Agile Exploration and Geo-modelling for European Critical Raw Materials – Introduction to the AGEMERA project

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The supply of European critical raw materials (CRMs) does not currently meet the European demand. This gap is predicted to increase, making Europe even more dependent on outside suppliers. AGEMERA is a project to help tackle this strategic problem by studying CRM sites in Finland, Poland, Spain, the Balkans, and Zambia. We conduct geological studies, develop and deploy novel mineral exploration techniques, use conventional geophysical methods, and apply machine-learning algorithms to process the acquired data. Special attention will be paid to transcrustal-scale geological domain boundaries, which may have acted as major controlling structures during mineralisation. AGEMERA will also enhance public awareness of our need for CRMs.

Keywords: critical raw materials, exploration, geochemistry, geochronology, structural geology, geophysics, passive seismics, drone geophysics, muography, data cubes

1. The need for critical raw materials in the EU

The worldwide demand for critical raw materials (CRMs) is rapidly increasing due to the transition to greener tech and energy production and a more digitalised world. For the EU to become more resilient and develop strategic autonomy, it is essential to increase Europe's domestic CRM production. Europe has a long tradition in mining and extracting base metals (e.g., Cu, Zn and Pb), but less so to source CRMs (e.g., Li, Co, Nb, W, V, and REEs). Previously, CRMs were not considered very valuable. Their demand was low as only a few applications needed CRMs, and investing in or studying them was not profitable. However, Europe has significant CRM potential locked in many ore districts. Other main bottlenecks in European mineral exploration and mining are the various and lengthy national permitting procedures and the low levels of public acceptance due to both real and perceived hazards.

It is paramount that raw material supply bottlenecks are corrected to achieve strategic autonomy for the supply chains of European industries. This is especially important for CRMs, which have an essential role in transitioning to a low-carbon and digital economy. In many cases, the same raw materials are required by multiple technologies and sectors critical for the clean energy transition (e.g., Li-ion batteries, electric vehicles, fuel cells, solar panels, and wind generators) or the overall technological upgrades (e.g., consumer electronics, drones, robots, 3D printing, digital technologies). Therefore, many competing interests need CRMs, further underlying the need for the EU to produce more CRMs domestically.

AGEMERA is a 3-year R&D project to tackle some critical CRM sourcing problems. It focuses on challenges related to the exploration, characterisation, and exploitation of CRMs in Bosnia-Herzegovina, Bulgaria, Finland, Poland, Spain, and Zambia. AGEMERA combines the resources, expertise, innovation power, and novel technologies of the 20 consortium partners (Table 1), who believe that knowledge and intelligence on CRM potential and market impact

are preconditions for informed decision-making at the country, company, and also citizen level. These will, in turn, unlock various European CRM resources for future use.

AGEMERA has a budget of 7.5 million euros funded by Horizon Europe. The 2022–2025 project is coordinated by the Kerttu Saalasti Institute of the University of Oulu in Finland. The AGEMERA activities (work packages or WPs) most relevant to geosciences and the mining industry are geology (WP1), geophysical data acquisition (WP3), and data fusion (WP4). The three are intricately linked, although, in this paper, we mainly focus on WP1.

Table 1. Partners of the AGEMERA project and their main geoscientific activities.

Organisation	Country	Type	Activities[1)]
University of Oulu	Finland	Academia	GL, DF
University of Lapland	Finland	Academia	
University of Zagreb, Faculty of Mining, Geol. & PE	Croatia	Academia	GL, GPDA, DF
University of Zambia IWRM Centre	Zambia	Academia	GL, GPDA, DF
Tallinn University of Technology	Estonia	Academia	GL, DF
Geological Institute, Bulgarian Acad. of Sciences	Bulgaria	Academia	GL, GPDA
CSIC	Spain	Research	GL, GPDA, DF
Technische Universität Bergakademie Freiberg	Germany	Academia	GL
KGHM Cuprum Research & Development Centre	Poland	Research	GL, GPDA, DF
Lithica SCCL	Spain	SME	GL, GPDA, DF
Radai	Finland	SME	GPDA, DF
Muon Solutions	Finland	SME	GPDA, DF
OPT/NET	Netherlands	SME	GPDA, DF
Geonardo Environmental Solutions	Hungary	SME	
Latitude 66 Cobalt	Finland	Industry	GL, GPDA, DF
Bauxite Mines Jajce	Bosnia-Herzegovina	Industry	GL, GPDA, DF
Bauxite Mines Posušje	Bosnia-Herzegovina	Industry	GL, GPDA, DF
MATSA	Spain	Industry	GL, GPDA, DF
Assarel Medet	Bulgaria	Industry	GL, GPDA, DF
KGHM Polska Miedź	Poland	Industry	GL, GPDA, DF

[1)] Geosciences-related work in AGEMERA: GL = geology (WP1), GPDA = geophysical data acquisition (WP3), DF = data fusion (WP4).

2. Objectives of the AGEMERA project

AGEMERA's goals are to (1) increase geologic understanding of ore districts and improve the genetic models of their known CRM deposits, and (2) enhance public awareness of the crucial role CRMs have in the green transition and the EU's strategic autonomy and resilience.

Data layers will be analysed and interpreted to better understand geological structures, lithologies, hydrothermal alteration systematics, and other footprints of mineral systems. The emphasis will be not only on assisting present miners in maintaining mining longer but also on guiding future projects in finding new ore deposit systems.

3. Research methods

The project will develop and test three novel but proven mineral exploration methods and technologies. Each of them is innovative and non-invasive. These techniques are:

1. Passive seismic methods (e.g., Ugalde et al., 2013) for shallow subsurface characterisation (CSIC & Lithica SCCL);
2. Multi-sensing drone with magnetic, radiometric and EM sensing (e.g., Heincke et al., 2019) for subsurface characterisation down to 300–500 m depth (Radai Oy); and
3. Muon-based density characterisation of rocks (i.e., cosmic-ray muography; e.g. Holma et al., 2022) down to 1 000 m depth (Muon Solutions Oy).

Drone surveys are active and rapid methods capable of covering vast areas relatively quickly, whereas muography and seismic techniques are passive and slow methods capable of covering large volumes with increasing accuracy over time (see the comparison in Figure 1).

In addition, some study sites will be surveyed with more conventional near-surface geophysical methods. Geological studies will include structural geological mapping, rock and soil sampling, and mineralogical studies (e.g., in-situ mineral chemistry and geochronology). The laboratory methods available to the project include microscopy, XRD, XRF, Cold-CL imaging, SEM, EPMA, LA-ICP-MS, and fluid inclusion studies.

Data analysis and fusion tasks include developing machine-learning algorithms to process the vast amount of acquired geoscientific data. The software MOVE is used to produce 3D models of the selected CRM deposits. Results are visualised using hyper-data cubes. Additional satellite-based data will be acquired when appropriate for the data fusion.

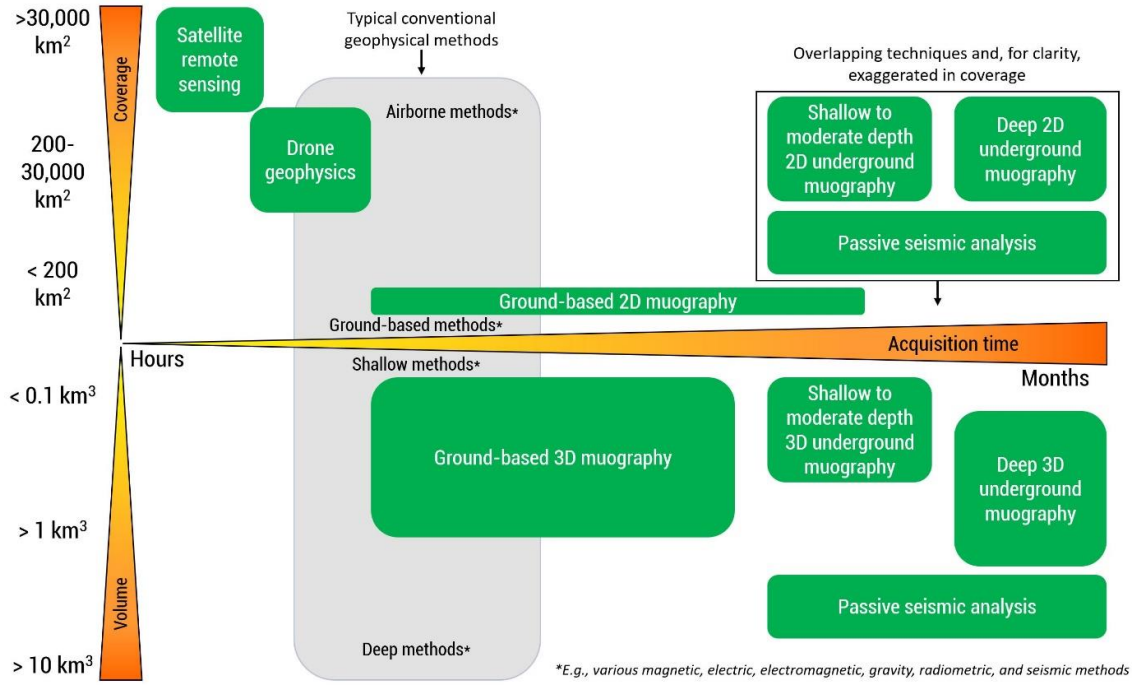

Figure 1. The geophysical technologies used in the AGEMERA project, given as a plot of survey coverage (upper y-axis) and volume (lower y-axis) vs the acquisition time (x-axis). All methods are non-invasive and hence have a minimum environmental impact.

4. Target sites

The AGEMERA consortium will conduct mineral exploration targeting, sampling, modelling, and geophysical field trialling in active mining/exploration sites in Europe and Zambia (Table 2). The targets represent ten mineral system types: orogenic Au, karst bauxite, volcanic-hosted massive sulphide, greisen, porphyry Cu, epithermal, skarn, stratabound Cu-Ag, Fe-oxide Cu-Au, and sediment-hosted stratiform Cu. The deposits to be studied are located in the Peräpohja Schist Belt (Finland), the Iberian Pyrite Belt (Spain), the Kupferschiefer district (Poland), the Panagyurishte & Rossen districts (Bulgaria), the Jajce & Posušje areas (Bosnia-Herzegovina) and the Zambian Copperbelt (Zambia). The Zinnwald Li-greisen deposit (Erzgebirge, Germany) is a backup site for alternative and complementary studies.

5. Thematic connections to lithosphere-scale processes

Crustal structures will be reviewed down to the upper mantle. Special attention will be paid to the known and suspected transcrustal-scale geological domain boundaries, such as terrane sutures, thrust zones, oroclinal bends, basin-controlling master faults, etc. These boundaries may have acted as major controlling structures during mineralisation (e.g., as fluid and/or magma pathways or as controlling factors for local subsidence, uplift, or basin inversion). These studies are based on new field data, updated conceptual orogenic and mineral system models, literature reviews, and various seismic techniques (e.g., ambient noise interferometry and Rayleigh wave ellipticity). The combination and joint inversion of different data sets are expected to provide relevant information in understanding the structural mechanisms that control the CRM mineral systems.

Table 2. List of target sites and the related mineral systems of the AGEMERA project. REE = rare earth elements, PGMs = platinum group metals.

Location	Mineral system	CRMs	Total area, minimum (km²)	Survey area, minimum (km²)
Finland	Orogenic gold with atypical metal association	Cobalt	2 950	1 500
Bosnia-Herzegovina	Karst bauxite	Bauxite, REE	343 + 620	343 + 620
Spain	Volcanic-hosted massive sulphide (VMS)	Cobalt, PGMs	3 500	800
Germany	Greisen (post-magmatic metasomatic alteration of late stage, geochemically specialised granites)	Lithium	52	0 (50)
Bulgaria	Porphyry copper systems (incl. epithermal gold and skarn deposits), iron-oxide copper-gold (IOCG)	PGMs, niobium, tantalum, lithium, REE	17	5 + 5
Poland	Strata-bound type copper and silver deposit	Cobalt, vanadium, molybdenum,	416	154
Zambia	Sediment-hosted stratiform copper (SSC)	Cobalt	32 328 + 125 826	1 200

7. Conclusions

AGEMERA is a three-year EU-funded project aimed at finding and utilising CRM deposits. The project will study ten different mineral system types in Europe and Africa. This will be done with conventional geological, geochemical and geophysical methods and the help of novel and non-invasive geophysical survey methods. The AGEMERA partners look forward to networking and collaborating with other projects which thematically adjoin our project.

Acknowledgements

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101058178.

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