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Mineral resource and sustainable exploration
23–24 April 2024
Abstracts

Shenghong Yang, Nils Jansson, and Juha Kaija eds.

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Critical raw materials (CRM) are crucial for the green energy transition, however, there are challenges the mineral sectors are facing. To build up a sustainable mineral ecosystem, we need collaboration among the whole value chain of raw materials from exploration to mining, recycling and social and environmental sectors. In this event, we will focus on exploration which is the upper stream of the mineral value chain. We hope to bring together a wide range of stakeholders in the exploration ecosystem, including research projects developing new exploration technologies, exploration companies, resource rich African countries, educational programs, regional authorities, as well as other interested stakeholders, to discuss about the mineral resource potential, current technological and societal challenges and possible solutions. This event is co-organized by the *MINEARC - Mining Innovation Exchange through Arctic Regional Collaboration* project (funded by Bureau of Energy Resources of US), and Horizon Europe Projects *SEMACRET - Sustainable exploration for orthomagmatic (critical) raw materials in the EU: Charting the road to the green energy transition*, *EIS - Exploration Information System*, *AGEMERA - Agile Exploration and Geo-modelling for European Critical Raw materials* and EIT RawMaterials project *MinExTarget - Enhanced Use of Heavy Mineral Chemistry in Exploration Targeting.*

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Contents

A Mineral systems approach on critical raw material deposits in Europe

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In response to the escalating demand for Critical Raw Materials (CRMs) driven by the global shift towards renewable energy, Europe faces significant challenges in securing long-term supplies of essential metals and minerals. These challenges are exacerbated by geopolitical tensions and heightened competition for resources, as underscored by the European Union's projection of raw material demand doubling by 2060. To navigate these challenges, there is a pressing need to develop robust strategies for the exploration and sustainable exploitation of CRM-bearing deposits within the EU.

The Horizon Europe project Exploration Information System (EIS; HORIZON-CL4-2021-RESILIENCE-01-n°1010557357) emerges as a pivotal initiative in this endeavor, focusing on investigating CRM-bearing mineral systems across Europe. This project prioritizes cobalt in Volcanogenic Massive Sulfide (VMS) systems, -tin-tantalum-tungsten in granite/pegmatite-related systems, alongside REEs and cobalt in Iron Oxide-Copper-Gold (IOCG) systems.

The EIS project aims to address the substantial but underexplored potential of these deposit types, challenging due to their exotic and atypical nature which necessitates specialized exploration strategies. The EIS project harnesses the mineral systems approach for the exploration and development of CRM-bearing deposits within Europe. Originating from studies on Australia's Proterozoic mineral systems, this method prioritizes a holistic grasp of the geological phenomena underpinning the formation and conservation of mineral deposits. It leverages both geological and geophysical data to create conceptual models, shedding light on ore formation dynamics in alignment with the regional geological context. As part of the initiative, new mineral system models are being incorporated into the EIS toolkit, alongside the EIS QGIS Wizard for perspective mapping. These tools, destined for the mining industry and the broader public, underscore the project's commitment to open-source resources, facilitating wider access and usage.

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Mineral systems driven prospectivity modelling of orthomagmatic ore deposits

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Nickel (Ni), cobalt (Co), platinum group metals (PGMs), chromium (Cr), vanadium (V), and copper (Cu) are some of the metals that are considered critical or strategic raw materials by the European Commission and are hosted in orthomagmatic ore deposits. The SEMACRET project aims to develop responsible exploration methods for such critical metals within the EU and beyond to ensure a consistent supply for the green energy transition.

This contribution describes geological modelling of such deposits following the concept of mineral systems which includes (1) fertile magma sources, (2) pathways for magma transport, and (3) mechanisms of metal deposition, followed by its application to regional-scale exploration targeting. The study area is in the Lapland area in northern Finland, hosting two types of orthomagmatic mineralisation – layered mafic intrusions-hosted PGM-Cr-V-(Co-Ni-Cu) and conduit-type Ni-Cu-(PGM-Co) sulphide deposits (Maier and Hanski, 2017).

There is ongoing debate regarding the sources of mafic-ultramafic magma, with isotopic systems like Re-Os and Sm-Nd serving as valuable tools in distinguishing different mantle sources. Preliminary results suggest that plume or asthenospheric mantle is the primary source of such magmas. This inference is supported by geochemical and thermodynamic modelling, particularly focusing on plume magmatism in Fennoscandia (e.g., Guo et al., 2023). The process of magma transport is being modelled numerically, with a focus on underplating and the formation of magma reservoirs. Magma fractionation and assimilation processes are studied using petrological analysis and thermodynamic simulations with implications for exploration. High-temperature experimental studies are conducted to explore the interaction between sulphur-bearing rocks and magma.

Regional exploration targeting involves compiling mineral system models incorporating all crucial ore-forming processes for the two types of orthomagmatic mineral deposits. Targeting models are then generated based on these mineral system models, identifying specific targeting criteria for the Lapland study area considering the scale of the study area and the datasets available. Spatial data processing and GIS analysis tools are used to map spatial proxies of each targeting criterion, generating predictor maps. Openly available geoscientific datasets are utilised for analysis, demonstrating the widespread applicability of the workflow. In addition to commonly used geodata (e.g., gravity, magnetic, and surficial geochemistry), the project aims at generating novel proxies and data sources for prospectivity modelling. This includes interpreting seismic data to understand the lithospheric structure, mapping craton boundaries to represent transient geodynamic settings, and using structural data to represent fault density as focal points of magmatic flow accumulation. These predictor maps are then integrated using Fuzzy Inference Systems (FIS; Porwal et al., 2015), an artificial intelligence-based algorithm, to generate prospectivity maps.

Preliminary results show good agreement of the model with known metal occurrences, with high-prospective areas identified in the north-central and western parts of the study area. These areas are recommended for further detailed exploration to narrow down target areas for eventual ground exploration.

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Multi-scale and interdisciplinary approaches to the granite-related ore-forming systems in the Segura-Argemela-Panasqueira-Góis belt (Portugal), insights for innovative exploration surveys

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The Segura-Argemela-Panasqueira-Góis belt (Portugal) extends for ca. 150 km, including various granite-related ore-forming systems: Sn(-Nb-Ta) and Li(-Sn-Nb-Ta) aplite/pegmatite-types and Sn-Li, Sn(-W), W-Cu(-Sn) quartz vein-types.

The pre-Ordovician metasediments are affected by many shear zones and intruded by voluminous Cambrian-Ordovician and Carboniferous-Permian (Variscan) plutons and different arrays of dykes. The Average Shale-normalised composition of metapelites denotes variable enrichments in Li, Cs, Sn, Hf, Bi, As and Sc. Variscan granite suites are more fertile than those of Cambrian-Ordovician age; among them, the strongly differentiated and ferroan leucogranites indicate the most promising targets. The latter two granite groups and related magmatic-hydrothermal ore-forming processes can be traced by Nb/Ta, K/Rb, Y/Ho, Sr/Eu, Eu/Eu*, Zr/Hf, and Rb/Sr ratios. Also, the lanthanide “tetrad effect” parameter (TE1,3) co-varies positively with magmatic differentiation and metal-enrichment. The geochronological data obtained confine to ca. 310-290 Ma the mineralising events within the surveyed belt.

Segura aplite-pegmatite dykes are compositionally close to the Argemela granites, depicting the involvement of highly differentiated, Na2O-rich magmas. Compared to Panasqueira granites, Segura aplite-pegmatite dykes are characterised by excess P not linked to apatite but to amblygonite-montebrasite and to Fe-Mn rich phosphates. These dykes also include Nb-Ta- and Sn-oxides, often displaying complex compositional zonings. The composition of several minerals (e.g., muscovite, tourmaline, and zircon) in different settings, including contact metamorphic aureoles encircling “fertile” granites, are being successfully tested as finger- and footprints to different mineralisation types. Similarly, the abundance and composition of alluvial TiO2-polymorphs, cassiterite, wolframite, and scheelite produce anomaly haloes useful to geochemical exploration in the belt.

Gold deposits in northern Finland: Characteristics and current understanding

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Northern Finland hosts several known gold deposits including the Europe´s largest active gold mine in Kittilä. There are potential for new discoveries, highlighted by recent >4 Moz gold discovery Ikkari Au deposit in the Central Lapland belt. Most of the known gold deposits in northern Finland can be classified as belonging to the orogenic gold deposit class, which is globally the dominant gold deposit class in metamorphic terrains. However, many of the Finnish examples show atypical characteristics compared to the traditional Au-only orogenic deposits as they show enrichment of e.g. Co, Cu and U, not typical products from orogenic metamorphic fluids responsible for formation of orogenic gold. Given the global green energy transition towards a low-carbon society, interest to understand these atypical base-metal deposits has increased during the past decade, as for example cobalt is one of the most important metals needed in the lithium-ion batteries and currently listed as critical mineral in EU. This presentation discusses the key characteristics of the known gold deposits in northern Finland and the current understanding of their formation. Examples are given from the three volcano-sedimentary sequences in northern Finland which shows potential for world-class discoveries.

Deposit to Regional Scale exploration in Fennoscandia

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The D-Rex project addresses the ERA-MIN Joint Call 2019 “Raw materials for sustainable development and the circular economy”, topic 1: “Supply of raw materials from exploration and mining”. Formation and concentration of metals into economic mineral deposits requires a combination of processes operating at different scales. Mineral deposits are themselves a small part of a very large geological context, the so-called mineral system, which further includes an often deeply seated source for fluids, a source region for metals, an energy source for driving hydrothermal circulation, pathways for the migration of enriched fluids, a depositional mechanism responsible for the formation of the deposit and a fluid outflow. The primary objective of the D-Rex project is to improve the identification of previously unrealised endowed regions. Historically, efforts to understand mineralised systems have focused on the near surface identification and evaluation of individual resource bodies using shallow imaging techniques. The manageable logistical requirements and small environmental footprint of magnetotellurics coupled with its broadband depth sensitivity (from 10s of meters to 100+ kilometers) are making it an increasingly important and powerful tool for geophysical studies with multiple depth scales of interest. For these reasons magnetotellurics is the primary new geophysical data set collected in D-Rex. We have collected regional datasets at three prospective areas in Sweden, Norway and Finland to generate the regional and deposit scale models needed to identify the deeper footprints of metal concentration.

Closing the gap between airborne EM and galvanic induced polarization for sustainable mineral exploration

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Nowadays it is widely accepted that Induced Polarization (IP) affects Airborne Electromagnetic (AEM) acquisitions, but the extraction of reliable IP information from AEM data is difficult, because conduction and polarization effects give rise to significant equivalences in the AEM method. Here we present a novel inversion approach for AEM data (Fiandaca et al., 2023) able to retrieve reliable IP models from AEM data alone, thanks to the use of the Maximum Phase Angle (MPA) re-parameterization of the IP phenomenon (Fiandaca et al., 2018) and of a coarser mesh for the definition of the spectral IP parameters, in order to minimize correlations and maximize resolution.

This new approach has been tested on data collected in a survey carried out in 2023 for the PanGlobal mining company in Spain, comprising both AEM data and 17 galvanic IP lines. Moreover, a joint inversion between the two entire datasets has been performed, with significant improvement in the lateral resolution of the retrieved IP model.

The results show that it is possible to effectively retrieve IP information from airborne EM measurements and to jointly model ground and airborne IP data. These findings open the way for a radical change in mineral exploration with electric and electromagnetic methods: the AEM method can be used to guide the ground exploration also for finding chargeability anomalies, and then the joint inversion of AEM and ground IP data can further enhance the resolution of the imaging results.

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The DroneSOM project and its achievements

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The DroneSOM project is an upscaling project co-funded by EIT RawMaterials, with the goal of developing rapid and cost-effective tools and services for data collection, interpretation, and integration in the exploration industry. The primary objective of this upscaling project is to transform existing prototypes into market-ready products. The Geological Survey of Finland (GTK) coordinates the project, and other partners are the Technical University of Denmark (DTU), Radai Ltd (Radai), and Beak Consultants GmbH (Beak).

The DroneSOM project is upscaling several products, including a drone-based electromagnetic survey technique upscaled by Radai, a drone-based gravity survey technique upscaled by DTU, Advangeo®3D data integration software upscaled by Beak, and GisSOM software and 3D EM-inversion upscaled by GTK. Additionally, the project includes the organization of short courses focusing on drone geophysics and data integration techniques. Given that the project's primary emphasis is to bring upscaled products to the market soon after the project, market studies and the development of a Go-To-Market strategy play a crucial role.

The major objective of the project is to establish a chain of products and services that enable expedited geophysical data collection, creation of 3D models, and integration with other datasets for the purpose of more cost-efficient and accurate mineral exploration.

The DroneSOM project commenced in early 2022 and is scheduled to conclude by the end of 2024. Notable milestones achieved thus far include successful survey flights and the organization of a drone geophysics workshop in Finland. Significant progress has also been made in the development of electromagnetic (EM) geophysics, with a pivotal role played by collaboration with exploration companies. In 2024, two designated test sites will be utilized for drone-based data collection. The activities at these sites will involve both modelling of survey data and integration with other datasets. Additionally, an open workshop focused on data integration techniques and the project's final seminar will be organized.

Quantum leaps in mineral exploration: Adapting high-energy particle research for innovative geophysical techniques

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The field of geophysics has traditionally emphasised *continuum mechanics*, often underestimating the benefits particle physics could bring to enhancing conventional methods. In continuum mechanics, materials are considered as continuous masses, modelling physical properties as continuous rather than discrete. Examples of conventional geophysical methods that rely on the principles of continuum mechanics include gravimetric and seismic methods. For example, the latter treats the Earth's subsurface as a continuous elastic medium. On the other hand, methods based on electromagnetism provide data that can be analysed using continuum concepts, even as electromagnetism itself is not a part of continuum mechanics. Methods falling into this category include electromagnetic (EM) surveying, induced polarisation (IP) and magnetotellurics (MT).

Muon imaging, in contrast to the traditional geophysical methods grounded in continuum mechanics and electromagnetism, introduces a novel approach to hard-rock resource exploration. Muon imaging, or (cosmic-ray) muography (Tanaka et al., 2023), is based on the principles of particle physics and *quantum mechanics*. This technique utilises cosmic-ray muons—high-energy particles originating from cosmic rays interacting with the Earth's atmosphere—to image the internal density distribution of geological volumes and man-made structures. Unlike methods that depend on the propagation of waves or fields through a continuous medium, muography relies on the detection of discrete muon particles as they pass through and are partially absorbed or deflected by different materials. Due to their high energies, muons travel almost straight underground with minimal deflection, reflecting their quantum mechanical nature. Muography, relying on large statistical data, is thus effective in underground measurements. The straight muon trajectories offer an additional advantage to the muon mapping method because the mapping process (the muon trajectory) is independent of the physical properties of the medium under investigation, unlike seismic or electromagnetic wave propagation. Consequently, the inversion of measurements becomes simpler and more reliable. In essence, muon mapping provides a robust way to explore subsurface structures without being hindered by the specific characteristics of the medium. It is like having a versatile tool that works consistently across different scenarios, regardless of the material properties.

Muography is also uniquely sensitive to density variations within the volume under investigation. For example, since muons are minimally affected by EM fields due to their high momentum, a characteristic rooted in quantum mechanics, the technique bypasses the limitations associated with EM methods, offering a direct measure of material density. This allows for the direct observation of density variations in a way that is not directly achievable with seismic or electromagnetic methods, which infer subsurface properties indirectly through wave reflections, refractions, or conductivity variations. Moreover, muography offers high-resolution imaging capabilities from a passive, non-invasive standpoint. This is a significant departure from the continuum-based approaches, opening new possibilities for geophysical exploration and monitoring with minimal environmental impact, marking a true “quantum leap” in mineral exploration technologies. In this talk, we will summarise the methodology principles of muography and present its application use cases in the Horizon Europe AGEMERA project (Holma et al., 2022).

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Enhanced application of heavy mineral chemistry in mineral exploration targeting: the MinExTarget project

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Recognition of geochemical anomalies and indicator minerals in transported surface material such as unconsolidated stream and till sediments, as well as in soils, and evaluation of their spatial distributions are widely used methods for definition of targets during the early stages of mineral exploration.

Identification of indicator minerals in separated fractions of unconsolidated sediment or soil samples is especially used in exploration for diamond and gold, but many of those minerals only predict the potential occurrence of such rocks that may host mineralization and do not discriminate between types of deposits. Geochemical anomalies in heavy mineral fractions from sediments can be linked to the presence of sulphide, native metallic, or other preserved mineral grains originated from a primary source. Associations of trace elements, stable and radiogenic isotopes in several common ore-forming heavy minerals (e.g. pyrite, chalcopyrite, arsenopyrite, magnetite, cassiterite, etc.), and other minerals (e.g. scheelite, monazite, tourmaline etc.) fingerprint the type of ore deposit in which these minerals were formed.

The LA-ICPMS analytical technique is capable to measure not only trace elements but also stable and radiogenic isotope compositions in mineral grains with down to a few tens of micrometers sizes. The successful application of the LA-ICPMS analytical technique to target definition in mineral exploration depends on the identification of mineral grains applicable to trace element and isotope fingerprinting. Application of automated mineral identification through modern electron-microscopy methods on properly prepared samples supports fast detection and selection of mineral grains for the LA-ICPMS analyses.

The MinExTarget project developed a service package for recognition of the type of the predicted ore deposit on the basis of the application of automated mineral identification through modern electron-microscopy methods on properly prepared heavy mineral separates and unsupervised machine learning and self organized mapping methods in interpretation of data. The test areas of the project were located in intensely explored terrains with diverse types of metallic mineral deposits in Northern and Eastern Europe and Greenland. The presentation will deliver some aspects of the methodological approach of the MinExTarget project and results of tests completed in those areas.

This research has been conducted within the MinExTarget (Enhanced Use of Heavy Mineral Chemistry in Exploration Targeting) project, and has received funding from European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation.

Geochemical exploration for pegmatites: results from the GREENPEG project

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The EU H2020 GREENPEG project (2020-2024) has recently produced a toolset of pegmatite exploration methods at all scales from province to district to prospect. In this presentation, the tested prospect-scale geochemical methods are outlined. The methods include geochemical mapping of soils, stream sediment analysis, pegmatite trace-elements-in-quartz analysis and analysis of pegmatite metasomatic halos in both the lab on whole-rock samples and using portable laser induced breakdown spectroscopy (LIBS) in the field.

Each method was tested in areas of known rare metal pegmatite outcrop or subcrop. These include Tysfjord, Norway; Wolfsberg, Austria; Moylisha, Ireland; and pegmatite prospects spanning the border between Spain and Portugal. The pegmatites studied are of two types: the Tysford pegmatites are NYF / Group 2 pegmatites that are economic sources of ultrapure quartz; the others are LCT / Group 1 pegmatites that are all at least sub-economic for lithium. The rationale for using each method, the sampling and analytical methods used, and the results obtained are described. The lessons learned, including the strengths and weaknesses of each method in different geological and other contexts are discussed.

We show that soil chemical mapping in areas of thin (<1 m) in situ soil effectively locates both types of rare metal pegmatite, though radiometric methods offer superior speed and lower cost at Tysfjord. Both mineral (QEMSCAN) and whole-rock chemical vectors to lithium pegmatites may readily be established using stream sediment samples. The novel method of trace-elements-in-quartz analysis reveals major chemical anomalies in quartz extracted from both types of pegmatite. This method offers advantages in early-stage exploration where outcrop is limited or highly weathered. Metasomatic halos prove to be extremely variable in width. Where they are of comparable to or greater in thickness than pegmatite dykes, both LIBS and whole-rock analysis can reveal buried pegmatite bodies of either type.

Exploration progress by different mineral explorers – opportunities and challenges

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Earth´s geology and mineralization are independent of human-created borders. The human-made borders, however, create a challenge for exploration companies and affect their operations in many ways in different areas. In addition, there is a time aspect making things even more demanding. What was considered industry standard way of operating twenty years ago is not an applicable way of working today.

Another dimension to take into account is the different types of mineral explorers; mining companies conducting mineral exploration, active exploration companies, junior exploration companies, and different types of target generators. The way of operating and handling the same question varies between the type of operator facing the challenges within mineral exploration. For example, the resources and level of information when it comes to communication with stakeholders between a junior exploration company and a mining company since the goal for the companies is different. An exploration company wants to make a discovery and a mining company aims to open a mining operation.

The global technological development has provided many opportunities for humankind and within exploration it has led to the search for new types of minerals, that hadn't any interest ten or more years ago. The combination of having both new technological possibilities to conduct exploration work and the challenges executing exploration in areas where exploration hasn't been conducted so much before, is dealt differently by the different operators we have within the mineral exploration industry.

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Exploration of the Per Geijer IOA deposit in a nutshell

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The Per Geijer iron oxide-apatite (IOA) deposit in Norrbotten, Sweden, has been a subject of an intense exploration campaign by LKAB since 2020. The surface parts of the deposit were discovered in the late 19th century and mined throughout the first half of the 20th century. The parts of the deposit at depths of >500 m from the surface were first drilled in the 1960s, but the exploration activities stopped as the deposit was considered as uneconomic at the time.

The Kiruna area is the type-locality for the Kiruna-type IOA ores. The IOA deposits in the area are located within the volcanic and volcano-sedimentary formations of the Kiirunavaara Group at several stratigraphic levels. The Per Geijer IOA deposit comprises magnetite, hematite, and mixed Fe-oxide mineralisation, as well as local but anomalously high levels of apatite and REEs. The high apatite content of the Per Geijer ores has been known since their discovery (see e.g., Geijer, 1919) and studied later by Parák (1973) and Frietsch & Perdahl (1995).

In the current exploration campaign from May 2020 onwards, several geophysical surveys have been conducted using magnetic, magnetotelluric, electromagnetic and seismic methods. The resultant drill programs have amounted to 79 diamond drill holes with a total length of 88 km. A maiden Inferred Mineral Resource of 408 Mt grading 54.3% Fe and 2.73% P was reported for the Per Geijer deposit in 2021. The most recent resource update in June 2023 (LKAB, 2023) reported a Mineral Resource of 734 Mt grading 47.3% Fe and 2.3% P comprising an Indicated Mineral Resource of 307 Mt grading 50.2% Fe and 2.6% P and an Inferred Mineral Resource of approximately 421 Mt grading 45.5% Fe and 2.0% P. In addition to Fe and P, but contained within the same rock volume, the Per Geijer deposit contains an Inferred Mineral Resource of 734 Mt grading 0.18% Total Rare Earth Oxide.

Exploration and the gathering of orebody knowledge is planned to continue at the Per Geijer deposit for the next several years and beyond.

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Exploring the partly underwater Kolmisoppi Ni-Zn-Cu-Co deposit in the Kainuu schist belt

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The Mineral Resource of Terrafame Oy consists of two Ni, Zn, Co, Cu bearing deposits, Kuusilampi and Kolmisoppi in the Kainuu Schist Belt in Central Finland. The orebodies are hosted by black schists and surrounded by unmineralized black schists and mica schists. Combined the two deposits contain around 1500 Mt of Mineral Resources with average grades of 0.26% Ni, 0.55% Zn, 0.15% Cu and 0.02% Co (JORC Report 2020). This makes the Terrafame deposit the largest black-shale hosted deposit in the world and the largest Nickel and Cobalt deposit in Europe.

The Kolmisoppi deposit, originally discovered in the 1970s, has been subject to exploration efforts by various entities across different time periods. Between 2020 and 2022, Terrafame Oy undertook an infill drilling campaign aimed at enhancing the geological understanding and resource estimation of the deposit. This endeavour presented unique challenges due to a portion of the deposit being situated beneath the Lake Kolmisoppi, necessitating the development of drilling techniques to facilitate drilling operations during both winter and summer seasons. A total of 149 drillholes were successfully executed from land, ice, and pontoon platform.

Discovery history and geology of the Nautanen North Cu-Au-Ag-(Mo) deposit, Norrbotten, Sweden

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Nautanen North is a newly discovered iron oxide copper-gold deposit located in the northern Norrbotten ore province of Sweden which contains a resource of 25.5 Mt at 1.51% Cu, 0.8g/t Au, 6g/t Ag and 105 g/t Mo. The deposit was discovered in 2012 by Boliden Mines AB while targeting ground EM and magnetic anomalies within the regional-scale Nautanen Deformation Zone (NDZ). Extensive drilling over the past 12 years has defined a large scale alteration system consisting of sodic and high temperature calcic-iron, with high temperature potassic-iron and low temperature potassic-iron facies occurring at the core of the deposit, and hosting the highest grades of copper. Chalcopyrite and magnetite dominate the mineralization assemblage with pyrite, pyrrhotite and molybdenite. Sulfides and magnetite occur within discrete zones of breccia and veining as well as along shears and as disseminations adjacent to structures. The talk will examine the exploration history that lead to the discovery of the deposit and the recent insights gained from research work conducted at the site.

The Vittangi graphite project

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Talga AB has been developing and permitting its flagship Vittangi Graphite Project over the last decade. Talga AB is a part of Talga Group Ltd which has its head office located in Perth, Australia, pilot plant facilities in located in Rudolstadt, Germany and Luleå, Sweden, and R&D located in Cambridge, UK. Talga's mission is to enable the world's most sustainable batteries and consumer products through innovative graphitic materials.

The Vittangi Graphite Project aims to produce 20,000 tonnes of graphite anode (Talnode-C) from its planned mine located in Vittangi and refinery located in Luleå. Talga's process is vertically integrated, from mine to finished product with several specific processes involved including mining, concentrating, purification, shaping and coating. An overview of the project, including its history, geology and status will be presented.

Multimetal water analysis system (MWAS) a fast on-site analysis tool of dissolved metals in water

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Conventional methods for analysing dissolved metals in water, such as sending samples to laboratories for analysis using AAS, ICP-MS, or ICP-OES techniques, often entail significant delays due to logistical constraints. Consequently, real-time information on dissolved metal concentrations in water is typically unavailable.

To address this limitation, 3Awater has introduced the Multimetal Water Analysis System (MWAS), which enables the simultaneous analysis of multiple dissolved metals in field conditions in under ten minutes. Tiihonen et al. (2022) presented the innovative technology behind MWAS. This system offers rapid, user-friendly operation and reliable results with detection limits as low as single ppb (µg/l) level.

MWAS holds promise for enhancing mineral exploration efforts by providing timely data on water quality. It can identify proximity to mineralization and geochemical anomalies through primary or pathfinder elements. Moreover, the system's ability to quickly analyse the spatial distribution of metal concentrations in water samples facilitates vectoring toward potential deposits. Furthermore, MWAS facilitates the assessment of environmental impacts associated with exploration activities by analysing metals in environmental waters, thereby extending its potential applications.

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The mineral resources management education programme in Mozambique – A cooperation between Luleå University of Technology and Eduardo Mondlane University, Maputo

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SIDA (The Swedish International Development Cooperation Agency) supports the Eduardo Mondlane University (UEM) and its collaboration with Swedish and South African universities. The national research capacity is strengthened and improves Mozambique's ability to plan, produce and use research for poverty reduction. Over the years, research capacity has been built and in 2023 and 2024, 100 Mozambicans are expected to graduate with a PhD under Sida's support to research.

The focus is on research collaborations and postgraduate education, master's programmes, improving the research environment and strengthening research leaders. The assistance also supports research and innovation projects through the National Research Fund (NRF) to build up the Department of Research and Innovation with a focus on environmental sustainability.

The MSc and PhD Programmes in Mineral Resources Management is twofold. First it is aiming at equipping the candidates with advanced knowledge on the ore genesis, mineral exploration methods and technics, environmental impacts related to exploitation of mineral resources and sustainable management of minerals resources. The second aim is building an international standard capacity at the Geology Department to deliver post graduate programmes.

The programmes are building on the previous programme on MSc on Mineral Resources Management which benefited from SIDA funding between 2013 and 2016. Both the previous programme and the current one is delivered in the partnership between UEM and LTU.

The programme is intended to deliver two editions of UEM MSc, giving a total of 15 MSc students and a LTU PhD program which initially was designed to accept 5 students. The PhD students would spend 6 to 9 months at LTU per year and would benefit from supervision and first world infrastructures for research. PhD students would also spend 3 to 6 months in Mozambique, carrying out additional research and field work. PhD students are supervised jointly by researchers from LTU and UEM with shared responsibilities.

The PhD topics were carefully selected in order to make an impact contribution to the geological knowledge of the two main metallogenetic provinces of Mozambique (Manica and Tete). Tete with world class coal reserves and Manica with the prospective Archean Greenstone belt rich in gold, copper-nickel and iron deposits. Additionally, the boundary between the Archean Craton and the Proterozoic terrains is being investigated with respect to significance for the mineral prospectivity. A PhD in mineral Economics is analysing the current and potential benefits to the Mozambican economy from mining.

Tanzania's expansion opportunities from gold mining to strategic minerals and battery metals

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Tanzania, along with the broader African continent, is indeed becoming a pivotal player in the global technological transformation, particularly in the green energy sector. The continent's rich endowment of critical and strategic minerals, which account for about 30% of the world's reserves, positions it as a key supplier in the emerging economy. These minerals are essential for the production of renewable energy technologies and battery storage solutions, which are integral to the transition towards a low-carbon future.

As Africa continues to harness its vast mineral resources and digital potential, it stands to make significant contributions to the global economy while advancing its own sustainable development. The geology of Tanzania provides compelling evidence of Africa's potential role in technological transformation, particularly in the green energy sector. Commodities such as nickel (Ni), copper (Cu), lithium (Li), and rare earth elements (REE) are among the scarce metals found in Tanzania, supported by the geological conditions that favor their deposits. The geological similarities between the Democratic Republic of Congo (DRC) and Tanzania further underscore Tanzania's potential in this industry. Notably, the rare metal-rich Kibaran Belt in the DRC extends eastward into Tanzania, locally known as the Karagwe-Ankolean Belt. Within these belts, early Proterozoic schists and gneisses of Eburnean/Ubendian age, along with less frequently occurring Archaean granitoids, granulites, and greenstone, emerge in the cores of antiforms and uplifted blocks. These belts are richly endowed with rare metal deposits (such as tin, tungsten, and tantalum), gold (found in the Archaean Greenstone Belts), nickel (as seen in the Kabanga-Musongati nickel deposits, often associated with copper, cobalt, and platinum), niobium (Nb), rare earth elements (REE), copper (Cu), cobalt (Co), iron (Fe), vanadium (V), titanium (Ti), and graphite.

Rare earth elements (REE), nickel, graphite, and lithium are among the rare metal deposits that have reached an advanced phase of development in Tanzania. These valuable resources are poised to position Tanzania as a significant global supplier. The mobile belts surrounding Tanzania's Archaean Craton have been identified as hosts for a substantial portion of these deposits. For instance, the Pan African Mozambique belt (approximately 600 million years old) serves as the host for major graphite deposits. The quality of this graphite is favorably compared to the renowned high-quality graphite found in Madagascar.Lithium in Tanzania derives from two primary sources: Lithium pegmatites, such as those found in Hombolo, extend into the mobile belts. These pegmatites contribute significantly to the lithium supply. Lithium deposits in clay, located in the rift basins around Mount Meru and Kilimanjaro, represent an emerging area of exploration. Although still in its infancy, this source shows immense potential as a contributor to the economy's lithium supply. Tanzania's geological richness underscores its pivotal role in the global metals market, particularly in the context of sustainable energy and technological advancements. As a nation, we anticipate that the revenue generated from supplying these rare metals will exceed the traditional mining sector's income, which was primarily derived from gold exports.

Mineral resource potential in Africa

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Finnish companies Radai Ltd and Dronnair Ltd are pioneering drone-based geophysical surveys across Scandinavia and extending their innovation to Africa with the establishment of two startups: Zanifi Ltd in Lusaka and Zambia, and Tukutech Ltd in Dar Es Salaam and Tanzania. These nations have set ambitious goals to conduct extensive, high-detail geophysical surveys by 2030, aiming to enhance mineral exploration by mapping bedrock structures more precisely and attracting new investment.

This initiative aligns with Zambia and Tanzania's commitment to the global green transition, seeking to provide the critical raw materials essential for the mainstream industry. Zanifi Ltd and Tukutech Ltd are at the forefront, introducing cutting-edge technologies and applications that promise to strengthen EU-Africa relations through educational partnerships and collaboration in EU-funded projects. These ventures will not only bring technological advancements but also focus on empowering local communities with the knowledge and skills necessary for effective mineral exploration and the development of a sustainable and profitable mining sector.

Tanzania and Zambia are recognized for their rich mineral potential. The real challenge lies in educating and engaging local populations to build a competent and effective value chain from greenfield exploration to sustainable mining operations, while also navigating cultural and political landscapes.

Geological investigations of critical raw materials: a case study of manganese ore deposits in Zambia

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Manganese (Mn) is among the listed critical raw materials (CRMs) been sought for to support the global transition to renewable energy and green technologies. Its current exponential increase in demand is been necessitated by its use in the manufacture of rechargeable lithium-ion batteries (LiBs) for electric vehicles (EVs). Mn ore has, however, never been found as pure metal but in combination with other elements, diffused in varying quantities as oxides, silicates, carbonates, sulphides and phosphates. This mineral composition complexity can hamper efforts towards the exploration ore discoveries and beneficiation processes. Therefore, knowledge on the mineral compositions of the contemporaneous host rocks and minerals of Mn ores and how they occur is crucial. This study attempted to investigate Mn ores through field geology surveys, x-ray fluorescence (XRF), x-ray diffraction (XRD) and atomic absorption spectrometer (AAS) analyses.

Preliminary results show that the Mn ores; (i) occur in laterites and layered deposits; (ii) are laterally surrounded by shales and sandstones beneath; (iii) show the presence of minerals such as goethite, hematite and kaolinite in their host rocks. These characteristics are found in low temperature environments associated with the sedimentary deposits. Pyrolusite (MnO_2) and manganite (MnO(OH) are the dominant Mn ore with average concentrations ranging between 40 – 50%. So far, our findings reveals that the lateral extent of the Mn ores and other CRMs in the studied region is limited due to the previous exploration techniques that have been used during the search. Thus, to promote mapping of CRMs resource database, the study has scheduled to conduct both the deep-land and near-surface investigations using drone technology and geophysical methods. It is to be expected that the application of such technological innovations will unravel the potential presence of concealed and untapped CRMs deposits not only in Zambia but globally.

TIMREX: EIT-labelled T-shaped MSc program for innovative mineral exploration

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The European mineral exploration landscape is rapidly evolving, with Nordic and West Balkan countries emerging as key investment areas. However, a shortage of skilled personnel, particularly in the West Balkans, poses a significant challenge. To tackle this issue, a consortium comprising the University of Miskolc (Hungary), University of Zagreb (Croatia), Wroclaw University of Science and Technology (Poland), and Luleå University of Technology (Sweden) has developed TIMREX, an EIT-labelled joint master's program. TIMREX focuses on training future mineral exploration professionals, emphasizing state-of-the-art exploration techniques, innovation, entrepreneurship, and social responsibility. The curriculum integrates EIT Overarching Learning Outcomes (OLOs), emphasizing skills such as innovation, entrepreneurship, sustainability, leadership, and intercultural competences. Cross-organizational components such as an Exploration entrepreneurship course, Summer field camp, Internship, and internship foster these skills. TIMREX addresses the mineral demands of the European Green Deal, Critical Raw Materials Act and COP26 by focusing on innovative field techniques, advanced data processing, entrepreneurial mindset, and sustainability. Fieldwork modules, conducted in Northern Sweden, aim to cultivate practical skills through hands-on mapping campaigns and exploration simulations. Industry experts deliver presentations on exploration business models, social license to operate, research and development, success stories, and career development. The fieldwork module utilizes a flipped classroom approach, providing study materials online before the field mapping week, enriching the learning experience and preparing students for real-world mineral exploration teams.

Development of professional competence for geochemical and indicator mineral research in mineral exploration

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The mining industry is growing business in Finland. The most significant growth and strongest investment are focusing on eastern and northern Finland, and especially in the Central Lapland area. At the same time, there is increasing demand on educating staff for the exploration purposes in the northern, Arctic or sub-Arctic environments. To response the demand, there are several examples of education development programs having also strong practical approach.

The Oulu Mining School (OMS) of the University of Oulu provides a state-of-the art platform for mining related research and education. In OMS, a big portion of geoscientific education and teaching is related to economic and surficial geology, and use of them in mineral exploration. Basic geological and surficial geological teaching and research are supported by the applied geochemistry and geophysics. Furthermore, the unit has a strong research input and a practical approach. For example, thesis works are carried out networked projects with business and research institutes, where students can apply their skills to real research questions. Postgraduate studies and other research activities are international and multidisciplinary, and funded not only own core funding, but also various co-funded funding sources and assignments from companies.

Education and teaching are also including strong development aspect for maintaining professional competence in mineral exploration on different levels. For example, one of the developing projects was 'Development of competence for ore exploration and research' (METSO) funded by the European Social Fund and lead by the Lapland Education Centre REDU, Sodankylä. OMS participated to the project as a partner. An aim of the METSO project was to increase the technical know-how of subcontractors doing simple ore exploration, for example by providing sampling services, field pre-processing and analyses, to improve and expand their product range and thus add value to their products. During the project, the readiness of teachers at REDU was increased by giving professional geoscience education and producing teaching materials in the field of modern ore exploration, and by planning and piloting exploration projects and equipment procurement. Based on the competence needs of companies, locally offered degree components or entities consisting of already existing degree components were planned, for research assistant and technician who have readiness to work in challenging Arctic conditions and are experienced in modern field techniques in ore exploration.

Other example is a basic course for exploration the battery metals and critical raw materials as a part of continuous learning. The course is designed for people working in tasks related to the battery metal industry. The course material includes self-study, online lectures, and additional material, including basic knowledge of bedrock and surfing geology, as well as the principles of mineral exploration.

In addition, OMS is providing practical training course for field techniques in mineral exploration and economy geology. The course is planned as one-week training in the field including the basic steps of mineral exploration starting from the regional geological overview and GIS-based data interpretation to practices related to mapping, sampling and survey techniques commonly used in generative greenfield exploration campaigns in the glaciated terrains. The methodological practices are supported using on-site geochemical analysers, heavy minerals concentration and analytical techniques, surface geochemical methods, and geophysical survey methods. The course can be organised in cooperation with exploration companies.

The AGEMERA Online Lecture – Raising University Students' Awareness Regarding the Importance of Critical Raw Materials in Everyday Life

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The online lecture 'European Critical Raw Materials for the Green and Digital Transition' is designed to meet the growing need for educational resources that raise awareness of critical raw materials and their importance in everyday life. It also addresses the challenges associated with the digital and green transition, which are crucial for the future careers of aspiring scientists and engineers.

The online lecture, initiated by the academic partners of the AGEMERA project (EU grant agreement ID: 101058178), is hosted on the Opal online platform. The course is intended to complement the graduate and postgraduate curricula of students from TU Bergakademie Freiberg, Tallinn University of Technology, University of Oulu, University of Lapland and University of Zambia.

The course was designed for aspiring scientists and engineers who wish to pursue a professional career in the raw materials industry. Therefore, the content encompasses geological and engineering information while addressing geopolitical, economic, marketing aspects, as well as social and environmental aspects. Additionally, the course provides information on the UN Sustainable Development Goals, the UN Framework Classification for Resources, and the UN Resource Management System.

The lecture is divided into seven chapters, which contain mandatory course content for students. A special section within the course (chapter 8) provides non-mandatory bonus content for students interested in more in-depth information on the material presented and related topics.

Upon successful completion of Opal's automated online performance assessments and feedback to the course coordinators via an online questionnaire, participants will receive a certificate of attendance. This certificate, together with enrolment at TU Bergakademie Freiberg, is a prerequisite for being authorised to take a written (online) examination. For the written exam, representatives of each partner university formulate questions relating to the seven chapters. Upon successful completion of the written exam, participants are eligible to receive 3 credits through the European Credit Transfer and Accumulation System.

Due to its unique organisational approach, the course serves as an early example of how micro-credentials can be integrated into the educational system of the TU Bergakademie Freiberg.

Machine learning topic detection of social media attitudes about mineral development in Europe

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For reasons of both energy security and the green energy transition, the European Union has recently sponsored several initiatives that seek to understand and characterize the mineral resources of member states in order to prepare for independence in green energy development. Currently, Europe imports the vast majority of its critical minerals, including 85% of its niobium from Brazil, 93% magnesium from China, and 98% borate from Turkey (van Wieringen and Álvarez, 2022). Rare earth minerals are a particular risk-point for the EU's plans for green energy development, as the market is currently dominated by countries with a tenuous relationship with the west.

Within this context of necessity for reliably and sustainably sourced critical minerals, attitudes within Europe about mining and exploration vary widely and are sometimes contentious. Europe has some of the most robust environmental and social regulations in the world, and stakeholder opinions and attitudes are an extremely important check point on the road to critical mineral development. One significant example of the power of public opinion is the 2022 revocation of Rio Tinto's permit to mine Lithium in Serbia due to mass protests over environmental concerns. According to Reuters, this $2.4 billion project could supply up 90% of Europe's current lithium needs, if completed (Sekularac, 2022). This example highlights the importance of stakeholder opinion in decision-making around critical mineral exploration, characterization, and development.

One of the major difficulties in addressing stakeholder concerns is the fact that no population in monolithic in its opinion, and different sets of stakeholders have different and often competing priorities and values. To understand and address stakeholder concerns, it is necessary to identify not only what stakeholders are saying about a given project or industry, but also which stakeholders are saying it, how much they are saying it, which stakeholders disagree, and how much they disagree. To that end, the author uses a machine learning technique called latent Dirichlet allocation (LDA) to statistically identify topics of concern to stakeholders based on their stated opinions. These opinions may be stated within the context of an interview, written in a blog or news article, or posted on social media. In this presentation, results are presented from a study of social media opinions in four EU member states, including the Czech Republic, Portugal, Poland, and Finland. The LDA method is language agnostic, which allows for analysis to be performed on social media posted in the native language of the focal country and compared across the set. The concerns, issues, and topics detected from this analysis vary widely across the target countries, and range from resource nationalism to environmental concerns, to EU policy criticisms, to discussions of the green transition and future prospects of space mining. Understanding these topics and the stakeholder values they represent is crucial to determining EU mineral and industrial development going forward.

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