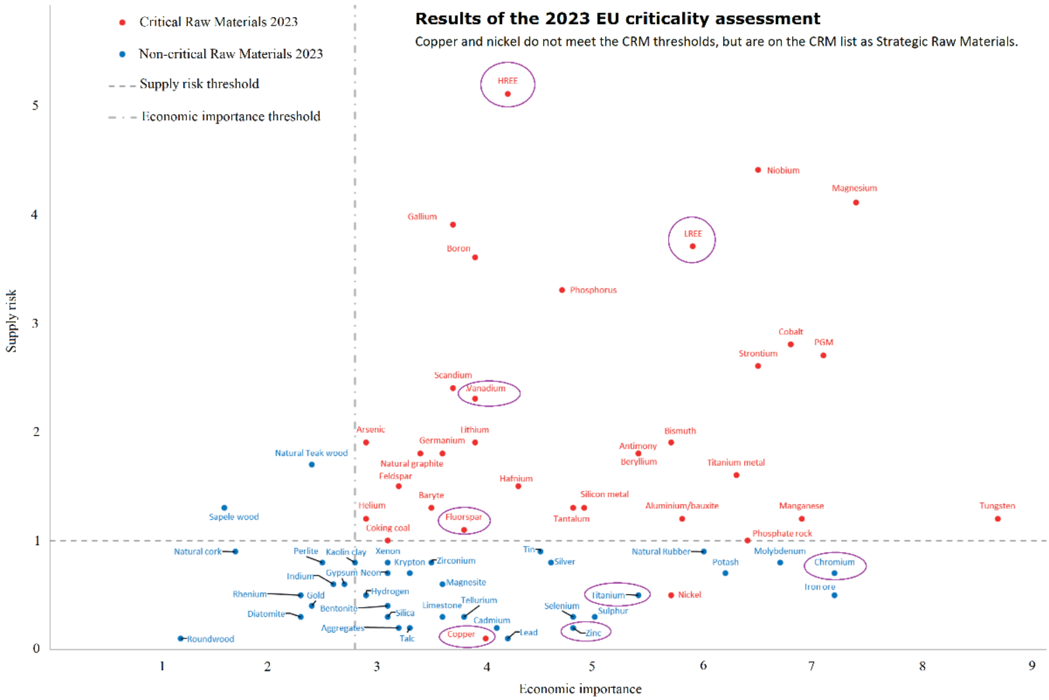


***Figure 1****. Target elements in the MINEYE case studies within the framework of the EU criticality assessment (Modified from “Study on the critical raw materials for the EU 2023: final report”).*

The Consortium is composed by 13 partners (Table 1). Three case studies were chosen: (i) the mining areas of Tharsis (Spain) with massive sulphide deposits; (ii) Norrbotten County (Sweden) with rare earth element potential; and (iii) the SO.RI.CO.M. mine (Albania) with deposits of chromite. Target elements are reported in Figure 1.

### *1.1 MINEYE case studies in brief*

MINEYE’s implementation is centered around three characteristically diverse demonstration sites. The first site, Tharsis and the Iberian Pyrite Belt (Spain), offers both brownfield and greenfield explorations with large variety of deposit types including volcanic and shale hosted massive sulphides (VHMS), skarns, iron oxide copper gold deposits (IOCG) and vein-hosted mineralization. The MINEYE activity is exploring for more sulphur deposits and, in addition, studying the re-mining potential from dominantly sulphur-rich tailings with variable content of copper, base and precious metals. The second site, Norrbotten (Sweden) is one of Sweden’s main mining areas and hosts iron and copper deposits. Phosphate occurs as by-product from iron ore mining. Moreover, Norrbotten hosts the recently announced REE deposit discovery, which is classified as one of Europe’s largest REE deposit. The MINEYE approach is focused on REE/phosphates greenfield exploration. It will showcase how EO data combined with regional airborne magnetic data and gravity data can be used for exploring similar types of deposits in the entire Norrbotten province. The third site, the Ternove chromite mine, is a full-value chain in-operation mine hosting chromium deposits, with significant amount of tailings and other mining residues.

The MINEYE objective is to get a clear understanding of mineralization and to target chromite pockets for exploitation. The selection of the three demo-sites has been done carefully to cover diverse highly demanded elements and other significant minerals. Moreover, the combination of the three case studies offers a great opportunity to investigate the capability of the MINEYE’s approach to address exploration, ground stability and safety, and environmental-related issues.

## 2. Materials and methods

The MINEYE approach is centred around the development of an *Interfacing, Programming and Optimization Platform (IPOP)* with efficient data handling capabilities and the functionality to run processors on demand. New analyses tools will be implemented such as: *Mineral Potential Mapping MPM* and *Inventory Map and Mining Residues Package IM-MRP.* Moreover, MINEYE will provide tools for time series analysis and 3D geological/geophysical modelling. IPOP will furthermore provide mine managers and decision makers with comprehensive overview about data and operation progress of the mine from past and present activities, thereby facilitating the planning of future operations. The full MINEYE application to the mining value chain is outlined in Fig. 2. The impacts of the action move towards a sustainable mining: increased success rate of exploration, increased digitalisation of procedures, increased safety for workers, reduced mining wastes, reduced environmental impact, increased social license to operate (Fig. 3).

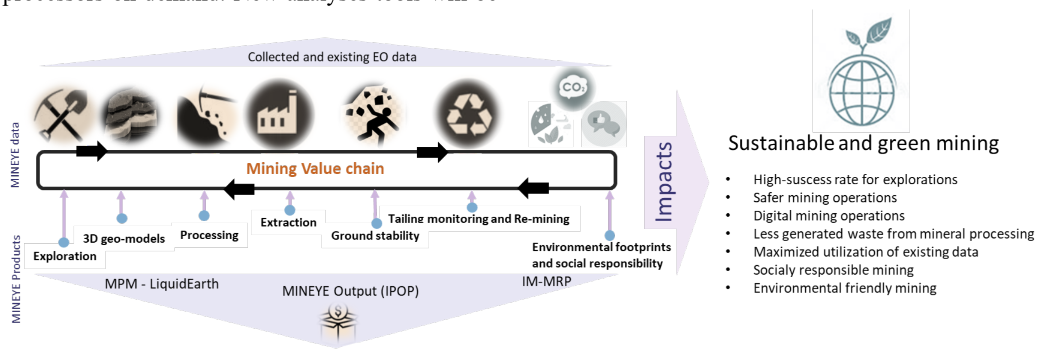


***Figure 2**. Description of the three MINEYE outputs within the mining value chain.*

## 3. Preliminary applications on chromite deposits

In the Bulqiza massif, about 174 chromite deposits and occurrences are known, which constitute around 90% of the total discovered chromite in Albania nowadays (Fig. 4). Chromite occurs related to peridotites, dunites and hazburgites. The biggest and highest-grade ore bodies, which constitute about 90% of the total reserves of Albanian chromites, are typically located within depleted harzburgites, 500 m below the harzburgite transition zone boundary. Locally, the chromites show a sharp contact with the wall harzburgites. Ore bodies of this kind are those of Bulqiza, Shkalla, Ternove, Theken and Lugu i Qershise. The thickness of ore bodies varies from 1 up to 10 m, in pockets and small veins, with grades changing from very low (<10%), low (10%), medium (40%) and high (>40%). The cut-off grade of $Cr_2O_3$ for selling and shipping the tout venant is currently around 40%. Low grade mineral bodies are treated by spiral plants and shaking tables located besides the mines for chromite enrichment. Gravity is the most used method for mineral separation, due to the high density of chromite minerals with respect to gangue minerals. Besides chrome, potential occurrences of iron, nickel, vanadium and titanium are object of investigation.

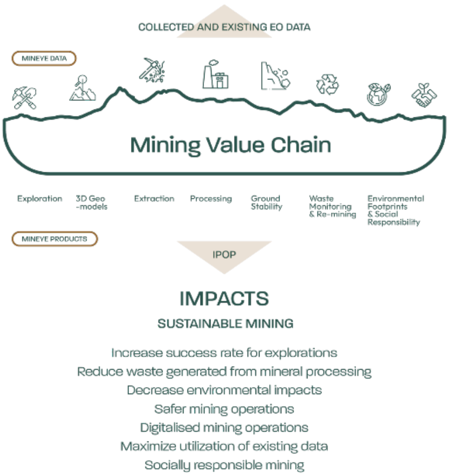


***Figure 3**. Expected Impacts of the MINEYE approach*


***Figure 4.** Chromite belt and focus on Bulquiza*

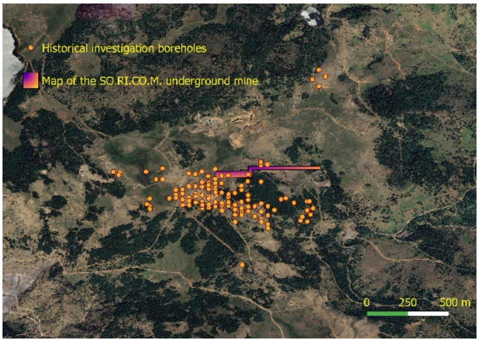


***Figure 5.** Localization of historical boreholes and map of the authorization area*

The Ternove underground mine was opened around 1990: the works were preceded by a vast sampling campaign, and the calculation of reserves was performed in 1987 (Beqiraj, 1987).

In recent times, the mine was reactivated by SO.RI.CO.M. (Fig. 5). Currently, approximately 600 m of tunnels have been established, divided in two levels of size 2.0×2.5 (Fig. 6). Preliminary investigations suggest mineralization should extend 400 m long and 40 m thick. The MINEYE researchers visited the site on July 2024 (Fig. 7).

***Figure 6**. Entrance of the mine*

***Figure 7****. Site visit by the MINEYE researchers.*

## 4. Results and conclusions

As the preliminary step, before the site visit, Sentinel 2 images (Level 2A atmospherically corrected surface reflectance) (https://dataspace.copernicus.eu/), were used (sensing date: 2023-07-10) to detect the possible Chromite outcrops on the surface. The spectral signatures of Chromite outcrops nearby mine has been studied and used as the reference to test several band ratios (Figure 8 top) and at the end chromite outcrops were highlighted using band ratio (B3/B4) as shown in Figure 8 bottom. The Chromite outcrops obtained from remote sensing analysis will be integrated with possible geochemical samples, geophysical measurements and available boreholes for further exploration steps to identify Chromite anomalies in Ternove mine.

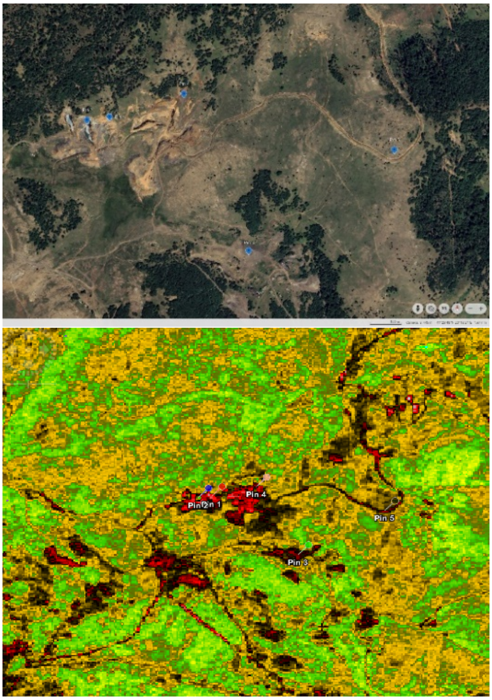


***Figure 8****. Chromite outcrops and shallow excavations well detected by band-ratio (B3/B4) at the investigation area.*

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# Sustainability in geo-resource management through international cooperation and competence-building projects: the GEODES Project

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**Abstract**

*Natural resources, and in particular geo-resources, are a precious and irreplaceable asset that has always been of primary economic interest, and only secondary environmental and social interest. In recent decades, the concept of sustainability and sustainable development has become more 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 us to rethink and redesign our production and consumption patterns. 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 are prerequisites for a profound change in human attitudes at both individual and societal levels.*

*In this context, education and training of all actors involved in geo-resource management is an indispensable starting point for sustainable development. 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 framework, the Erasmus project GEODES, a continuation of the previous Erasmus project SUGERE, aims at standardising and implementing training programmes for the teaching of Mining Engineering and Geosciences in non-EU countries (focus on Angola and Mozambique).*

*The GEODES project brings together 3 European universities, 2 African universities with advanced facilities and extensive teaching experience in geosciences, already involved in the SUGERE project, and 4 new African institutions from Angola and Mozambique.*

*The GEODES project promotes new international collaborations focusing on sustainable development in the geo-mineral context. By strengthening geoscientific expertise and exchanging experiences, we can develop modern strategies for the responsible and sustainable management of natural resources and acquire the ethical values needed to solve local problems. In order to achieve this ambitious goal, it is necessary to promote the creation and maintenance of a strong network of sharing, exchange and research activities between European and non-European universities.*

*GEODES is an important step in the development of a culture of sustainability: the representatives of the African institutions involved in the previous capacity-building project (SUGERE) have in turn become trainers and promoters of sustainable practices and activities in this project.*
*Education for sustainable development is the basis for the development of critical, ethical and conscious thinking and the right skills needed 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 socio-economic factors and natural systems.*

**Keywords**: Geology and mining engineering high education, sustainable development and georesources, EU–Africa cooperation projects, responsible mining.

## 1. Introduction

Approximately one third of the world's RM reserves are in Africa; there are currently around 700 active mines, with many more sites being explored in light of the global transition to a low-carbon future. Several mining agreements between African countries and international companies include low royalty rates and extensive tax exemptions, (Gajigo et al., 2012), factors that benefit international investors and provide minimal benefits to local governments. These agreements often do not consider the local social context and the impacts of extractive activities on the environment. In several countries (e.g. South Africa, Uganda, Sierra Leone, etc.), mining has experienced an increase in social crimes and episodes of civil instability and ethnic and political violence (Marais et al., 2022; Ojewale, 2022).

International standards, such as the United Nations Global Compact (UNGC), also promote a more inclusive and sustainable global economy by requiring mining companies operating in Africa to address social and environmental issues according to the principle of sustainability (Ackah-Baidoo, 2016, Teschner, 2012). Industrial mining projects can play an important role in the sustainable and economic income development of low and medium-sized countries (Yakovleva et al., 2017). The positive effects of sustainably conducted mining, with the adoption of high-quality governance coupled with in-depth technical expertise, are evident on the welfare (improvement of essential services, health care) and economy of local communities (Widana, 2019).

However, the potential negative impacts associated with mining should not be underestimated (Haddaway et al., 2019); these must be carefully assessed and managed appropriately to ensure the expected level of sustainable development (Carvalho, 2017).

Sustainable and responsible management of geo-resources requires a rethinking and redesign of our production and consumption patterns. 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 are prerequisites for a profound change in human attitudes at both individual and societal levels. In this context, training and education of all actors involved in the management of georesources is an indispensable starting point for the acquisition of critical, ethical, and conscious thinking and the technical skills necessary to solve local problems and initiate sustainable development.

In the last decade, international cooperation projects have been implemented in Europe to promote sustainable mining. These projects aim at capacity building in the field of geo-resources and for the development of a shared legislative and policy framework (Erasmus+ projects), the development of research and innovation activities (Horizon 2020-R&I projects) for the development of a circular economy and the building of EU-Africa partnerships on sustainable RM value chains (Horizon 2020-CSA projects).

Some examples of successfully completed Erasmus+ projects in the field of mining and geosciences are the MINERAL project, TUNING

AFRICA and SUGERE (Teklemariam et al., 2014, Dino et al., 2022). GEODES fits into this group of projects.

The GEODES project aims to train "smart and responsible" experts in geology and mining engineering who can work, hand in hand with the mining sector, towards a more ethical and sustainable mining. It is based on the enhancement of university education with a focus on the economic, environmental, and social sustainability aspects of mineral resource operations. The project acronym 'GEODES' reminds us of the pieces of rock that from the outside look rough but inside can have beautiful crystals.

### *1.1. Aims of research*

This research focuses on GEODES - "Geosciences, Development and Sustainability - Africa and Europe together," an ERASMUS+ project, which aims to create strong research and training networks between European and non-European universities interested in mining issues.

The project participants belong to 3 European universities, 3 institutions from Angola and 3 institutions from Mozambique (Tab.1).

| PROJECT PARTICIPANTS | City | Country |
|---|---|---|
| Universidade De Coimbra (UC) | Coimbra | Portugal |
| Universidad De Salamanca (USAL) | Salamanca | Spain |
| Universita' Degli Studi Di Torino (UNITO) | Torino | Italy |
| Universidade Katyavala Bwila (UKB) | Benguela | Angola |
| Universidade Agostinho Neto (UAN) | Luanda | Angola |
| Universidade Mandume Ya Ndemufayo (UMU) | Lubango | Angola |
| Universidade Eduardo Mondlane (UEM) | Maputo | Mozambique |
| Universidade Lurio (UniLurio) | Nampula | Mozambique |
| Universidade Pungue (Unipungue) | Chimoio | Mozambique |

***Table 1.*** Institutions participating in GEODES project

GEODES represents a continuation of an earlier project, SUGERE, focused on the development and alignment of Geology and Mining Engineering degree programs, which was successfully concluded in 2023 (Fig. 1).

The operational objectives of the GEODES project include:

- the hosting of four higher education institutions (HEIs) from less developed areas (Central and Southern Angola, Central and North-Eastern Mozambique),
- the technical training of teachers and final year students of six HEIs (3 from Angola UAN, UKB, UMN and 3 from Mozambique UEM, UniLurio, UniPungue) in the area of Earth Sciences,
- the reinforcement of trainers in two institutions (UAN, UEM) for the training of national scholars,
- the upgrading and development of undergraduate (4) and postgraduate (2) courses in the area of Earth Sciences.
- the ground preparation for a 'GEODES Initiative (policy objective): Earth Sciences as the basis for resilient and sustainable development and the empowerment of students and educators on Local Community Development (LCD) as opposed to Local Economic Development (LED)'.

Updating takes place mainly through the implementation of eLearning courses and the preparation of specific bibliographic material and involves the training of at least 20 lecturers and more than 100 students over two years of courses and approximately 30 in-company placements. The cooperation of companies in Angola and Mozambique is crucial for internships and for adapting CVs to industrial needs.

The project follows the recommendations of AU (African Union) Agenda 2063 (AU, 2015), UN Sustainable Development Goals (UN, 2015), 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change and Agenda 2063 (EU, 2020).According to the Sustainable Development Goals (SDGs), economic, environmental, health and social issues must be managed simultaneously to ensure the valorisation of sustainable industries and, in particular, the mining sector (Mvile and Bishoge, 2024). This project aims to develop key SDGs sustainability objectives such as maximising the benefits of regional economic integration and trade (SGD1), ensuring well-governed migration and mobility (SDG17), promoting education, research and innovation (SDG4), strengthening the rules-based multilateral order by promoting universal values, human rights, democracy, rule of law and gender equality (SDG5, SDG10), and creating decent and value-adding jobs through sustainable investments (SDG8);The basic idea of GEODES is the integration of the four new institutions from less favoured areas (UKB, UMN, UniLurio and UPungue) into the ERASMUS programme, in order to improve the implementation of degrees in the area of Geosciences, together with the training of students and teachers in practical aspects.

The project also aims to change the vision of the *Geosciences*, usually labelled as '*grey sciences'* due to old and inappropriate extractive practices, into *Sustainable Geosciences* that support everything, including life.

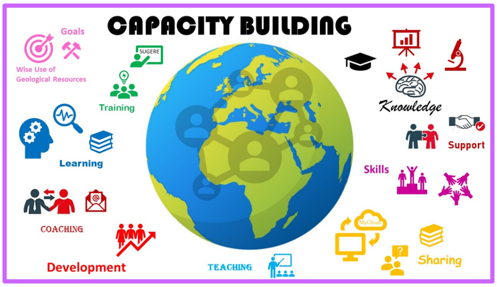


***Figure 1****. Capacity building in international standardisation of* Higher Education training and teaching in Earth Sciences and Mining Engineering.

## 2. Outline of the project

The GEODES project is based on: (1) the analysis of the necessities of the HEIs; (2) a prioritized list of equipment needed to improve the capacities of the African partners; (3) a coherent training programme for teachers & final year students from the main beneficiaries; (4) the training of the main beneficiaries on research proposal preparation; and (5) the creation of conditions for future sustainability of supported courses.

GEODES is structured in 10 Work Packages (WP), each characterised by specific activities necessary for the development of the project. Each Work Package has a WP leader who is in charge of coordinating the planned work; the progress of the project is periodically shared with the participants through online meetings.

The project follows a STRAND1 initiative (welcoming new participants from Angola and Mozambique) and benefits from the experience accumulated by two institutions that participated in the previous SUGERE project (Agostinho Neto-UAN University, Angola, and Eduardo Mondlane-UEM University, Mozambique). The latter will also act as local training institutions in cooperation with the European partners. The structure was designed to share responsibilities among all partners and to enable newcomers to participate in project management. Having that in mind the consortium cooperation has been devised in WP.

After designing the structure, project phases and role of the partners (WP1), the tools and equipment to be purchased (WP2) were defined by the beneficiary partners (UAN, UKB, UMN, EMU, UniLurio, UPungue). The EU institutions (UC, USAL and UNITO) and the EMU and UAN partners carry out a review of the existing geoscience curricula and curricula with the preparation of reports and suggestions on potential improvements (WP3).

In addition to the training of teachers and final-year students of UKB and UMN by trainers from UAN, EMU (with the cooperation of the European institutions. WP4), online training modules are prepared and delivered to the main beneficiaries (UKB, UMN, UPungue and UniLurio) by the European partners (USAL, UC and UNITO. WP5). The extensive experience of previous years has shown that the limits of face-to-face teaching can be enriched and implemented in new ways with teaching materials and activities developed at the institutions involved in the project.

The vocational training activities with internships in private companies and local public institutions (WP6) in Angola (10 students) and Mozambique (10 students) and the training abroad (WP7) of the trainees selected by UKB, UMN, ULurio and UPungue (the main beneficiaries of the project) represent an important phase of the project as they provide experience in preparing new research projects for financial support in their countries and abroad, with in-depth insights into the definition of research project objectives and key steps for proposal submission. Finally, an important part of the project concerns dissemination and awareness-raising activities among the main stakeholders (WP9): HEIs, companies and the general public. The design of a communication plan is done through the identification of target groups/stakeholders with specific dissemination tools and through the creation and maintenance of the project website, the creation of social network profiles, the preparation of a newsletter (https://www.uc.pt/en/geodes/news/geodes-wp4-training-in-africa-mozambique) and the organisation of a conference at the end of the project to define a sustainability plan to ensure a long-term perspective.

Quality control (WP8) and management (WP10) of the project activities aim to guarantee the effectiveness and quality of the consortium and to ensure the quality of the project and its results.

***Figure 2**. Laboratory activities of GEODES project.*

## 3. Outcomes

The main objectives and results of the GEODES project are the international standardisation of training and university teaching in Earth Sciences and Mining Engineering and the promotion of a more responsible and sustainable use of geo-resources (Fig. 3). Currently, geoscience-related subject areas are lacking in the curricula of partner colleges, creating a shortage of qualified African specialists. Furthermore, the increased demand for energy and raw materials, which has led to a renewed global interest in minerals and natural resources, makes the training of qualified specialists necessary and essential (Rey et al., 2021).

The African Union Agenda 2063 (AU, 2015) recognizes science, technology and innovation (STI) as multifunctional tools and an enabler for achieving continental development goals. In addition, the agenda emphasizes that Africa's sustained growth, competitiveness and economic transformation require substantial investment in new technologies and continuous innovation.

To realize the full potential of science, technology, and innovation in support of sustainable socioeconomic growth and development, and to enhance African competitiveness in global research and innovation, countries need to continue to expand the availability of quality postgraduate education, including doctoral qualifications.

The project follows the National development strategies of Angola and Mozambique:

- In Angola the training of highly qualified personnel is part of a number of National plans, most notably the "Angola Strategy 2025," which gave rise to the National Plan for the Training of High-Level Personnel. This plan, which was recently reconfirmed, set a target for 2020: 4800 MSc and 1500 PhD and 6900 HE teachers; the failure to meet these targets required an update of the plan that sets a new deadline (2025) to meet the targets set.

- The National Development Strategy 2015-2035 of Mozambique refers to proper utilization of natural resources and human capital formation as key issues for sustainable social and economic development.

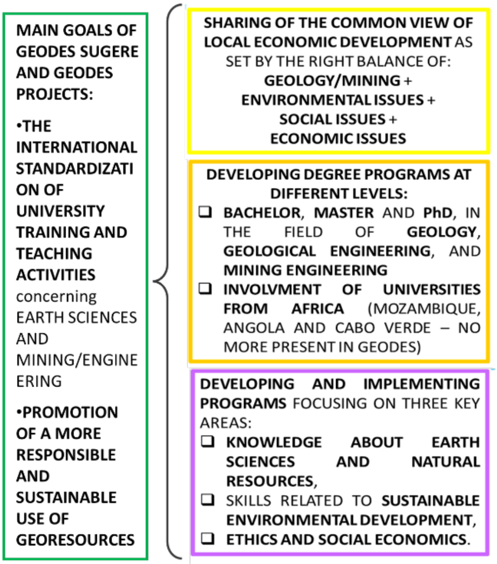


***Figure 3*** *Main goals of GEODES project.*

A strong research and training networks between european and noneuropean universities interested in mining issues have been set up. GEODES aims at promoting the culture of sustainability and the deepening of skills in the field of geomining: from the development of critical thinking, fundamental for the resolution of local problems, to the acquisition of ethical values and technical skills that underpin sustainable development.

The sustainability measures of the project objectives implemented are based on the effective dissemination of results with a long-term impact.

Fostering communication and exchange between scientists by bringing together complementary and common interests allows for improved research standards, methods and techniques, including the transfer of fundamental and applied knowledge between partners. This partnership brings a new attitude to resource exploitation in Africa and a resilient attitude to tackling climate change.

## 3. Conclusions

The main goals of the GEODES project, like those of SUGERE, concern the international standardization of higher education training and teaching in Earth Sciences and Mining Engineering with basic preparation for resilient and sustainable development through empowering students and educators on Local Community Development (LCD) as opposed to Local Economic Development (LED).

Cross-cutting objectives of the project include increasing the international cooperation capacities of institutions from third countries not associated with the programme and the preparation of research proposals: this will improve the research capacities of the institutions involved and establish long-term connections between the project partners, but also with existing partnerships that the 'seniors' already have.

GEODES builds on SUGERE experience in the sense that two partner HEIs (University Agostinho Neto and University Eduardo Mondlane) will be acting as local training institutions by upgrading MSc programmes to respond to the needs of the other local institutions (University Mandume Ya Ndemufaya and University Katyavala Bwila in AO and University Pungue and University Lurio in MZ).

Innovative aspects: (i) Two African HEIs assuming the role of ToT (as a natural evolution of the previous support and collaboration received); (ii) Use of local partners for supplying internships and as active suppliers of input for the academic programmes; (iii) Focus on Local Community Development and not Local Economic Development; (iv) Geosciences as the basis for a greener future and not a grey science.

Education for sustainable development is the basis for the development of critical, ethical and conscious thinking and the right skills needed to solve local problems.

The path towards environmental and social sustainability in the use of geological and natural resources is a process that takes time and leads to 'rethinking' 'our' way of producing and consuming in an intergenerational perspective, through an ever deeper understanding of the ethical value of the relationships between socio-economic and cultural factors, and natural systems.

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# Reliable long-term $CO_2$ storage as clathrate hydrates: The $CO_2$ -RESTO Project

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**Abstract**

Carbon capture and storage refers to the separation and capture of carbon dioxide ($CO_2$) from anthropogenic emissions and its permanent storage. Recently, the possibility of storing $CO_2$ as clathrate hydrate (CH) has been investigated. $CO_2$ storage as CH is supported by the millennial stable occurrence of natural gas hydrates in marine sediments and permafrost that have been extensively studied. This is an important starting point for the feasibility of the hydrate-based $CO_2$ storage solution. In this context, the $CO_2$-RESTO project aims to develop a technological solution for $CO_2$ sequestration in the form of CH both in seawater and under the seafloor. The following activities are planned to achieve this goal:

- Theoretical survey of the approaches for $CO_2$ storage as clathrate hydrates;
- Laboratory reproduction of $CO_2$ CH in water and determination of the influence of chemical and thermodynamic parameters;
- Laboratory reproduction of $CO_2$ CH in under-seafloor sediments and determination of the influence of chemical and thermodynamic parameters;
- Theoretical model applicable on $CO_2$ CH formations and energy/environmental evaluations on the proposed technological solution.

The expected results will be:

- New knowledge on the $CO_2$ CH stability in natural conditions;
- Development of an efficient technological solution for $CO_2$ injection in the sediment.

# The quarrying of ornamental stones and their commercial exploitation: an environmental approach integrating sedimentological studies and 3D modelling from UAV survey

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## Abstract
Quarrying ornamental stone involves the excavation of lithoid material that is often fractured to varying degrees. Thismaterial is generally heterogeneous, resulting in different commercial p roducts with varying qualities. As a result, it is often challenging to plan and manage the quarrying process efficiently. In fact, over time quarrying efforts have focused primarily on extracting only the most commercially valuable materials, often at the expense of the rest of the deposit. Over time, this approach can lead to occupational safety hazards and environmental issues, such as challenges in proper landscaping and reclamation of the quarry once extraction is complete. The use of sedimentological studies, particularly facies analysis [1], can help identify the most valuable lithotypes even from the earliest stages of the construction site. This, in turn, aids in preparing efficient and effective mining plans from various perspectives, such as safety, the use of economic and environmental resources for extraction, and ensuring the correct landscape integration of the quarry after its exploitation. The use of unmanned aerial vehicles (UAVs) in conjunction with precise and accurate Global Navigation Satellite Systems (GNSS) stations, allows for the creation of 3D terrain models with associated errors of just a few centimeters. Integrating
these models with high-definition photographs using specialized software simplifies the application of facies analysis, making it easier, to estimate the positions and volumes of certain lithofacies of particular interest. This reduce extraction costs and enhances the sustainability of mining processes. We present the experimental application of this approach at the Poggio La Vecchia quarry in the municipality of Manciano (Grosseto Province) where the commercial variety of Manciano Sandstone known as "Pietra Santafiora" is extracted.

**Keywords:** facies analysis, UAV, 3D model, sandstone, quarry

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# Potential Critical Raw Materials (CRM) resources in historically dismissed volcanogenic massive sulphide (VMS) deposits in Boccassuolo ophiolite, Modena Province, Italy: a petro-geochemical study

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## Abstract
The last update on Critical Raw Materials (CRM) drawn up by the European Union (2023) identified 34 CRM, minerals, elements, or materials defined as “critic” due to their economic relevance and supply risk. This led many European countries, including Italy, to focus on recovering metal from dismissed mine sites and landfills. Italy has more than 100 historically dismissed sites in the North, including Volcanogenic Massive Sulphide (VMS) deposits, these metal sulphide ore deposits occur because of underwater eruptions, associated with hydrothermal events in submarine environments [1]. Here, they are ophiolitic basalts cropping out as olistoliths in the Northern Apennine External Ligurian units; VMS superimposed the mafic rocks forming by metal-rich hydrothermal circulations which developed quartz-sulphide veins when mixed with seawater through fissures network [2,3]. Preliminary major and trace elements bulk rock geochemistry was performed in a group of basalts of the Boccassuolo ophiolite and compared with the previous results [*e.g.,* 4]. Results showed strongly mineralized weathered spilitised basalts with even naked-eye visible sulphide minerals, forming an association of pyrite, chalcopyrite, sphalerite, kësterite, and pyrrhotite, as revealed by XRD measurements. Geochemical studies revealed mafic rocks enriched in Cu and Cu-Zn, concerning oceanic and continental crust average composition. Both Cu and Zn belong to the last European CRM update; moreover, *in-situ* analyses are planned on sulphide to identify other CRM, such as Platinum-Group Elements, PGE, to increase the available dataset and improve Italian and European roles in local and internal mining for potential internal supply, thus limiting the import of commodities.

**Keywords**: CRM investigation, VMS deposits, sulphides, PGE, ore deposits

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# Critical raw materials in the global high-throughput ceramic industry

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## Abstract
The high-throughput ceramic industry is exposed, at the global level, to the risk of shortage and/or sudden price growth of raw materials, particularly Critical Raw Materials (CRMs). The goal of the present study is to overview the dependence on CRMs of a sector transforming a large amount of mineral resources, the ceramic manufacturing and its supply chain (wall and floor tiles, sanitaryware and tableware, frits and glazes, pigments and inks, and so on). For this purpose, a critical assessment with expert consultation was carried out to quantify demand, uses, recycling and possible substitutes of CRMs. The production of inks, pigments, dyes and effects for ceramic decoration is mainly exposed to supply risk, and similarly that of frits, glazes and grinding media. End-users of these materials are equally exposed to risk, albeit indirectly. However, the direct use of CRMs in ceramic bodies occurs massively only for feldspar. The ceramic industry must implement actions to mitigate the different degrees of supply risk to which the CRM is exposed. The extreme risk (Cobalt and Praseodymium) makes it necessary to search for substitutes and technological solutions to reduce CRM consumption. These actions are also recommended in the case of high risk (Antimony and Lithium). The recommended actions to mitigate moderate risk (Barium, Bismuth, Borates, Feldspar, Tungsten, Vanadium and Yttrium) consist mainly of strengthening the supply chain and improving resource efficiency. No action appears to be necessary for low risk (Cerium, Manganese, Phosphate and Platinum), while no risk has been found for Fluorine and Niobium.

**Keywords:** Ceramic industry - Ceramic tiles – Glazes – Pigments - Raw materials

# Transizione verde: strumenti e protocolli per aiutare governance, decision makers e le aziende a decidere se e quando applicare lo sfruttamento dei rifiuti estrattivi come alternativa alla bonifica

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**Abstract**

Le discariche ospitanti rifiuti estrattivi (EW) presentano spesso gravi problemi in termini di impatto ambientale, sicurezza sanitaria e stabilità delle strutture. La loro gestione causa impatti economici e sociali che, insieme a quelli ambientali, devono essere considerati da governance, decision maker e dalle aziende: l’individuazione e la quantificazione degli impatti sono utili per la valutazione della migliore soluzione gestionale delle discariche di EW.

D'altro canto, l'approvvigionamento di materie prime (RM), comprese quelle critiche (CRM), è una sfida da affrontare per garantire elevati standard di sviluppo dell'UE. L'enorme domanda di RM e CRM ha quindi spinto l'Europa ad adottare politiche per trovare fonti alternative e integrative da sfruttare.

Negli ultimi decenni, è stato compiuto un forte sforzo per prevenire, ridurre e minimizzare gli impatti ambientali negativi derivanti dalla gestione degli EW, attraverso l'adozione di nuove strategie e tecnologie di gestione. L'estrazione e il recupero di RM e CRM da discariche estrattive e da rifiuti attualmente prodotti in fase di estrazione e processazione, applicando rispettivamente approcci di landfill mining ed economia circolare, possono offrire benefici non solo economici, ma anche ambientali e sociali.

Per valutare rapidamente se le discariche estrattive sono sufficientemente ricche da diventare potenzialmente sfruttabili, vengono qui presentati protocolli operativi di indagine e decision support tool (DST) che possono venire in aiuto per decidere se una struttura EW merita di essere considerata "sostenibilmente sfruttabile" per garantire l’approvvigionamento di RM e CRM da depositi antropici. In particolare, attraverso una valutazione preliminare o sicura della fattibilità dello sfruttamento EW, con l’introduzione dei fattori sociali, ambientali ed economici coinvolti nei processi di sfruttamento, è stato progettato un DST per EW. Questo strumento esamina le strutture EW sia con dati quantitativi (tecnici, economici, ambientali) che qualitativi (sociali). Gli output del DST sono rappresentati da diversi possibili scenari, utili per decidere se e come affrontare lo sfruttamento di EW. Il DST utilizza informazioni specifiche del sito per identificare quali parametri contribuiscono a rendere lo sfruttamento di EW praticabile, i costi e i benefici, gli impatti sociali e ambientali e il processo più adatto per coltivare la discarica. Grazie al DST è possibile studiare diverse alternative per lo sfruttamento degli EW: ad esempio, la bonifica dell'area di discarica; la produzione di materiali da applicare in ambito civile per opere pubbliche, materie prime seconde per la produzione di aggregati; lo sfruttamento di RM e CRM, ecc. È fondamentale definire la tipologia di discariche estrattive interessate dal recupero, caratterizzarne il contenuto, proporre diversi scenari per il recupero degli EW e associare a ciascuno di essi le tecnologie e le azioni necessarie per ottenere prodotti specifici.

I protocolli per l'indagine di campo e di laboratorio insieme al DST sono stati testati e convalidati utilizzando dati e diagrammi di flusso di elaborazione di casi di studio reali (Montorfano, Monte Bracco, Campello Monti).

**Parole chiave:** Decision Support Tool, sfruttamento dei rifiuti estrattivi, transizione verde

# Approvvigionamento di materie prime critiche: sfide e potenzialità nello sfruttamento delle terre rare provenienti da rocce silicatiche e scarti estrattivi

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## Abstract

L'approvvigionamento di materie prime critiche (CRM) è una sfida che i paesi dell'UE devono affrontare, investendo anche sull'approvvigionamento domestico da depositi naturali (giacimenti minerari) ed antropici (discariche e impianti di smaltimento dei rifiuti estrattivi).

La presente ricerca si concentra sulle possibilità legate all'approvvigionamento di CRM e sul potenziale di sfruttamento degli elementi delle terre rare (REE), attraverso l'esame di un gran numero di rifiuti estrattivi e rocce silicee nella regione Piemonte (Italia settentrionale). Il recupero di REE dai rifiuti estrattivi (EW) associati a cave di rocce ornamentali silicatiche (gneiss, graniti e dioriti) e da altri depositi di rocce silicei (i.e. gneiss caolinizzati) può dimostrarsi strategico al fine di ridurre i rischi della catena di approvvigionamento di CRM/RM. Partendo da una revisione della letteratura sulle attività minerarie in Piemonte, e proseguendo con il campionamento e la caratterizzazione geochimica, mineralogica, petrografica e ambientale di discariche estrattive collegate a rocce ornamentali silicatiche, di gneiss caolinizzati e di suoli presenti in prossimità delle aree indagate, questo studio mostra che il grado di arricchimento di REE differisce a seconda dell'area e tipologia di campionamento (suolo o EW) e della litologia.

La percentuale di REE in alcuni dei campioni analizzati sembrerebbe soddisfare i requisiti necessari per pensare ad un loro sfruttamento: l'elevata produzione di scarti in alcune aree (i.e. gneiss-Pietra di Luserna) o la presenza di giacimenti di ampie dimensioni (gneiss caolinizzato zona Monte Bracco), uniti ai positivi effetti legati al loro sfruttamento, integrando, ad esempio, lo sfruttamento di quarzo e feldspato per l'industria ceramica e vetraria, sembrerebbero indicare una prospettiva praticabile di recupero di REE da EW. Tuttavia, lo sfruttamento a scala industriale di REE deve affrontare sfide come la difficoltà di ottenere un recupero efficiente su larga scala a causa delle differenze regionali nell'abbondanza di REE, la discrepanza tra il potenziale valore di mercato e la produzione annuale di rifiuti, ecc.

La gestione di EW di cava può essere impostata in modo tale da sfruttare i diversi gradi di arricchimento e distribuzione degli elementi. In questo lavoro vengono illustrate le procedure di indagine per determinare le potenzialità dei CRM e le problematiche ambientali, e le procedure per la stima delle quantità di rifiuti e i dei valori economici provvisori delle REE presenti nelle aree indagate. Questo approccio, testato su un'area ampia (la regione del Piemonte), è replicabile e applicabile ad altri casi di studio simili (a livello UE e non UE) e offre a governance e decisori la possibilità di avere una panoramica generale delle potenziali risorse disponibili, al fine di decidere se e dove concentrare gli sforzi (anche economici) su uno studio più dettagliato per valutare i depositi antropici sfruttabili.

**Parole chiave:** REE, caratterizzazione, rifiuti estrattivi

# Critical raw materials in the italian deposits of the sapropel and of the Messinian Gessoso Solfifera deposits

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## Abstract

The Mediterranean is a heterotrophic basin, where oxygen is consumed more than its production (Powley et al., 2017) which can easily reach critical conditions with the early deposition of sediments rich in organic substance (sapropel) [1], the deposition of dog algae, up to evaporite deposits of sulphur, strontium, magnesium, barium, potassium, arsenic, iodides and bromides. Sapropels contain more than 2% organic carbon and high quantities of S, Ba, Mo, Re, U and V, the Tripoli formation are high purity silica resources and evaporitic rocks have been strategic since prehistoric times to meet needs of sulphur, chalk and salt. The extraction of sulphur, gypsum and rock salt has produced significant volumes of material accumulated in landfills, the potential of which is little explored but which produces important negative effects on the quality of surface and groundwater. A strong impact occurs in the fresh waters of the Southern Imera basin which are fed in the mountain area by the high quality karst fresh waters of the Madonie, but are salinised due to the supply of groundwater and surface salt water to the evaporitic rocks.
From this overall perspective, the gypsum extraction sites and landfills in Piedmont, Emilia Romagna and Abruzzo will also be analysed.
This study highlights the environmental benefits that can derive from the redevelopment, restoration and transformation of waste from mineral deposits linked to the periodic restricted environmental conditions of the anoxic marine deposits that preceded, characterized and followed the salinity crisis of the Messinian age. A national census is underway in the areas affected by landfills aimed at defining the degree of liberation of the various metals classified as CRM to support the national independence plan for the CRMs supply.

**Keywords:** Critical raw materials, sapropel, evaporates, mining waste, geological and mining heritage

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# Sulphur slag dumps "Rosticci" open new possibilities for the recovery of CRMs from mining waste: The case study of the Geo-mining Regional Park of the Tufo and Altavilla Irpina Zolfare

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## Abstract

In sulphur mines, until the early nineteenth century, the thermal extraction process took place in channel furnaces equipped with “Tegulae Sulfuris” for the collection of molten sulphur and the production of boiled sulphur cakes. These rudimentary furnaces produced large volumes of sterile slag < 2/3% sulphur. The “slag” of the tailings was partly reused for the “jacketing” of the furnace with the function of optimising the smelting and limiting the dispersion of sulphur dioxide vapours into the environment. The slag not reused was transported and deposited in landfills near the mines. Starting from the 19th century the furnaces were modified to produce sulfuric acid and artificial soda but until the closure of the mines significant volumes of Sulphur slag dumps continued to accumulate on the edges of the Sulphur mines creating landscape and environmental impacts. In this work the potential for redevelopment of the environmental matrices and the landscape with redevelopment interventions of the Rosticci landfills are analyzed. Some of these landfills are an integral part of the cultural landscape for which interventions are planned for the collection of leaching water and recovery of critical metals respectful of the anthropic morphologies that have assumed cultural and landscape value, inserted in the geotourism routes of the geo-mining parks. The strategic resources of the Regional Geo-mining Park of Tufo and Zolfare di Altavilla Irpina: cultural and environmental heritage of a thriving industry linked to the extraction and processing of sulfur.

**Keywords:** Critical raw materials, Sulphur slag, geological and mining heritage

# Industrial technologies for the production and separation of Rare Earth

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**Abstract**
The core of the Rare Earth (RE) separation process is to convert the RE concentrate obtained from the ore into a mixture of the different elements that constitutes the final or intermediate product for the subsequent production of the single RE. Usually, the process requires leaching with more or less concentrated strong acids or bases to break down the ore and bring the RE into solution. Once all the metal is in solution, the separation and purification process can be carried out by solvent extraction or, alternatively, ion exchange, fractional crystallization or chemical precipitation with the addition of appropriate reagents, possibly followed by calcination or electrolysis if the final product is to be obtained as a metallic RE.
The type of minerals, the amount of RE in to the concentrate and the desired final product (mixture of elements or single element and relative degree of purity) are the main aspects to consider before choosing the separation process. Solvent extraction (SX) is the most commonly used technique in the separation of RE, especially in industries, thanks to the speed of the process, the high separation capacity and the high recovery capacity of the final product from the starting matrix. The basic routine of SX includes extraction and subsequent stripping for solvent recovery, followed by one or more washing and purification phases of the extracts, depending on the purity requirements for the final product. The type of solvent and the process conditions (temperature, duration and number of the different stages, weight ratios between the extractant and the material to be treated, etc.) obviously depend on both the chemical-physical characteristics of the starting material and those of the elements to be recovered. There are many variables in play for the separation of RE and all play an important role in the choice of extractants to be used. For example the use of one acid rather than another in the initial leaching stage and the different concentration of the same acid lead to the choice of a different extractant depending on the case.

# Building a competitive future: revitalizing Italian Mining Policy with ethics and innovation

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## Abstract

Italy responds to EU Regulation 2024/1252, the "Critical Raw Material Act" [1], with Legislative Decree 84 of 25 June 2024. This is the moment to establish a modern and ethical mining policy that ensures a secure supply of critical raw materials while enhancing Italy's industrial potential, characterized by creativity, technological innovation, and manufacturing excellence. This step is crucial for strengthening the country's global competitiveness. My international experience with Vuelta Mining Attitude has shown me that the value of the mining industry extends beyond the economic aspect; it lies in the opportunities it creates and the territories it transforms. True wealth in mining is not merely profit but the potential to generate growth and improve the lives of those involved. The mining industry of excellence demonstrates hat responsible resource management can lead to not only economic prosperity but also cultural and social renewal. Mining in Italy must be more than a self-serving investment; it must become a model of development that, rooted in tradition, creates new growth horizons for companies, territories, and communities. The strategy should promote, from the earliest stages of prospecting and exploration, an industrial model that transcends the boundaries of the mine, generating cascading benefits for all players in the supply chain and fostering a shared and sustainable future. This is the goal: to unite ethics and industry in a consolidated and innovative national mining policy [2].

**Keywords:** Italy for mining, ethical mining, sustainability, innovation, critical raw materials

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# Pollino Massif (Southern Italy) serpentinite quarries: environmental and economic implications

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**Abstract**
Recently, several studies provided information about asbestiform minerals cropping out in serpentinite rocks in the Pollino Massif, on the border between Lucania and Calabria regions (southern Italy) [1,2,3,4,5]. In the serpentinite quarries of Pollino Massif, several fibrous minerals were found such as chrysotile, antigorite, tremolite, lizardite and edenite [6]. Asbestiform minerals are potentially toxic and harmful to health and the environment; indeed, the chrysotile asbestos has been extensively used in the past due to its fibre strength and heat resistance. The small fibres associated to asbestiform minerals can be easily inhaled by humans causing serious health problems especially to the respiratory tract and for this reason, these minerals represent a serious problem due to their damaging potential, However, due for their unique aesthetic features and to their mechanical properties, serpentinite rocks have been extensively used, used as building and construction stones. The Pollino Massif serpentinite rocks crop out in several quarries producing asbestos-containing wastes. Generally, the asbestos containing wastes are generally confined in controlled landfills and represent an important environmental problem and a health hazard. Recent studies proposed an alternative to landfill confinement through the waste inertisation that can provide asbestos-free inert material in a short processing time and an economically sustainable solution. Finally, a further interesting promising potential related to serpentinites rocks is related to using these rocks as trap for $CO_2$ sequestration, making them environmentally interesting [7]. The interest for these rocks and the associated fibrous minerals is becoming increasingly intense due to both environmental and economic implications [8,9].

**Keywords** Pollino Massif, Asbestiform minerals, serpentinite, $CO_2$ sequestration

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# Mining and sustainability: understanding the value chain as a key to competitive development

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**Abstract**
In the current race for critical raw materials, mining communities may face increasing pressure. The energy transition towards sustainability through supply diversification could widen global social inequalities instead of reducing them [1]. In this context, creating shared value beyond the useful mine life by optimizing the production chain is crucial. A mining approach focused on the human value of operators demonstrates that investments can generate value when centered on people, their management and operation. Understanding the value chain is essential for the mining industry to optimize processes, improve efficiency, and enhance competitiveness by generating value at every stage of production, from exploration to distribution. Revitalizing Italian mining policy requires a clear understanding of value chain mechanisms, framed within a circular economy and the enhancement of mining cultural competencies. Decisions about production processes, technologies, and sustainability policies directly impact the responsibility of the value chain for critical minerals whenever mining concessions are granted.
When developed responsibly, mining can be a growth engine with significant socio-environmental impacts, transforming its effects into positive compensation opportunities for all stakeholders. A successful mining strategy requires balanced management of the value chain, reflecting the identities and needs of producers, local communities, and end consumers [2].

**Keywords:** Value chain, critical raw materials, mining compensation, energy transition, socioenvironmental effects

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# Insights into the marine minerals and energy resources with an environmental approach: the Chilean continental shelf case study

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## Abstract

Chile is the world's leading producer of many terrestrial mineral resources; however, the potential of the country's marine mineral resources has been largely overlooked. Within its continental shelf, Chile has favorable geological characteristics for hosting and forming marine minerals and energy resources. During the last decades, several novel studies have demonstrated the potential of gas hydrate reservoirs in Chile as an energy resource and source of greenhouse gases, which has attracted the attention of the Chilean scientific community. In addition, some studies have highlighted the potential value of marine minerals in the Chilean continental shelf, mainly due to the increasing demand for minerals for low-carbon energy production, such as cobalt-rich ferromanganese crusts, polymetallic nodules, and massive sulfides on the seafloor.

This study provides a primer for policymakers to apprise them of future research needed to develop potential mineral and energy resources within prospective deep-sea areas. It also includes advice on developing an environmental baseline for future environmental impact assessment. The new understanding of mineral and energy resources in offshore Chile presented here is an example that could be repeated in other countries including Italy.

# I giacimenti rinnovabili di $CO_2$ in toscana

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**Abstract**

L'Anidride Carbonica ($CO_2$) si forma per degassamento nel mantello terrestre e raggiunge la superficie attraverso le emissioni vulcaniche, mentre quella non vulcanica raggiunge ugualmente la superficie attraverso le faglie associate a strutture geologiche. Le manifestazioni superficiali hanno prodotto, storicamente in Toscana un interesse industriale fin dal 1869 con la produzione della biacca e successivamente, l'attività mineraria per la captazione del gas si è sviluppata dai primi anni del secolo XX con la captazione mediante pozzi per alimentare impianti industriali per la produzione di ghiaccio secco. L'Italia è sempre stata un'importatrice di $CO_2$ e l'interesse per questo minerale di origine naturale è elevata essendo utilizzata in ambito alimentare e medicale (addizionato per le bibite gassate, conservazione alimenti in atmosfera modificata, ecc.) in alternativa alla $CO_2$ di sintesi chimica che trova applicazioni nella surgelazione alimentare ed in molti processi industriali, compreso il siderurgico.
Attualmente in Italia sono presenti 11 concessioni minerarie per $CO_2$ e di queste ben 9 sono in Toscana: 3 in fase di chiusura ed una nuova che entrerà in produzione nel 2025. Nella nota si classificano le strutture mineralizzate e si descrivono la peculiarità per la captazione del gas.

**Keywords:** $CO_2$, deposits, wells, thermal

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# From perception to practice: the crucial role of geocommunication in the revitalization of Italian Mining Policy

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## Abstract
The assessment of EU mineral resources and their exploitability is central to the debate on securing strategic raw materials, which are vital for economic development and mitigating associated risks. In Italy, geocommunication—the strategic and effective dissemination of geological and mining information—will be crucial for revitalizing national mining policy. As mineral resources become increasingly essential for the energy transition and circular economy, transparent communication can enhance public acceptance, support policy decisions, and promote sustainable investments. 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 dissonant publics, underpinned by a culture change in geocommunication. Public perception, frequently linked to environmental damage and adverse impacts on local communities, remains a significant challenge for the mining industry. Effective dissemination of information will enable the education of the public, support political governance, present comprehensible technical data, facilitate dialogue with local communities, and showcase best practices in technological sustainability. Thus, a robust approach to geocommunication at the national level can lay a foundation for a synergistic bridge among the mining sector, policymakers, local communities, and the general public.

**Keywords:** Geocommunication, governance, scientific information, education, mineral resources

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# “Riding the *Leopard*”: reflections on mining activity 50 years after the publication of the 1:1,000,000 scale mineral map of Italy

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## Abstract

After the II World War, the Italian state, driven by the need to maintain employment and ensure economic development, intervened in the capital of private companies. As a result, the mining industry continued to benefit from a system of corporate protection but lacked genuine incentives to enhance know-how and industrial capital. The situation became critical for Italian companies, accustomed to a protected market, with Italy's accession to the ECSC (1951) and the EEC (1957).

The 1973 oil crisis marked a turning point in industrial history on a global scale. It exposed the vulnerability of the world economy, heavily reliant on fossil fuels, while simultaneously promoting a new environmental ethic, which over time led to the current environmental awareness, the EU Green Deal, and the Critical Raw Materials Act.

In response to the crisis, the international industry underwent radical transformation through processes of financial power expansion, globalisation, and, most notably, vertical integration of production. In the same year, the Italian Geological Survey published the Mineral Map of Italy at a 1:1,000,000 scale, and in 1975, the volume of the Memoirs [1, 2]. This was a deliberate effort by the then-director Luigi Jacobacci, who sought to demonstrate that, despite the crisis, our country still possessed both mineral reserves and exceptional human capital.

As then, so now, major cultural transformations compel radical shifts in the economic and societal paradigms. Paraphrasing Tomasi di Lampedusa’s work, The Leopard, "everything must change so that everything can stay the same" [3]. Therefore, the economy, industry, and research, at the beginning of the third millennium, must "ride the Leopard" to lead the mining industry towards environmental sustainability.

**Keywords:** Mining industry, Mineral Map of Italy

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# The Critical Raw Materials database of Sardinia for planning, prospecting and exploring mineral resources

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## Abstract

The EU's commitment to sustainable development, supported by modern knowledge, technologies, and legislation, met the necessity of mapping and evaluating ore deposits and discovering new ones by leveraging the available datasets.

Sardinia, a historical mining region in Italy, was a crucial source of raw materials for Europe between the 19th and 20th centuries, leaving behind extensive mining data. The Economic Geology Group of the University of Cagliari is developing a comprehensive database of Sardinian mineral occurrences, including the ore-defining parameters and technical information from mineralogy, base geology, structural geology and mining works. The goal is to enable ore modelling, economic evaluation, drafting of metallogenic maps, and planning of future exploration activities.

Sardinia hosts nearly 800 mineralisations of various styles that contain Critical Raw Materials (CRMs). Two common types are widespread across the island: mixed sulphides skarn along variscan thrusts host CRMs associations such as Cu, W-Sn-Bi, Ni-Co, and F-Ba; F-Ba and Ni-Co-Bi veins with distinct zonation [1] concentrating LREE in carbonates [2]; Mo-W-Sn-(+-Cu) greisen veins concentrating LREE in phosphates and fluoro-carbonates [3] bordering intrusive contacts along feldspar-rich pegmatites.

Sardinia exemplifies how dismissed mine sites can preserve significant potential for their "under-exploitation" and under-exploration according to modern economic requirements and raw materials. Moreover, the dismissed mine data are fundamental for building predictive ore models that can be used on underexplored areas and at depth. The application of modern geological knowledge, expanded over the last decades, enables more efficient prediction, prospecting, and modelling of mineralisations, highlighting the region's untapped resources.

**Keywords:** Sustainable development, Database, Ore model, Economic evaluation, Metallogenic Maps

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# Training the future: empowering Italian human resources for a forward looking and innovative Mining Policy

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## Abstract

I believe that geology has a key role to play in the near future: demonstrating that wealth is not merely about money, but about opportunity. Today, Italy faces an extraordinary chance to shape its future by educating and inspiring young mining professionals. Building a robust and dynamic mining ecosystem requires substantial investment in human resources, cultivating the talents and skills that will drive future economic growth and innovation in this sector.

To support this vision, it is essential to rebuild a high-quality educational system, starting from schools and universities, to lay the foundation for a forward-thinking mining policy. The journey from exploration to production in mining can span decades, and this time, should simultaneously be dedicated to cultivating specialized and passionate technicians who are equipped to enhance the skills needed to support sustainable national mining strategies.

Being a key player in the value chain of critical raw materials demands an integrated and multidisciplinary approach. Collaboration among engineering, geology, economics, environmental science, and public policy must be encouraged to create solutions that are economically sustainable, socially inclusive, and ecologically effective. This synergy will enable Italy to transform mining challenges into opportunities and build a future that is both professional and innovative [1].

**Keywords:** Mining ecosystem, integrated training, human resources, mining policy, sustainable development

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