

Editorial for Special Issue “Mineralogical and Geochemical Characterization of Geological Materials, 2nd Edition”

Teresa Pereira da Silva ^{1,*} , Daniel P. S. De Oliveira ^{1,2}  and João Pedro Veiga ³ 

¹ LNEG (National Laboratory for Energy and Geology), Mineral Resources and Geophysics Research Unit, Estrada da Portela, Apartado 7586, 2610-999 Amadora, Portugal; daniel.oliveira@lneg.pt

² Mineral Resources Expert Group, EuroGeoSurveys, Rue Joseph II, 36–38, 1000 Brussels, Belgium

³ Department of Conservation and Restoration & CENIMAT/i3N, Faculty of Sciences and Technology, NOVA University of Lisbon, Campus de Caparica, 2829-516 Caparica, Portugal; jpv@fct.unl.pt

* Correspondence: teresa.pena@lneg.pt

The characterization of geological materials through advanced mineralogical and geochemical approaches remains a cornerstone of geoscientific research, underpinning our understanding of Earth systems, the distribution and accessibility of natural resources, environmental processes, and the preservation of cultural heritage. In an era marked by increasing demand for critical raw materials, growing environmental pressures, and the urgent need to support the energy transition, these analytical disciplines have become more important than ever.

As global challenges associated with resource security, environmental sustainability, resource efficiency, and climate change continue to intensify, high-quality characterization of geological materials is essential for informed decision-making across exploration, extraction, processing, and remediation activities. The development and application of innovative analytical methodologies, combined with multi- and interdisciplinary research frameworks, are therefore critical to generating the knowledge required to address these complex societal challenges. Such advances not only enhance our capacity to identify and responsibly develop strategic mineral resources but also contribute to environmental monitoring, circular economy initiatives, and the sustainable management of natural capital, reinforcing the pivotal role of geosciences in supporting a resilient and sustainable future.

Following the success of the first Special Issue, “Mineralogical and Geochemical Characterization of Geological Materials”, we are pleased to present this second edition. This collection brings together 12 contributions that highlight the evolving and increasingly strategic role of mineralogy and geochemistry in addressing some of the most pressing scientific, environmental, technological, and societal challenges of our time. Collectively, these studies demonstrate how advances in the characterization of geological materials are expanding our understanding of Earth systems, supporting the sustainable management of natural resources, enabling the identification and development of critical raw materials, and contributing to environmental protection and cultural heritage preservation.

Macchiarella et al. (Contribution 1) demonstrated that mineral precipitation patterns in the Trapani–Paceco saltworks are closely linked to pond typology and microbial activity, highlighting the sustainable reuse of the byproduct *mamma caura* as a valuable resource within the salt production cycle and supporting circular economy practices in traditional Mediterranean saltworks.

An integrated mineralogical, geochemical, and geostatistical approach was applied by Brime Barrios et al. (Contribution 2) to evaluate the critical raw material (CRM) potential of nine mining and metallurgical waste types from the Cartagena–La Unión Mining District



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(SE Spain). The authors identified significant enrichments in Co, Ni, Cu, Ga, Nb, and rare-earth elements, controlled by lithogenic, sulfide-derived, and oxidation–adsorption processes. They also highlighted both the economic potential of residue reprocessing and its environmental benefits for the remediation of mining areas.

Keim et al. (Contribution 3) investigated floating mineral rafts from hypersaline coastal environments using advanced imaging and analytical microscopy techniques. They proposed that raft formation is driven by evaporation-induced supersaturation at the air–water interface, where reduced activation energy promotes mineral nucleation and subsequent crystal growth, providing new insights into carbonate precipitation processes in hypersaline systems.

The Special Issue further includes contributions focused on geoheritage, industrial heritage, and the conservation of geological and architectural materials. Salisid et al. (Contribution 4) demonstrated through a systematic review that geopolymers are promising, sustainable, and durable materials for the conservation of tuff- and coral rock-built architectural heritage structures, providing compatible alternatives to increasingly scarce original building stones. Geopolymer formulations, commonly based on metakaolin and alkaline activators, can be tailored to match the esthetic, chemical, physical, and mechanical properties of original heritage stones, while providing comparable durability under accelerated aging and long-term exposure conditions.

An integrated multi-analytical approach combining Raman spectroscopy, SEM–EDS, LA-ICP-MS, and ToF-SIMS was employed by Xie et al. (Contribution 5) to investigate Lower Cambrian phosphatic deposits from the Pedroche Formation (Spain). They revealed that phosphatization processes were strongly controlled by host lithology, porewater chemistry, and microbial activity, with carbonate fluorapatite formation occurring under seawater-influenced suboxic conditions, preserving valuable information on early diagenetic mineralization during the Cambrian radiation.

Studies on lithium-bearing ores and pegmatite deposits contribute valuable knowledge regarding the mineralogical and geochemical characteristics of materials that are increasingly essential for the energy transition and the development of advanced technologies. Durjagina et al. (Contribution 6) demonstrated that the beneficiation efficiency of European lithium-bearing ores is strongly controlled by their microstructural characteristics, showing that coarse-grained zinnwaldite ores are more favorable for selective comminution than finer-grained lepidolite ores, thereby emphasizing the importance of integrating mineralogical and mechanical analyses to optimize lithium recovery and support sustainable European supply chains.

Several articles address the growing importance of critical raw materials and strategic mineral resources. Silva et al. (Contribution 7) studied the abandoned Preguiça mine (Portugal) and revealed a diverse assemblage of secondary minerals, as well as the first reported occurrence of massicot. Through XRD, SEM, and pXRF analyses, the authors documented significant enrichments in Fe, Ca, Zn, and Pb and highlighted the presence of vanadium- and arsenic-bearing minerals that may constitute potential critical raw materials. The study provides new insights into supergene mineral transformations and metal behavior in abandoned mining environments, while emphasizing the potential of legacy mining sites as valuable targets for sustainable resource recovery and strategic raw material assessment.

Zimanovskaya et al. (Contribution 8) demonstrated that the Alday rare-metal occurrence in East Kazakhstan hosts fault-controlled lithium-bearing albite–spodumene pegmatites formed through fluid–magmatic fractionation of the Kalba granite complex, establishing key geological, geochemical, and metasomatic indicators for the exploration of rare-metal mineralization enriched in Li, Ta, Nb, Be, and Sn.

The applicability of optical light microscopy combined with automated image processing for the classification of real coal mine dust particles was evaluated by Santa et al. (Contribution 9), demonstrating its potential as a rapid monitoring tool for occupational health protection, while identifying particle agglomeration and site-specific optical variability as critical challenges that require appropriate sample dispersion and local calibration to ensure accurate dust characterization.

The development of rapid in situ mineral identification procedures and improved data-processing workflows reflects the ongoing effort to increase analytical efficiency and accuracy in both laboratory and field environments. Gokuladas et al. (Contribution 10) developed an innovative in situ Raman spectroscopy methodology for underground mineral identification that combines dual excitation wavelengths, Shifted Excitation Raman Difference Spectroscopy (SERDS), and a deep learning-based U-Net model to produce fluorescence-free and quasi-noise-free spectra, significantly improving measurement reliability, acquisition speed, and mineral discrimination based on characteristic pseudo-Voigt peak positions and intensities.

Several studies reinforce the strong connection between geological resources and cultural heritage. Santo et al. (Contribution 11) demonstrated that serpentinites from the Monteferrato area are mineralogically and physically compatible with historically used stones in Tuscan monuments and therefore suitable for restoration purposes, although high chrysotile contents pose significant health risks that require strict safety measures and careful evaluation before their practical use in heritage conservation.

Environmental applications also represent a major theme of this collection. Stafilov and Šajn (Contribution 12) demonstrated that the distribution of uranium and thorium in North Macedonian soils is primarily controlled by geological formations and parent materials, with the highest concentrations occurring in areas dominated by Neogene and Paleozoic igneous rocks and mineralized zones, providing an important geochemical baseline for environmental assessment and soil monitoring.

The papers published in this second edition of “Mineralogical and Geochemical Characterization of Geological Materials” demonstrate the vitality, diversity, and interdisciplinary nature of current research in mineralogy and geochemistry. Together, they advance knowledge across a wide range of topics, including mineral resources, critical raw materials, environmental processes, geoheritage, and cultural heritage conservation. By integrating innovative analytical techniques with sustainability-oriented perspectives, these contributions highlight the pivotal role of geological materials characterization in supporting scientific discovery, resource security, environmental stewardship, and sustainable development.

As Guest Editors, we sincerely thank all authors for their excellent contributions, the reviewers for their rigorous evaluations and constructive comments, and the editorial team of *Minerals* for their continuous support throughout the publication process. We hope that this Special Issue will serve as a valuable reference for researchers, practitioners, and stakeholders working in the fields of mineralogy, geochemistry, and geological materials. By bringing together diverse case studies, innovative methodologies, and sustainability-oriented applications, it aims to stimulate further research and foster new advances in the characterization, management, and sustainable utilization of geological materials, supporting solutions to emerging scientific, environmental, technological, and societal challenges.

Conflicts of Interest: The authors declare no conflict of interest.

List of Contributions

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