

# Research and Innovation in Exploration and Mining of Raw Materials: The ROBOMINERS Project <sup>†</sup>

Eleni Koutsopoulou <sup>1,2,\*</sup> , Aikaterini Servou <sup>1,3</sup> , George Aggelopoulos <sup>1,4</sup> and Konstantinos Laskaridis <sup>2</sup> 

<sup>1</sup> Association of Greek Geologists (AGG), GR-10680 Athens, Greece; servoy\_aikaterini@upnet.gr (A.S.); gaggelo@gmail.com (G.A.)

<sup>2</sup> Hellenic Survey of Geology and Mineral Exploration (HSGME), Acharnae, GR-13677 Athens, Greece; laskaridis@igme.gr

<sup>3</sup> Department of Geology, University of Patras, GR-26500 Patras, Greece

<sup>4</sup> Geotechnical Chamber of Greece, GR-54631 Thessaloniki, Greece

\* Correspondence: ekoutsop@upatras.gr or ekoutsopoulou@igme.gr

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**Abstract:** ROBOMINERS is a new project funded under the European Union’s Research and Innovation Programme Horizon 2020, which aims at employing a bio-inspired robot, focused on the prospect of mineral exploration and extraction within Europe. ROBOMINERS’ innovative approach combines the creation of a new mining ecosystem through the development of a bioinspired robotic miner prototype, able to explore and mine mineral deposits which are currently considered uneconomic due to their small size and difficulty of access. The main objectives of the project include the creation of a European database of potentially suitable locations for the deployment of this novel technology. The building of the pan-EU mineral deposits database is considered vital for the development of the project as it will provide essential information related to deposit type and commodities, spatial and temporal distribution, and location of exploration targets. Several deposits have been reviewed and examined in Greece as potential targets suitable for the ROBOMINERS technology, after considering the specific restrictions and requirements of the project. The main targets have been determined and arranged according to the different aspects required by the applicability of the ROBOMINERS innovative technology.

**Keywords:** ROBOMINERS project; European database; raw materials; ore deposits; exploration; mining technology



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## 1. Introduction

The ROBOMINERS (Resilient Bio-inspired Modular Robotic Miner) project aims to develop new methods and technologies (including prototype automation and robotics technology) in order to locate and exploit underground mineral deposits and is funded under the European Union’s Research and Innovation Programme Horizon 2020 [1,2]. The project introduces robotization and miniaturization technologies (robotic autonomous explorers and miners) which allow localization and mapping of an orebody, extraction planning, optimization of extraction, and real-time selective mineralogy. The project targets mineral deposits that are generally considered “non-economical” either because they are not accessible anymore for conventional mining techniques, or they have been formerly explored but exploitation was considered uneconomic (abandoned, small, ultra-depth deposits) [3,4].

The Association of Greek Geologists (AGG) is participating as an EFG (European Federation of Geologists) Linked Third Party in the project, aiming to identify mineral deposits which are potential targets for the advanced mining technology, and the creation of a European database of ore deposits, suitable for the utilization of ROBOMINERS

technology. The development of a European mineral resources database is essential for the progress of the project as it will showcase prospective areas where the ROBOMINERS innovative approach can be applied. The AGG focused on the creation of a database, of the main and most important mineral deposits in Greece, based on the project requirements.

In general, ROBOMINERS advanced technology may provide a unique solution in hydrothermal vein-type deposits, porphyry, and epithermal deposits, but volcanogenic massive sulphide (VMS-type) and lens-like or layered orthomagmatic deposits could also be considered for the project. In Greece, epithermal deposits, deposits in hydrothermal veins, porphyry deposits, and VMS-type deposits are the most significant for the project. As for their spatial distribution, vein-type or metasomatic deposits are mainly located in Northern Greece (Western Macedonia and Thrace regions), whereas significant variable mineralization deposits are related with the Attico-Cycladic belt volcanism (mainly Lavrion, Evia, and islands in the Aegean Sea).

## 2. Objectives of the ROBOMINERS Project

The overall strategic objective of the ROBOMINERS project is to enable EU access to strategic mineral resources, and especially rare metals and elements required for high-tech applications [3]. The ROBOMINERS concept has been driven by the European Union's initiative to depend on supply from domestic sources and avoid the import of mineral raw materials [3,5,6]. The EU's policy on raw materials promotes the exploration and mining of resources that were considered economically or technologically unfeasible in the past.

The development of a common European ROBOMINERS database is of great importance for the advancement of the project, since it will help with the collection, harmonizing, and sharing data on European mineral deposits. The main targets of the project include the evaluation of the mineral resources (taking into account new strategic and 'green' commodities), the collection of essential information on the deposit type and commodities, information on the host rock, and the spatial distribution of the targeted ore deposits [4]. As a result, valuable knowledge for the future planning of the exploration and exploitation of the targeted deposits from the ROBOMINERS advanced technology approach can be produced.

The database structure includes the most important parameters required for the ROBOMINERS project and stores all the information related to critical mineral deposits in Europe (see Table 1). An evaluation of the mineral resources and critical assessment preceded according to the requirements of the ROBOMINERS technology. The contribution of AGG for the creation of the database includes approximately 172 records of mineral deposits located in Greece and was based on recently published literature and technical reports from the Hellenic Survey of Geology and Mineral Exploration, HSGME (formerly IGME) [6–16]. The required information, collected for each mineral deposit, which is important for the progress of the project and the development of the database, is briefly presented in Table 1.

Major environmental and social concerns usually associated with conventional mining, including public opposition, were taken under consideration during the development of the database. Valuable know-how on raw materials inventory spatial coverage and the development of the database was accomplished through the reviewing and evaluation of international literature and previous projects platforms [17–19]. The European data strategy aims to create an open database, where private and public entities can have easy access to a large pool of high-quality data.

**Table 1.** Most important specifications and requirements of the ROBOMINERS project included in the building of the database.

Site name	Most commonly used name applied to the site and other general information which are representative for the site.
Mine/unexploited resource	Information about the site being a former/existing mine or an explored but not exploited deposit.
Information for the exact location	Description with coordinates of the exact location and the corresponding altitude of the site. Longitude (WGS84), Latitude (WGS84), Altitude (MASL)
Depth of highest point of the deposit	The depth from the surface of the highest known point of the deposit
Historic time range	Time range of exploration and mining activities from year to year
Deposit type	The mineral deposit type that is investigated. Selection from the available mineral deposits that have been proposed by the ROBOMINERS project
Commodities	Name of the primary commodity or end product produced at the site. Name of all major by-product commodities recorded by hierarchy
Main host rock	Type of the dominant host rock
Geotechnical attributes	Geomechanical index of the host rock if known (e.g., RMR, Q-Barton, RQD).
Magnitude	Magnitude of the recently existing (remaining) resources/reserves: S (small, <10 Mt), M (medium, 10–100 Mt), L (large, >100 Mt)
Technical report available	Refer to technical reports available in literature
Geological information	Link to (a) the website or DOI of the most recent comprehensive information about the geology of the deposit, (b) ISBN identifier, (c) ISSN identifier of publication (details of the reference: authors, title, journal, volume, page)
National archive identifier	Identifier of reports and documents available in national archives
Geothermal gradient	The geothermal gradient in the site area
Exploration permission	Date and duration of exploration and/or mining permission if exists/existed
Restrictions	Description of possible restrictions

### 3. Suitability of Ore Deposit Types for the ROBOMINERS Technology

A number of ore deposits may be considered for the applicability of the ROBOMINERS advanced technology. These include epithermal type deposits and mostly vein-like types, porphyry-type deposits, volcanogenic massive sulphide (VMS-type), and lense-like or layered orthomagmatic deposits. Other type of deposits may also be considered, depending on the specific metal value of the ore and other market conditions, the favorable geotechnical properties, and the commercial technologies to extract and refine metals from the deposits [4].

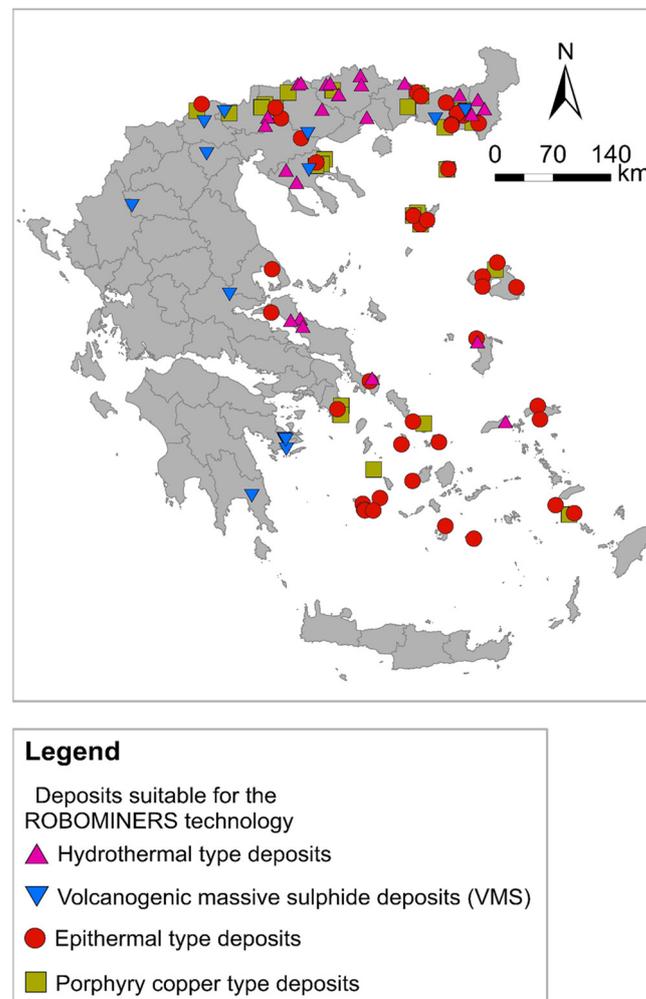
A scale ranking regarding the geological and mining aspects of the ROBOMINERS project is developed and the deposit types are classified according to the applicability of the deposit type for extraction by the advanced ROBOMINERS technology. The following four factors are considered for the suitability of the technology:

- Geometry. The geometry of ore deposits is a major classification aspect. The genesis of the deposit should be considered, but also the shape, which is driven by a number of factors during the formation of ore deposits, as well as by the post-mineralization tectonic regime, weathering, and geochemically driven changes in post mineralization/sedimentation phases.
- Rock mechanics—stability. The importance of stability of the host rock. Vertical shafts may be easier to stabilize and to export the exploited material.
- Rock mechanics—extractability. Hard rocks are usually preferred for the mobility of the robot. However, a vein system may consist of different rocks within the given location.

- Economy and criticality. The project focuses on raw material resources, of which exploitation by conventional mining may be expensive, but the specific value of the ore is high, or it includes critical elements [3,4]. Raw materials which are economically feasible to explore by conventional mining technology are not considered favorable for the project. Gold, PGE, and rare elements may be appropriate targets, especially if present in high concentrations; iron and industrial minerals are not regarded as such.

Several restrictions should be reviewed and examined for the applicability of the ROBOMINERS technology. Mines that are currently in exploration status or under evaluation for mining permission status cannot be considered for the project at the moment. Areas that have been characterized as mining parks, open museums, and protected areas (Natura 2000), are excluded from the project, as excavations of any type are forbidden in these areas. Conservation of natural ecosystems, land use, and preservation of natural areas have also been considered.

After taking into consideration the specifications and factors of the project, all mineral deposits located in Greece (which have been utilized in the development of the database) have been evaluated according to the requirements of the ROBOMINERS technology. The most important target mineralizations for the ROBOMINERS project are given in Figure 1.



**Figure 1.** Deposits suitable for the ROBOMINERS technology.

Briefly, hydrothermal-type deposits and especially hydrothermal vein-associated deposits are considered primary targets, as conventional mining of such deposits is expensive, usually governed by the vein's geometry, and parts of the veins may be ultra-deep or

permanently flooded. Volcanogenic massive sulphide (VMS) deposits are also suitable for the application of the ROBOMINERS technology, although dictated by a complex geometry, because of the clearly identifiable metal concentrations. In this case, a suitable mining layout and strategy should first be established [4].

Epithermal deposits are frequently associated with porphyry systems and are often considered as a continuation of porphyry deposits. They are separated into high sulfidation (HS) and low sulfidation (LS) systems. In general, porphyry deposits are considered as a potential target for the ROBOMINERS technology, especially if there is substantial secondary enrichment of the ore. Epithermal and especially the vein-like types are most suitable for the project as they usually have a simple definition of the zone to be mined [4]. Other types of deposits that follow the project's requirements may also be considered depending on the specific characteristics previously described.

The spatial distribution of the aforementioned type of deposits is shown in Figure 1. Deposits in hydrothermal veins, porphyry-type deposits, and epithermal-type, especially vein-like and associated, deposits are located mostly in Northern Greece (Western Macedonia and Thrace regions). VMS type deposits are also located in Central Greece and Peloponnese. Significant variable mineralization deposits are related with the Attico-Cycladic belt volcanism (mostly Lavrion, Evia, and islands in the Aegean Sea). It should be noted that some ore deposits may display characteristics of more than one mineralization type. In such cases, the classification was made according to the specifications of the project and recent literature [4,6–9].

#### 4. Conclusions

ROBOMINERS presents a unique solution for re-exploring many of what are considered Europe's uneconomical mines (abandoned, small, high-depth deposits). The project introduces robotics and mining-related autonomous technology. The project focuses on the creation of a European ROBOMINERS database of deposits types and commodities, host rocks, and spatial distribution of the targeted ore deposits. This is a fundamental step towards a better assessment of raw material resources in Europe as it will provide valuable knowledge regarding the future planning of the exploration and exploitation from the developed innovative technology approach.

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

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