Introduction to project SEMACRET: Sustainable exploration for orthomagmatic (critical) raw materials in the EU: Charting the road to the green energy transition

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Critical raw materials (CRMs) are fundamental to the EU industrial value chains and strategic sectors, particularly with regard to the green energy transition. Currently, the EU domestic supply of primary CRMs is below 3% for many important commodities. To obtain an improved understanding of the EU's critical raw materials potential, discover new ore deposits and thereby increase the internal sourcing of CRMs and secure its raw materials autonomy, the EU aims to boost the exploration and production of CRMs. This project is designed to develop socially and environmentally sustainable means of exploration for orthomagmatic CRMs. We will generate improved ore models for orthomagmatic mineral deposits which will be translated to mappable exploration criteria to delineate areas of high exploration potential, from regional scale to local scale. Through collaboration between geosciences and social sciences the project will also develop methods to promote social awareness of the importance of responsible exploration and mining. Further, we will map the exploration and production potential of CRM in the EU and key CRM supplier countries.

Keywords: exploration, green transition, critical raw material, orthomagmatic ore deposit

1. Introduction

To reduce the amount of drilling the efficiency of the exploration method needs to be maximised while improving the discovery rate. One way to achieve this is to improve the understanding of ore formation. A major advance in understanding ore deposits has been made with the application of the Minerals Systems Approach. Different from traditional exploration, this acknowledges that the formation of ore deposits is dependent on the interplay of several critical geological components, namely the presence of a metal source, a fluid pathway and a metal sink. If an area lacks one of these components, an ore deposit cannot form. In theory, this allows distinguishing prospective from non-prospective areas, making targeting more efficient. However, there remains controversy about the specific nature of the source, pathway and sink components (Barnes et al., 2016). In addition, it has proven challenging to translate the three components to exploration criteria that can guide explorers at both the regional scale (so-called greenfield exploration) and the local deposit scale (so-called brownfield exploration). There are several additional challenges for the exploration industry and governmental decision-makers in the EU: The social awareness of the significance of raw materials and their sustainable sourcing in the EU is relatively low and heterogeneous, which hampers the implementation of efficient exploration. Also, the amount of information on mineral resources and mineral potential in the EU is limited, and the currently reported resources are following different standards, making it difficult to integrate the data. The overarching goal of this project is to provide a clearer understanding of the EU's mineral potential, and to develop sustainable exploration techniques for green transition (critical) raw materials hosted in orthomagmatic ore deposits, thereby bridging this gap between academic research and the mineral exploration industry.

2. Project objectives and approach

Ore model refinement following the Mineral Systems Approach (WP1-OB1)

It was proposed several decades ago that the formation of orthomagmatic ore deposits is largely understood, yet the recent discovery of major ore deposits downdip of existing deposits in the

Bushveld Complex of South Africa, with a history of exploration and mining dating back a century, proves that this view was overly optimistic. The uncertainty in geological models results in serious limitations to our predictive capabilities for the exploration of critical metals, increasing the environmental footprint of exploration. A major advance has been the development of the Mineral Systems approach considering fundamental source-pathway-sink processes to identify regions of high exploration potential. However, there remains considerable controversy for each component. In this project we will refine the ore formation models using geochemistry, computational modelling and high temperature experimental study.

Developing methods for regional-scale exploration targeting (WP2-OB2)

Regional-scale (greenfield) exploration is particularly challenging as it usually is entirely conceptual, i.e. it cannot rely on historical discoveries. McCuaig et al. (2010) translated critical ore-formation factors defined under the scope of the Mineral Systems Approach to mappable proxies using multiple geoscience datasets including geophysics, geology and geochemistry. The multiple data layers can then be integrated on a GIS platform to generate prospectivity maps distinguishing areas of low and high exploration potential. In the present project, based on the refined ore model (see above section), we will define proxies reflecting all the components of the Mineral Systems Approach including ‘source’, ‘pathway’ and ‘sink’ to guide regional exploration targeting for orthomagmatic deposits.

Developing methods for brownfield exploration targeting (WP3-OB3)

Because ore deposits typically occur in clusters, explorers can assume that areas surrounding existing ore deposits are relatively prospective. They can use existing geodatabases as a starting point to develop refined ore models, and they can use the existing infrastructure to access deeper portions of the crust. Also, the Mineral Systems Approach is easier to apply as the ‘source’ component is not relevant, and research can focus on the ‘pathway’ and ‘sink’ components. For these reasons, brownfield exploration is often considered less challenging and more fruitful. However, as in the case of greenfield exploration, there is ample room for increasing efficiency. In this study, we will improve existing techniques (notably surficial geochemistry) and develop new techniques (notably 3-D modelling and inversion of ground and airborne geophysics), and introduce new machine learning tools for 3D prospectivity modelling using random forest methods.

Surficial geochemical exploration (upper soil, plant chemistry) allows to delineate geochemical domains and anomalies with low to zero environmental impact. It can be applied as well in agricultural used areas as in environmental protection areas. In this study, the focus lies on testing under different surface conditions with different host rocks how the use of surface media can be calibrated to find hidden mineralization of Ni-Cu dominated sulphide deposits and Cr-V-PGE dominated deposit. We will develop new data analytical tools and improve existing concepts, codes and guidelines to better filter relevant information for exploration from the highly variable surface geochemical data. The approach includes how to implement information about the mineral system, geology, geophysics and knowledge about the surface media to provide statistical models for target determination.

Traditionally, resource estimation has relied on intensive drilling. The main challenge is to predict metal grade in three dimensions, especially in complex ore bodies, where the continuity of mineralization is not always guaranteed. Supervised machine learning (ML) methods have been successfully applied to resource modelling, increasing the accuracy of resource estimation compared to the traditional geostatistical methods (e.g., kriging), but the method has not yet been applied to orthomagmatic deposits. In this study, we will apply ML to improve resource estimation in ore deposits.

Promote social awareness (WP4-OB4)

Social awareness of the importance and ethical sourcing of raw materials is critical for the sustainable supply of CRMs. Because of the many negative environmental and social impacts, mineral exploration and mining have started to receive more attention from traditional and social media platforms. Social acceptance of exploration and mining has become the key challenge for the whole sector. Awareness plays an important factor in molding acceptance which depends on the perceived impacts at the regional and local levels, but it is also driven by broader societal trends, discourses, and narratives (Boutillier 2021).

Against this background, we aim to investigate the preconditions and practices for gaining social awareness and acceptance for exploration and mining for CRMs. The other aim is to promote awareness about the significance of CRMs to broader audiences. The work focuses on the elements of awareness and acceptance of mining activities at two levels: 1) at the level of local (community) stakeholders and 2) at the level of media, social media, and policy narratives. The main stakeholders are citizens, exploration and mining companies, environmental organizations and other NGOs, municipalities, local and regional environmental authorities, geologists, investors, and the media.

Exploration and production potential survey in the EU and globally (WP5-OB5)

The future metal needs of the EU are such that they are unlikely to be met entirely by internal production. Imports of CRMs will thus remain a key pillar of the EU's CRM strategy. This requires a reliable survey of the exploration and production potential for CRMs in the EU and globally. For mafic-ultramafic mineral systems, Mudd et al. (2018) have published a database of known mineral resources and ore reserves. However, this database is mainly based on the JORC code, and data on many historic and recent exploration projects have not been included. In the EU, the UNFC (United Nations Framework Classification for Resources) code is recommended to harmonize the mineral resource data. Horn et al. (2020) has been the first to apply UNFC to the of cobalt (Co) mineral resources in the EU. In this study, we will update the available mineral resource database related to key commodities of orthomagmatic ore deposits (Ni, Cu, PGE, V, Ti, Cr), in a harmonized form using UNFC and UNRMS (United Nations Resource Management System) (UNECE, 2019).

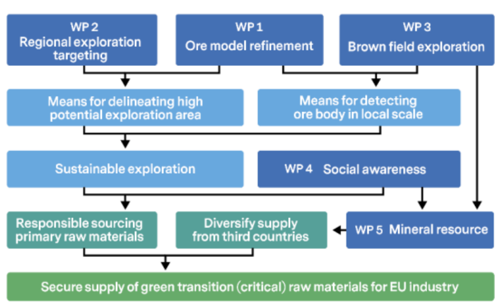

Figure. Structure of working packages and their links.

3. Reference sites

To address the objectives of the project, we have chosen several reference sites (Table 1). These include the most significant prospective regions in the EU: 1) Lapland Belt in Finland, 2) Variscan orogenic belt in Portugal, and less explored areas yet with all the hall marks of enhanced orthomagmatic ore potential including, 3) Bohemian belt in the Czech Republic, 4) Suwalki anorthosite belt in Poland, and 5) Sleza ophiolite in Poland. In addition, the chosen reference sites represent different tectonic settings, including continental rift zones, orogenic belts and ophiolites, and different mineralization styles varying from Ni-Cu-(Co-PGE) deposits in magma conduits (Ransko, Czech Republic) to sulphide-poor V-PGE-Cr-(Ni-Cu-Co) deposits in layered intrusions (Akanvaara/Finland, Beja/Portugal) and V-Ti-dominated oxide deposits in transitional (partly massive-type, partly layered) anorthosite complexes (Suwalki/Poland) (Table 1). The reference sites represent areas of variable exposure, different social and cultural environments.

Table 1. reference sites of regional metallogeny and key deposit in local scale

Site	Metallogeny	Tectonic setting	Key deposit in WP3	Country	Exploration maturity	Exploration potential
1	Lapland	Rifting	Akanvaara V-Cr-PGE	Finland	Relatively high	Highest
2	Variscan	Orogeny	Beja V-Ti	Portugal	Moderate	High
3	Bohemian	Orogeny	Ransko Ni-Cu-(Co-PGE)	Czech	Low	High
4	Suwalki	Post collision	Suwalki (Ti-V)	Poland	Low	Medium
5	Sleza	Ophiolite	Strzegomiany-Kunów V-Ti	Poland	Low	Medium

4. Expected result

Using Mineral Systems Approach in exploration for orthomagmatic ore deposits, comprehensive mineral resource mapping of exploration and production potential of (critical) raw materials in orthomagmatic ore deposits in EU and third countries, in harmonized with UNFC and UNRMS reporting standards. Low environmental impact geophysical and geochemistry exploration methods, 3D prospectivity modelling and resource modelling using machine learning. Development of sustainable exploration solution, promote social awareness of exploration and mining. The long-term impact would be efficient exploration targeting resulting in new discoveries in the EU, and diversify supply of critical raw materials from third countries. Transparency and improved comparability of assessments of mineral resource exploration and production potential; Better policymaking for raw materials supply in EU. Resilient, sustainable and secure (critical) raw mate-rials value chains for EU industrial ecosystems, in support of the twin green and digital transformations.

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