

Economic Geology of Mineral Resources

S.M. Timón-Sánchez^{1,*}, E. Álvarez-Areces², J.M. Baltuille-Martín², A. Bel-lan Ballester², E. Boixereu i Vila², S. del Barrio Martín², P. Delgado-Arenas², C. Fernández-Leyva³, J. Fernández-Suárez⁴, M. Iglesias-Martínez⁵, T. Llorens-González¹, F.J. López-Moro², I. Martín-Méndez², R. Martínez-Orío², T. Sánchez-García², F.L. Sanz-Pérez² and M. Trío-Maseda²

¹IGME, CSIC. Oficina de Proyectos Salamanca, Spain

²IGME, CSIC. Madrid, Spain

³IGME, CSIC. Oficina de Proyectos Granada, Spain

⁴IGME, CSIC. Oficina de Proyectos Oviedo, Spain

⁵CSIRO. Perth, Australia

*Corresp. Autor. Plaza de la Constitución, 1, 3ª, 37001 Salamanca, Spain. s.timon@igme.es

Abstract

The study of mineral resources of our country was, and still is, one of the foundational objectives of *Instituto Geológico y Minero de España* (IGME), that began to carry out studies on them and to elaborate maps of occurrences and ore deposits. Since the 70's of the 20th century, the metallogenic map has been the main tool for the transmission of knowledge in this field. In the European context in which we work, the present place us in front of the great challenge of identifying the supply potential of critical and strategic raw materials for the energy transition, in order to comply with the Green Deal promoted by the European Commission.

The Economic Geology of Mineral Resources research group (GI-GECOMIN) is made up of 17 members including researcher, specialized senior technician and higher graduate of technical and professional activities, with extensive experience in the study of geological resources. This work aims to describe the main objectives, the accredited experience, and the most relevant scientific-technical activities carried out by the GI-GECOMIN, grouped in four research lines.

Research Overview

GECOMIN's activities include four areas: (1) Characterization, genesis and assessment of mineral resources; (2) Mineral processing and metallurgy; (3) Mining heritage; and (4) Natural stone, historical quarries and architectural heritage (Figure 1). Moreover, the most relevant aspects of the GECOMIN's curriculum vitae may be viewed in Table 1.

Characterization, genesis and assessment of mineral resources

The main objective is to study the geological processes leading to the formation of mineral deposits, to assess the quantity and quality of resources, both of primary and secondary origin, and to identify areas with undiscovered mineral resources or with potential for future supply of raw materials (metallic, non-metallic and industrial), with special emphasis on critical or strategic ones, with the ultimate aim of increasing interest in mineral exploration.

To achieve these goals, the following studies are developed: mapping, geochemical exploration of rocks, minerals and sediments, geochronology, isotope geochemistry and fluid inclusions. It contributes to complete the existing databases, search for mineral resources and elaborate the genetic models to be applied in the evaluation of resources. Among the results of our work, it is worth mentioning: the National Database of Mineral Resources (BDMIN), metallogenic maps, predictive mineral potential mapping, maps of rocks and industrial minerals,

systematic geochemical exploration maps, at different scales, and the Geochemical Atlas of Spain.

Currently, major efforts are focused on the analysis of the regional and national mining potential for certain critical minerals, defined by the European Commission, and other elements that are considered fundamental for the fulfilment of the objectives of the Ecological Transition policy (implementation of renewable energies, electric mobility, etc.). Reports are prepared on the substances studied, highlighting the most promising areas and indicating recommendations to improve the degree of knowledge. In addition to working on the systematic maintenance of the databases and the updating of the mining cartography, it is planned to develop a database of critical mineral resources according to the INSPIRE directive requirements, under the international reporting standards (CRIRSCO) and the United Nations Framework Classification for Resources (UNFC). The results of this research have direct practical application, providing valuable information to geological resources managing bodies to facilitate strategic decision-making aligned with the Sustainable Development Goals of the 2030 Agenda, which translates into collaborations with public administrations.

This activity is combined with the development of fundamental research projects, focused on the study of the genesis of ore deposits. The mineral systems under investigation are: a) rift- and subduction-related magmatic-hydrothermal systems: rare-metal granites, pegmatites, greisen, skarns and quartz veins enriched in Sn, W, Nb, Ta, Li and Be; b) peralkaline magmatic systems and carbonatites; c) hydrothermal systems in shear zones: orogenic gold-type deposits and polymetallic sulphide deposits; d) continental marine basin systems: sedimentary exhalative (sedex-type deposits), iron-manganese oxides, black shale deposits, etc.; e) volcanogenic submarine hydrothermal systems: massive sulphide deposits; f) mafic and ultramafic magmatic systems: Ni-Cu-PGE sulphide deposits, Fe-Ti-V and, and Cr deposits; g) IOCG systems; and h) surface weathering systems: placer-type deposits. When research involves abandoned mining areas, comprehensive studies are carried out, including the use of mining waste (tailings ponds and dumps) to respond to the Spanish Circular Economy Strategy. This work is performed in close collaboration with the Mining Waste, Mineral Waters and Environmental Geochemistry research group.

The group actively has participated in projects on raw materials in FP7 and H2020 programs, such as Promine, Foram, Minerals4EU, GeoERA (Frame, Mintel4EU), and now, through the Horizon Europe framework programme, in projects such as Start, designed to research sustainable energy harvesting systems based on innovative waste recycling. In addition, the group also collaborates in international projects in Latin America and Africa, such as the National Geology Plan of Angola (Planageo), carrying out geochemical exploration in areas of mining interest. Within the framework of Planageo, the Carmina project is being developed for the exploration of industrial rocks and minerals and the elaboration of the corresponding cartography.

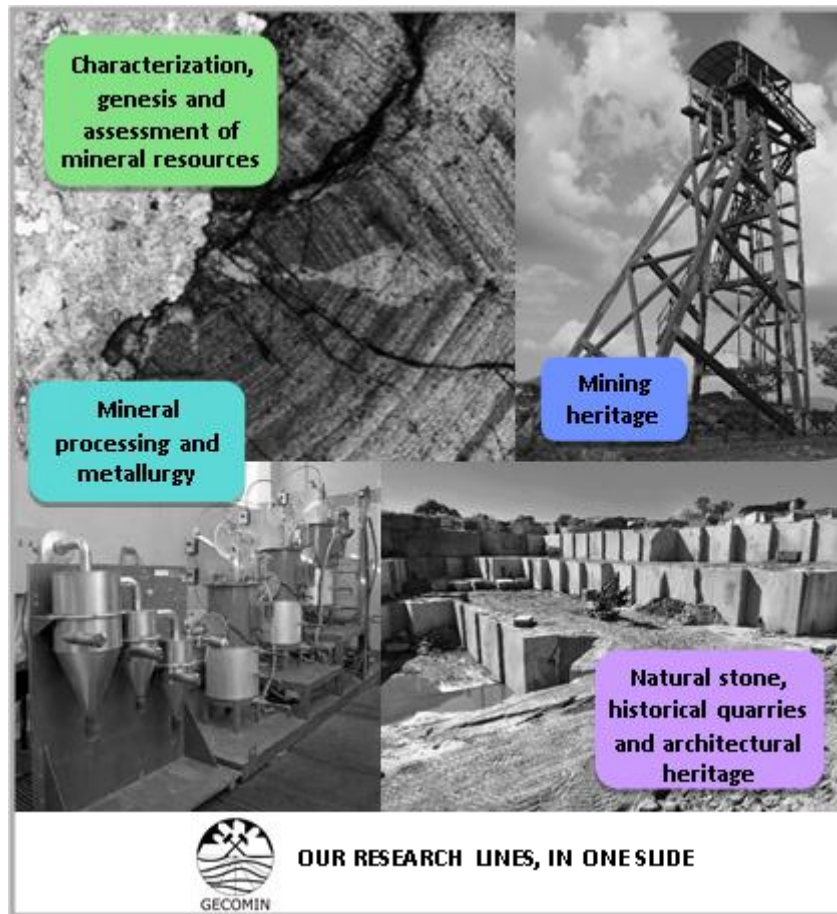


Figure 1. Research lines of the Economic Geology of Mineral Resources Group.

GECOMIN is also involved in European associations such as the Mineral Resources Expert Group (EGS-MREG), the Geochemistry Expert Group (EGS-GEG) and the Network of Practitioners-Europe (NoPE), as well as in other international organizations, such as the Association of Iberoamerican Geological and Mining Surveys (ASGMI).

Mineral processing and metallurgy

This research line is focused on the study of the viability of new environmentally friendly metallurgical treatment processes, for the use of both primary and secondary mineral resources, with the ultimate aim of providing a complete picture of the potential of geological resources. For this purpose, physical-chemical processing techniques are applied, such as flotation, gravimetric, magnetic and electrostatic separation, which allow the concentration of the minerals of interest, with the aim of achieving the best grade/recovery curve and identifying all potential products and by-products of the process.

Part of the R&D&I work that IGME has developed in the field of ore beneficiation has been focused on the search for alternative processing of the polymetallic sulphides of the Iberian Pyrite Belt. With the goal of reducing operating costs, two aspects have been considered: the recovery of the gold contained in sulphides and the extraction of any other metal present of economic interest. In the field of hydrometallurgy, research is aimed at improving hydrometallurgical treatments, on the one hand, to increase the recovery of non-ferrous metals

(Cu-Pb-Zn), which are quite abundant in the Iberian Pyrite Belt and, on the other, to recover the gold contained in refractory minerals with alternative processes to conventional cyanidation.

As a consequence of these studies, IGME, together with Protón Ingenieros company, has developed and patented a new hydrometallurgical process for the treatment of complex sulphides, which has also led to the construction of a pilot plant for leaching copper and zinc sulphides during 2017-2018.

Mining heritage

The IGME's Inventory of Historical Mining Heritage aims to systematically identify, research and contribute to the preservation of historical mining in Spain. It offers the possibility of evaluating mining entities according to the criteria proposed in the Plan Nacional de Patrimonio Industrial (National Industrial Heritage Plan) and in the Bierzo Charter, in order to prioritize their research, evaluation and protection. Furthermore, it contains a catalogue of protected mining heritage.

The Inventory got started in 2003 with the completion of the Pilot Study Case of the Mining District of the Alcudia Valley, and was subsequently expanded, in 2009 with the Inventory of Extremadura through a project co-financed by the Junta de Extremadura, and in 2013 with the Inventory of Galicia, within the framework of the European project Atlanterra GreenMines.

The Inventory methodology, is based on that established in the aforementioned Pilot Study Case, on the guidelines of the National Plan of Industrial Heritage, and on the Spanish Inventory of Places of Geological Interest implemented by the IGME.

We are currently working on the development of a new institutional database in SQLServer, with the aim to disseminate the previous work and resume the development of the Inventory in a multidisciplinary, collaborative and participatory way, in accordance with the principles of Citizen Science.

Natural stone, historical quarries and architectural heritage

The main objective is to study the natural stone and its technological and constructive applications in the Architectural and Monumental Heritage and in civil and current works. The areas where the rock used in construction was quarried (historical quarries) are located and characterized. Furthermore, technological tests are carried out to restore or treat pathologies, or replace the architectural asset.

The experience in this line of work includes the elaboration of the Inventory of Historic Quarries associated with the Architectural Heritage of the Autonomous Communities of Extremadura and Andalusia; the advice on ornamental rocks and industrial minerals, for MAGNA geological mapping; and the elaboration of specific cartographic databases, adapted to the mapping of industrial rocks and minerals and to the location and characterisation of historical quarries of construction rocks.

At the European level, through the GeoERA H2020 Programme, the group has participated in the Eurolithos project, with the aim of generating a European Atlas of the main ornamental and construction rocks. As a result of the collaboration with the Institute of History (IH-CSIC) and the School of Arabic Studies (EEA-CSIC), the group is participating in projects granted by the Spanish National Plan for Scientific and Technical Research and Innovation, such as those related with the Archaeology of the Hispanic churches of the 10th century.

In addition, work is being carried out on the creation and development of the INCHaPA Programme, National Inventory of Historic Quarries used in the Architectural Heritage.

Currently, the INCHaPA-Andalusia is being carried out, financed by that Autonomous Community, 541 quarries have been located and 863 architectural monuments have been studied. As a result of these studies, there are two registered industrial property titles associated with the CONSTRUROCK Network. CONSTRUROCK is a scientific-technical network, linked to natural stone and its relationship with historical-monumental heritage and civil works. It was created in 2008, coordinated by the IGME, and made up of 25 members, such as universities, public and private research organizations, technology centres, laboratories and business associations of the natural stone sector.

Table 1. GECOMIN curriculum summary (2017-2021).

32 publications in international peer reviewed journal (SCI) Q1=7, Q2=14
15 Competitive research projects participation (1 HorizonEU, 8 H2020, 5 Plan Estatal I+D+i, 1 Junta Castilla-La Mancha)
13 Non-competitive research projects (4 own projects, 5 collaboration agreements: Junta de Andalucía, Principado de Asturias and Diputación de Jaén, 2 Spain's Recovery, Transformation and Resilience Plan, 2 Services)
1 Patent (Hydrometallurgical plant for the treatment of complex sulphides) 2 Industrial Property Titles (Construrock Network)
1 New application (Development of Carmina Database - Angola)
Participation in Research Networks (ASGMI, EGS, NoPE)
2 Supervision of PhD Thesis, 2 Theses read by members of the research group, 5 Supervision of Master Thesis, 3 Degree Final Project Supervision; 4 training students. Participation in projects of innovation and teaching improvement.
2 Organization of symposiums and 1 international congresses, 4 invited talks.