SEMACRET - RESPONSIBLE EXPLORATION FOR GREEN TRANSITION CRITICAL RAW MATERIALS

by

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SEMACRET is a project co-funded by the European Union and UKRI (SEMACRET, GA101057741) that aims to develop socially and environmentally responsible exploration means for green transition (Critical) Raw Materials (CRMs), including Ni, Cu, Co, V, Ti, Cr, and platinum-group elements (PGE), hosted by ultramafic-mafic orthomagmatic mineral systems. The primary focus of this project includes refining geological knowledge of ore-forming processes following the mineral systems approach, optimising regional-scale exploration targeting, and providing integrated solutions to target ore bodies efficiently on the local scale.

Geological modelling of ore-forming processes per the mineral systems approach includes analysis of the magma sources, modelling the pathways architecture for magma transport system and metal deposition mechanisms. For magma source, there is controversy on the source mantle of the large volumes of mafic-ultramafic magma (Barnes et al. 2016, Fig. 1). Re-Os, Sm-Nd isotopic systems are robust tools to distinguish different mantle sources. A database of isotope geochemistry of large igneous provinces with ages spanning from Archean to Paleozoic is being created, utilising existing data from literature. Sampling and geochemical analyses are ongoing in Finland, Czechia and Portugal to supplement available data. Preliminary results show that most large igneous provinces and mafic intrusions have chondritic or positive γOs isotope composition, especially for the most primitive rocks. This indicates that the contribution of the sub-continental lithospheric mantle (SCLM) is insignificant, and the major mantle source is from plume or asthenospheric mantle. This inference is further supported by geochemical and thermodynamic modelling of plume magmatism in Fennoscandia (Guo et al. 2023). Pathways architecture is being modelled through mathematical modelling, which supports magma underplating and intermediate magma chambers (Fig. 1). The process of magma contamination and assimilation is studied using petrological analysis and thermodynamic simulations, investigating the effects of magma contamination on ore deposition, especially triggered by the assimilation of anhydrite and black shale. High-temperature experimental studies are being conducted to explore the interaction between sulphur-bearing rocks and magma (Fig. 1).

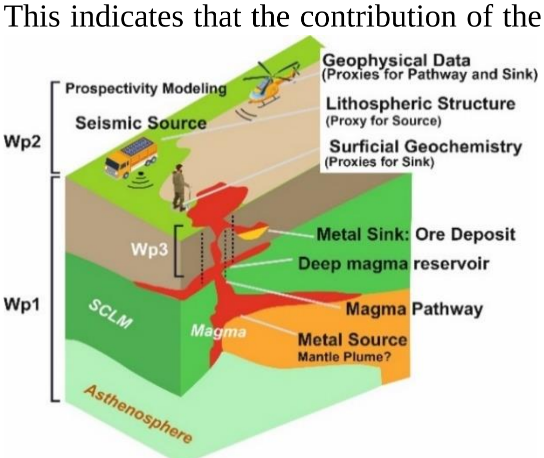

Figure 1. Mineral systems approach and regional prospectivity modelling

Regional exploration targeting of orthomagmatic mineral deposits at a regional scale involves the compilation of mineral system models for Ni-Cu-rich conduit type and PGE-Cr-rich layered mafic intrusion systems, supplemented by the insights gained from geological modelling (Fig. 1). These models compile all the crucial ore-forming processes of each mineral system, such that in the absence of even one of the processes, the deposit would not form. Targeting models are then generated based on the respective mineral system models identifying the targeting criteria dedicated for the reference study area, the Lapland belt in northern Finland, considering the datasets available and the scale of the study. Openly available public-domain geophysical datasets distributed by the Geological Survey of Finland (GTK) were utilised for the analysis to demonstrate the widespread applicability of the workflow. Spatial data processing and GIS analysis tools are then used to process primary geoscience data to map spatial proxies of each of the targeting criteria in the targeting model in the form of predictor maps. These predictor maps are then integrated using Fuzzy Inference Systems (FIS), a knowledge-driven, symbolic artificial intelligence-based integrating algorithm, to generate prospectivity maps (Porwal et al. 2015; Fig. 2). Two-stage FIS are employed, structured on the mineral systems model in which the first stage consists of a series of FIS were used to generate fuzzy prospectivity maps for individual components of the mineral system, namely, sources, pathways and traps, combining their respective fuzzy predictor maps. In the second stage, the fuzzy prospectivity maps of the individual components were combined using the product operator to generate the final mineral prospectivity maps (Fig. 2). The preliminary results show good agreement with the spatial pattern of known occurrences. High prospective areas are identified in the north-central and western part of the study area for further detailed scale exploration to narrow down target areas for eventual ground exploration.

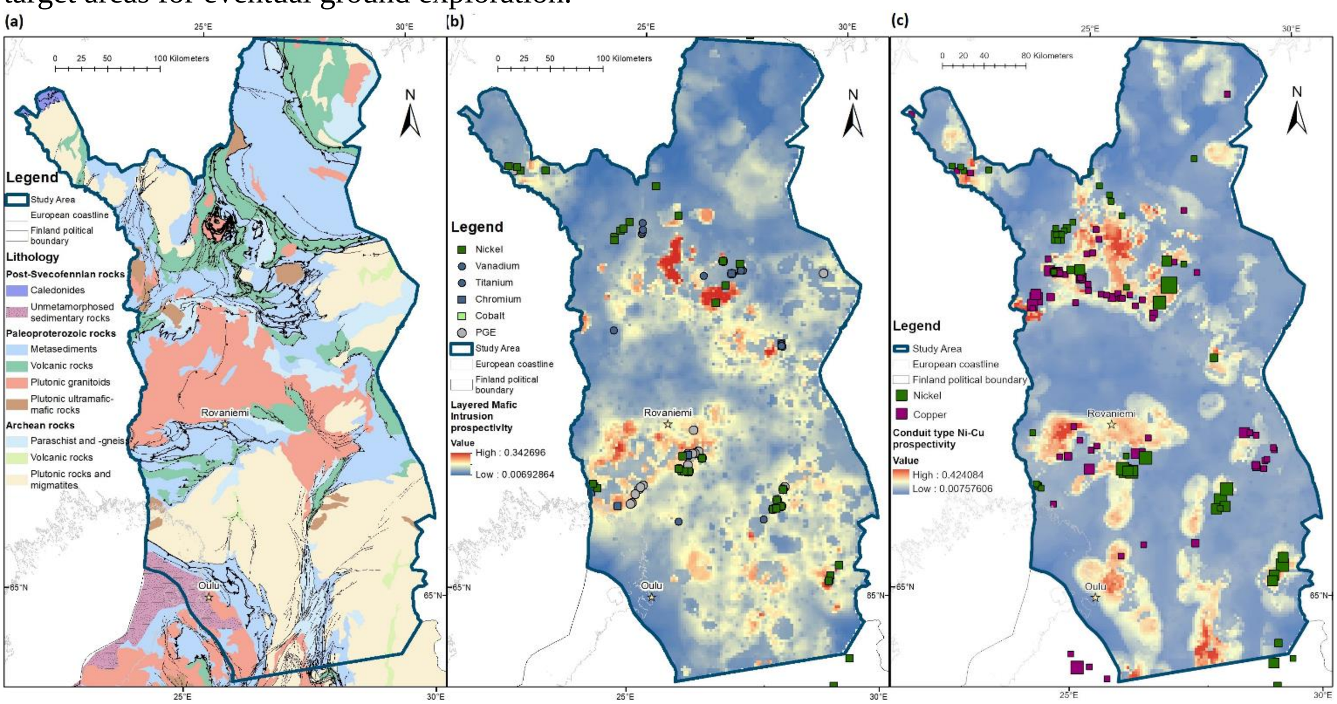

Figure 1: Preliminary results of prospectivity modelling done as part of WP2. (a) geology of the study area in northern Finland, (b) prospectivity map for layered mafic intrusion related mineralisation, (c) prospectivity map for conduit-type mineralisation. Metal occurrences include all known magmatic occurrences.

Besides the commonly used geodata, this project also involves parallel tasks to generate novel data sources and new proxies to be used in the prospectivity model, especially considering deeper geological processes in the mantle and deeper crustal level. A critical feature of large igneous provinces is the presence of a high-velocity, high-density lower crust (Alghamdi et al. 2018). This crust is interpreted as a signature of magmatic underplating, which could be remnants of deep reservoirs feeding shallower magma chambers. The seismic data interpretation further supports this. Thus, intermediate magma staging chambers, seen as magma underplating along the Moho boundary in tomography, and lower crustal thickness are considered a proxy for pathways architecture. The orthomagmatic mineral systems addressed in this project have a strong relationship with lithospheric structure and craton margins (e.g., Boscaini et al., 2022). However, lithospheric structure is often interpreted and subject to uncertainty, whereas the structure detected by geophysics represents present-day structure, which may differ from what existed at the time of mineralisation. To alleviate this problem, Lu-Hf isotopes are being used to map basement rocks and constrain lithospheric structure. Available data from literature has been compiled and interpreted. Furthermore, new zircon samples have been collected and are being analysed for Lu-Hf analysis, as well as Sm-Nd and U-Pb age determinations, to append the compiled database. Surficial till geochemistry is a significant proxy for metal deposition and preservation processes and has been instrumental in discovering many Finnish deposits. New research is being conducted in the analysis of surficial till geochemistry to improve the quality of interpretations. This task addresses the data variability problems, cleaning the dataset of erroneous values and the application of compositional data analysis (CoDA). In this effect, a new robust algorithm has also been developed to identify spatial outliers. Details of this task can be obtained in the dedicated abstract and poster submitted to the super-clustering event (Kalubowila et al. 2023).

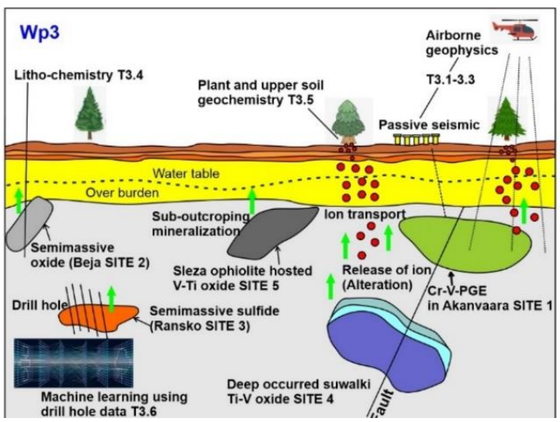

Figure 3. Local scale exploration integrating different methods as solutions.

Local-scale exploration focuses on creating an integrated solution that combines innovative methods to identify high potential areas at the local deposit scale to be applied in brownfield exploration. Five known deposits in the EU are being used as reference sites. Different mineralisation styles of the orthomagmatic deposit group pose challenges and require different methodologies. We explore optimised solutions combining different methods for different mineralisation styles. These include combining airborne electromagnetic surveys (AEM), audiomagnetotelluric (AMT) and full tensor magnetic gradiometry (FTMG) to constrain the deep occurrence of oxide ores better; 3D inversion for electromagnetic data of sulfide ores; using passive seismic to constrain the local structure and surficial geochemical data interpretation; integrating airborne and ground induced polarisation (IP) for oxide ores (Fig. 3). Surveys have been planned and executed in several areas to collect new data, covering known mineralisation and potential nearby areas (Fig. 4). FTMG and AEM surveys are being carried out at Ransko in Czechia (Fig. 4). AEM and magnetic data has been acquired at Beja in Portugal, and a ground IP survey has been planned for joint inversion (Fig. 4). Magnetic and IP measurements have been carried out at Ślęża in Poland, along with pXRF measurements. At Suwalki in Poland, AMT and FTMG have been conducted to detect V-Ti oxide mineralisation at depth (Fig. 4). In Finland, at Akanvaara, AEM, AMT, IP and magnetic surveys have been conducted (Fig. 4). Besides the new data, archived petrophysical and geophysical data in many of these regions is being digitised and reinterpreted. Furthermore, new and improved algorithms are being developed for the processing and interpretation of EM and IP data, to be publicised as QGIS plugins.

Novel environmentally friendly surficial geochemistry tools based on CoDA for upper soil horizons and plant geochemistry are being explored. Preliminary data analysis and interpretation of upper soil samples in Akanvaara has been completed, and plant and upper soil samples have been collected in three reference sites. Data processing, compositional data analysis and interpretation are currently ongoing.

Additionally, 3D prospectivity modelling is being carried out, especially in areas with extensive drill core data, to detect new mineralisation horizons within the known deposits. This involves the creation of 3D geological models based on the drill core data. Furthermore, the 3D geological model and borehole data are also being used for resource modelling using machine learning. This task aims to develop novel, machine learning-based techniques to interpolate resources between adjacent boreholes.

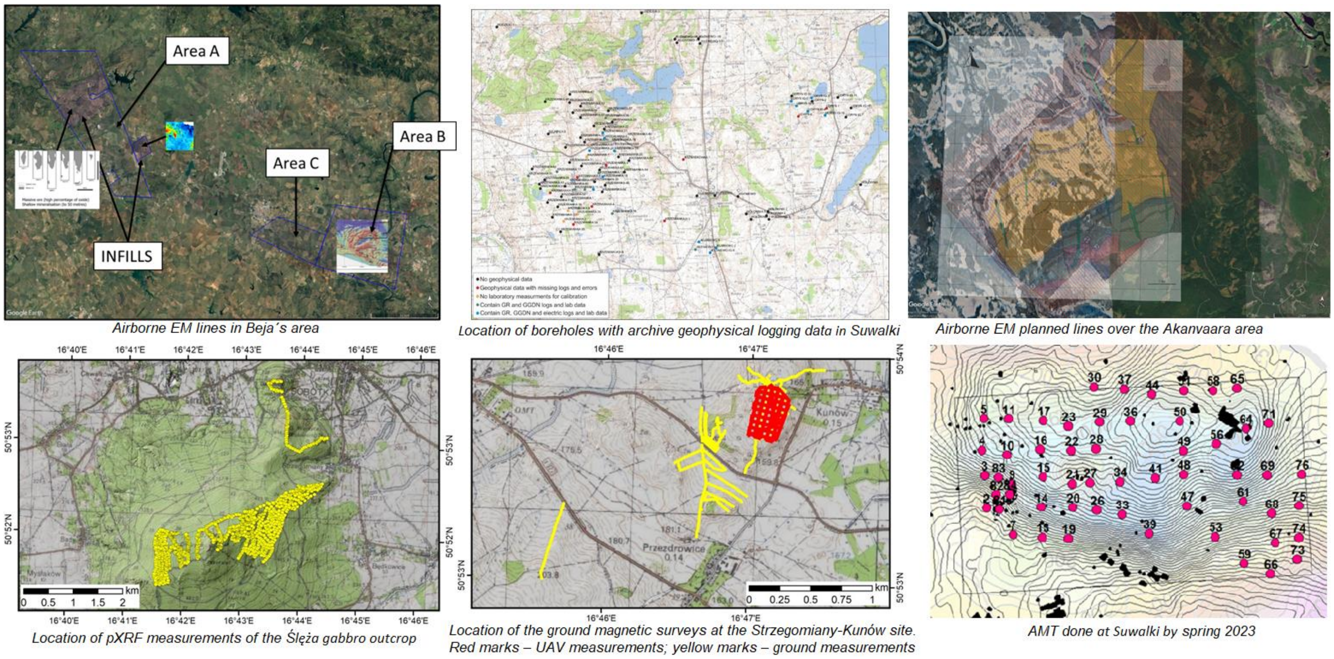

Figure 4: Graphic summarising the progress achieved in the geophysical surveys planned in the five reference sites of the SEMACRET project.

In addition to exploration technique development, SEMACRET promotes **social awareness** of raw materials exploration and mining. It aims to investigate the influence of citizens' knowledge levels on their attitudes and acceptance of mineral exploration through community events, interviews and social media analysis using artificial intelligence. This aspect of the project is detailed in a dedicated abstract and presentation at the super clustering event (Bahr et al. 2023).

This project also addresses estimating and reporting critical mineral resources to assess exploration and production potential. A key challenge lies in the diverse reporting methods used by different countries, with some using national standards instead of internationally recognised ones like the Joint Ore Reserve Committee (JORC) code. We intend to apply the United Nations Framework Classification (UNFC) code and the United Nations Resource Management System (UNRMS) system to categorise various mineral resource types within orthomagmatic ore deposits. Planning and preliminary preparation for the construction of a database have been initiated.

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