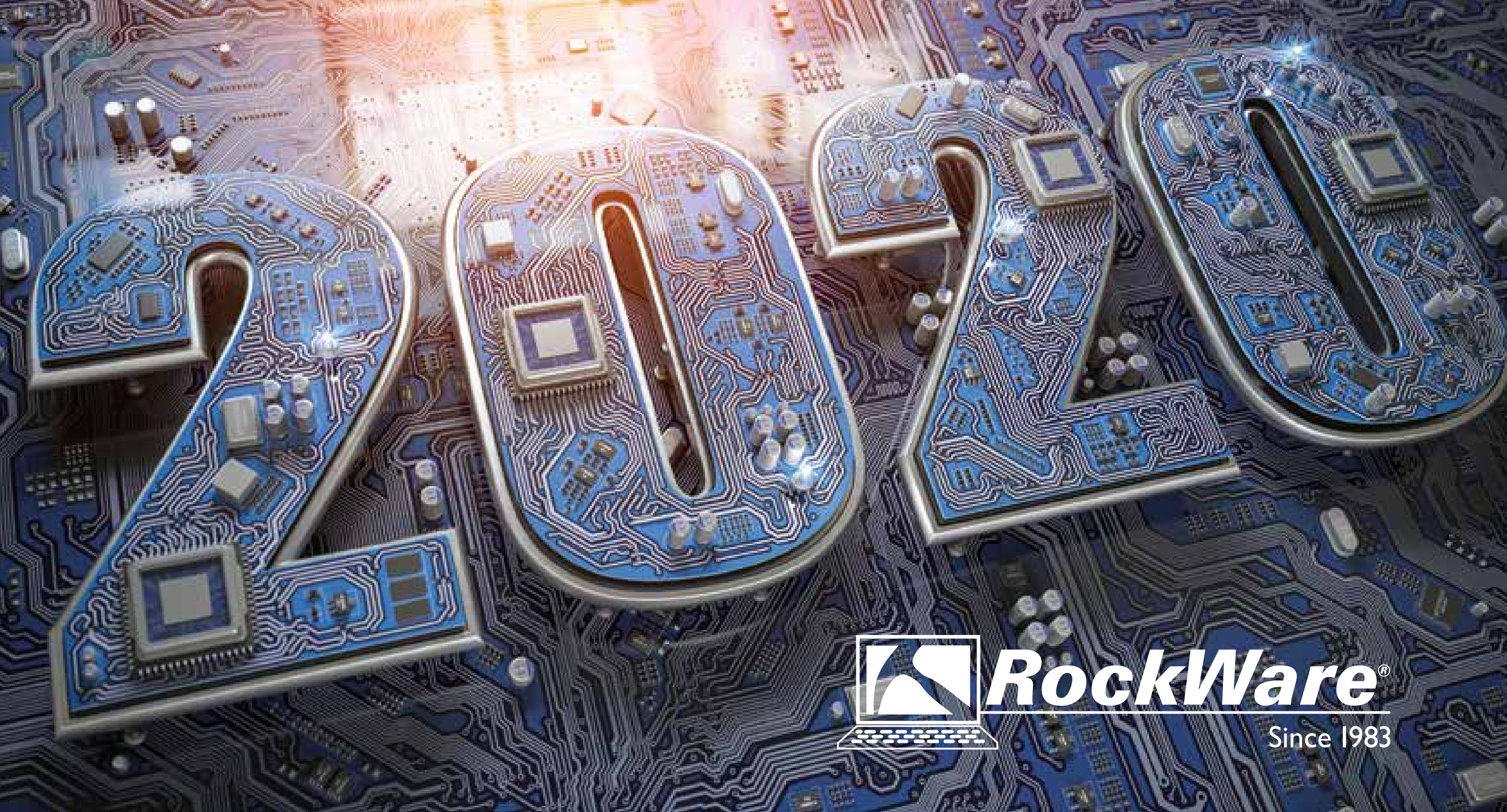
N° 49

May 2020

European Geologist

Journal of the European Federation of Geologists

Mineral raw materials in Europe - Chances and challenges for domestic production



What's New in RockWorks 2020®

Redesigned Interface with new items:

- Search option listing programs that include your search terms.
- Favorites option to list your frequently used programs within RockWorks.
- A "Full Expand" option to stretch the main RockWorks menu across multiple screens.
- Execution tab history to review program history and diagnose problems.
- Playlist tab to automate multiple tasks interactively.
- Borehole manager database comparison feature.
- Videos tab to access the entire library of RockWorks videos.

New Application Windows:

- Nested tab menus replace hard to read expanding/collapsing menu trees.
- Expanded time filtering now applied to most applications.
- Instruction checkbox now allows the user to enable/disable help messages.
- Playlist button allows the user to add the current application to the automated playlist.
- Output options now allows the user to export diagrams and reports directly to the desired output format.

General functionality, Data, Modeling and Display:

- New Playlist offers easy automation—just click a button to add a program to a Playlist. Then, click a button to run your Playlist to create models, maps, diagrams while you have lunch. Available for Basic (5 items), Standard (5 items) and Advanced (unlimited items).
- 2D, 3D and reporting programs now include output and export options that remove post-processing steps and facilitate uninterrupted Playlist scripting.
- RockWorks now supports over 5,800 coordinate systems.
- Time-Based Modeling in which a new T-Data Multiple Solids program automatically creates "snapshot" models at designated time intervals

Download FREE Trial at RockWare.com

37th ANNIVERSARY

Contents

We would like to express a particular thanks to all those who participated in the peer reviewing of this issue and thus contribute to the improvement of the standards of the European Geologist Journal. The content of this issue has been reviewed by Nikolaos Arvanitidis, János Földessy, Pedro Madureira, Manuel Regueiro, Giorgia Stasi and Thomas Seifert.

Cover photo:
© Roberto De La Rosa, HZDR, INFACT project 2019, https://www.infactproject.eu.

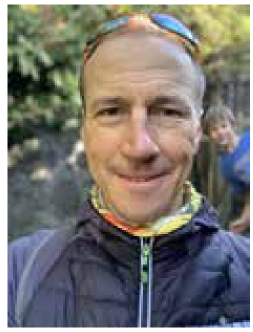
ISSN: 1028 - 267X

EUROPEAN GEOLOGIST

is published by the
European Federation of Geologists
C/O Service Géologique de Belgique
Rue Jenner 13
B-1000 Bruxelles, Belgium
Tel: +32 2 7887636
info.efg@eurogeologists.eu
www.eurogeologists.eu

Foreword

EurGeol. Marko Komac, EFG President



Dear Reader,

Welcome to another issue of the journal *European Geologist*! As always our journal strives to keep with the contemporary issues in the geoscience domain and wider areas that it impacts. Addressing the challenges of and discussing the potential approaches to solutions for domestic production of raw materials in Europe is by no doubt one of the more important issues and consequentially the issue of the EGJ you're reading just now is dedicated to the chances and challenges for production of mineral raw materials in Europe.

The necessity of critical raw materials (CRM) in Europe has been debated for quite some time and the irony is that the list has not been getting shorter through the years; instead, new raw materials are being added to the list and there are currently 27 of them. Europe's industry, being one of the biggest user of high-tech metals, steel alloy metals and REE, heavily depends on these raw materials and consequentially so do numerous jobs linked to it. Yet, the majority of CRMs need to be imported from outside Europe, as domestic contribution to the production of necessary, essential and critical raw materials is miniscule. According to the EC's European Green Deal (December, 2019), the access to critical raw materials used in digital and clean technologies is "a strategic security question". How the challenges related to the domestic raw mineral exploration and extraction will be addressed in the light of the European public acceptance constraints towards the mining industry raises numerous questions. The authors of the contributions to this issue of EGJ are addressing some of these questions from interesting perspectives, either from the financial and educational aspects, or through the versatile extraction and recovery opportunities Europe has, and finally with technological solutions and resources assessment.

I'm positive you'll find the 49th issue of *European Geologist* interesting and captivating, and maybe get inspired to contribute to the huge challenges our society is facing.

Marko Komac

Battery minerals from Finland: Improving the supply chain for the EU battery industry using a geometallurgical approach

Quentin Dehaine, Simon P. Michaux, Jussi Pokki, Mari Kivinen and Alan R. Butcher*

Battery raw materials (cobalt, lithium, graphite, and nickel) are essential for a technologically-advanced low-carbon society. Most of these commodities are produced in just a few countries, which leads to supply risk as well as environmental and ethical issues. Finland, with its available mineral resources (deposits and mines), industry (metallurgy, refining) and technical expertise (know-how, automation), has the ideal ecosystem to tackle the challenge of improving the rechargeable battery raw materials supply chain and securing sustainable sources for Europe. The profitable extraction of these commodities in a competitive market is a complex function of key ore properties that drive extraction process performance and are directly linked to deposit geology and ore mineralogy. Hence, geometallurgy – which combines geological and metallurgical information to improve resource management, optimise extraction, and reduce technical risks – is the key multidisciplinary approach to tackling the challenge of sustainable and responsible EU domestic production of battery raw materials.

Les matières premières de batteries (cobalt, lithium, graphite, nickel) sont essentielles pour une société technologiquement avancée à faible empreinte carbone. La plupart de ces matières premières sont produites dans une poignée de pays, ce qui entraîne des risques d'approvisionnement ainsi que des problèmes environnementaux et éthiques (minage artisanal, travail des enfants). La Finlande, avec ses ressources minérales (gisements et mines), son industrie (métallurgie, raffinage) et son expertise technique (savoir-faire, automatisation), dispose de l'écosystème idéal pour relever le défi de l'amélioration de la chaîne d'approvisionnement des matières premières nécessaires à la fabrication des batteries rechargeables et devenir une source durable de ces matières premières pour l'Europe. L'extraction rentable de ces dernières, dans un marché concurrentiel, dépend de certaines propriétés des minerais qui influencent la performance des procédés de valorisation et sont directement liées à la géologie et la minéralogie du gisement. Par conséquent, l'approche géométallurgique, qui combine les informations géologiques et métallurgiques pour améliorer la gestion des ressources, optimiser leur extraction et réduire les risques techniques, est l'approche multidisciplinaire clé pour relever le défi d'une production domestique européenne durable et responsable des matières premières de batteries.

Las materias primas usadas en baterías (cobalto, litio, grafito, níquel) son críticas para una sociedad tecnológicamente avanzada con tendencia a reducir las emisiones de carbono. La mayoría de estas materias primas se producen en un puñado de países, lo que conlleva riesgos de suministro y problemas ambientales y éticos (minería artesanal, trabajo infantil). Finlandia, con sus recursos minerales (depósitos y minas), su industria (metalurgia, refinación) y su experiencia técnica (know-how, automatización), tiene el ecosistema ideal para enfrentarse al desafío de mejorar la cadena de suministro de materias primas de baterías y garantizar una fuente sostenible de estas materias primas para Europa. La extracción rentable de estas materias, en un mercado competitivo, es una función compleja de ciertas propiedades minerales clave que determinan el rendimiento del proceso de extracción y están directamente asociados a la geología del depósito y la mineralogía del mineral. Por lo tanto, el enfoque geometalúrgico, que combina información geológica y metalúrgica para mejorar la gestión de recursos, optimizar su extracción y reducir los riesgos técnicos, es el enfoque multidisciplinario clave para enfrentar el desafío de una producción nacional europea sostenible y responsable en materias primas para la fabricación de baterías.

Introduction

With the "electric revolution" almost upon us, rechargeable batteries are likely to be the next key enabling technology for the transition towards a fossil fuel-free future for humankind. Batteries are essential for our high-tech devices (such as smartphones, tablets and laptops), our mobility through electric vehicles (EVs), and for our general energy supply (energy storage systems). The battery production industry will be challenged by predicted increased demand in the foreseeable future. While the vast majority of the batteries for EVs are currently manufactured in Asia, European car companies have expressed their interest in producing domestically with local battery manufacturing capabilities. Whilst more efficient recycling of materials will be achieved in the foreseeable future, as proposed by the concept of the circular economy, battery raw materials (*e.g.*, cobalt, lithium, graphite, and nickel), which represent about 50% of the costs of the battery cells, still need to be extracted from natural resources to meet

* Geological Survey of Finland (GTK), Espoo, Finland, quentin.dehaine@gtk.fi

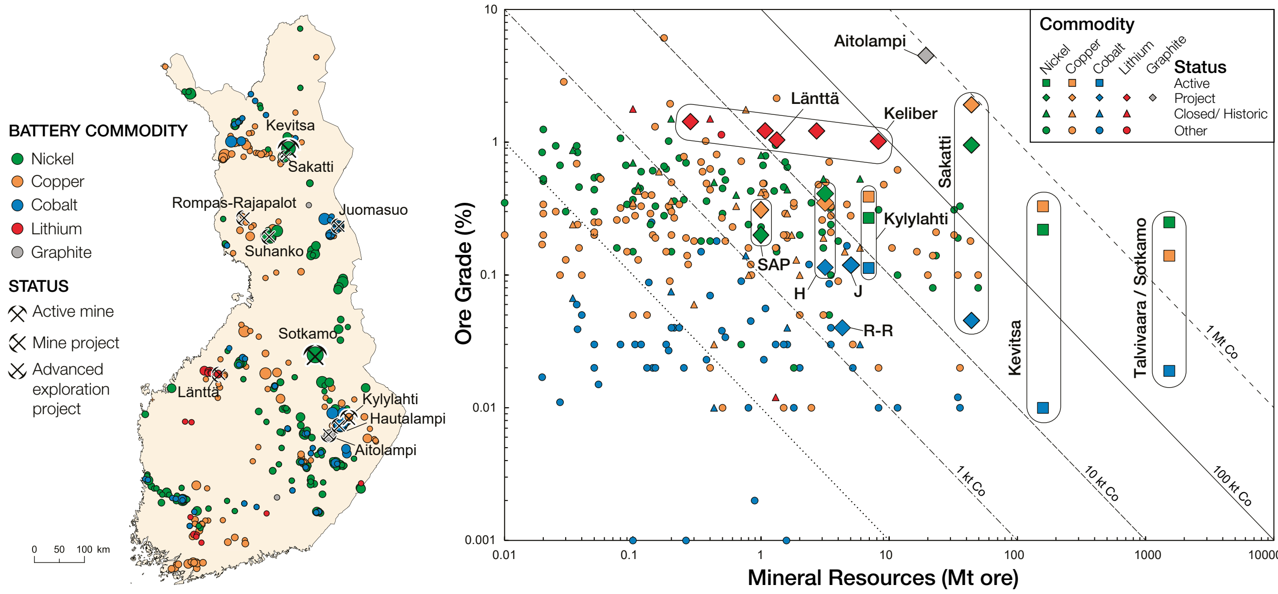


Figure 1: Finnish battery mineral deposits. Left: Map of the battery mineral deposits of Finland. Right: Resource grade-tonnage relationship by mining status with main operating mines and projects highlighted. H: Hautalampi, J: Juomasuo, R-R: Rompas-Rajapalot and SAP: Suhanko Arctic Platinum.

our growing societal needs. Raw material production has therefore an important role in enhancing the competitiveness of the European battery production. Currently the production of battery raw materials is concentrated in a few countries outside the EU, especially for cobalt and graphite, with about 70% of the global cobalt supply coming from the Democratic Republic of Congo (DRC) and 64% of the global graphite supply from China (USGS, 2020). Hence, the effective and efficient recovery of these minerals to supply the required battery ecosystem is fast becoming a strategic priority for Europe. Finland is one of the most important EU countries supplying battery raw materials to the EU market, meeting 66% of the EU demand for cobalt ores and concentrates and 16% of the demand for nickel (European Commission, 2018).

Battery minerals in Finland are found in a variety of mineral deposit types, often polymetallic, especially for nickel (Ni), copper (Cu) and cobalt (Co). To determine whether battery raw materials can be profitably recovered (as a main or by-product) from these deposits, one must assess three key factors: (i) the amount of material that can be mined and recovered as a marketable product; (ii) their typical recovery efficiency (which depends on the technologies used for recovery) and (iii) the relative costs and benefits of battery raw material (by-product) recovery (Mudd *et al.*, 2013). All of these factors are a complex function of key ore properties; they are directly linked to the deposit type and ore mineralogy and drive extraction process performance. These complex considerations can be linked through the development of integrated approaches supported by the discipline called *geometallurgy*. Geometallurgy could be considered as the next generation of mineral processing, where more effective recovery is achieved and a better understanding is reached of what waste products are produced. This allows more sophisticated stewardship of ore deposits and better management of waste, where future re-mining of tailings dams and waste dumps will be an activity in the circular economy.

The Finnish-based circular ecosystem of battery metals consortium (BATCircle), led by Aalto University, aims at improving the manufacturing processes of the mining industry, metals industry and battery chemicals, and increasing the recycling of lithium-ion batteries. The goal is to strengthen the cooperation between companies and research organisations in Finland and to find new business opportunities. Within this framework, the Geological Survey of Finland (GTK) is developing integrated solutions for Finnish battery mineral resources through the application of a geometallurgical approach to key battery minerals exploration projects in Finland.

The aim of this article is to present the Finnish battery ecosystem in terms of mineral resources and raw material production and introduce current developments to improve the battery raw material supply chain at the Finnish and EU level, through the example of the BATCircle and BATTRACE projects.

The battery ecosystem of Finland in brief

The Finnish battery ecosystem covers almost all the battery value chain with available battery mineral resources (nickel, copper, cobalt, lithium, and graphite) (Eilu, 2012); there is an active mining industry with operating mines extracting battery minerals, an active metallurgical industry (processing plants, smelters, refineries), as well as a growing manufacturing industry and internationally-renowned mining technology companies.

Battery minerals in Finland are found in a wide variety of polymetallic mineral deposit types (Eilu, 2012) such as: shale-hosted Ni-Zn-Cu-Co deposits (*e.g.*, Sotkamo); magmatic Ni-Cu-Co-PGE sulphides (*e.g.*, Kevitsa, Sakatti, Suhanko); Cu-Ni-Zn-Co(-Ag-Au) Volcanogenic Massive Sulphides (*e.g.*, Outokumpu area, Hautalampi); Li-pegmatites (*e.g.*, Syväjärvi, Länttä); Supracrustal-rock-hosted polymetallic Au-Co(-Cu) deposits (*e.g.*, Kuusamo belt, Juomasuo, Rompas-Rajapalot); and metamorphic graphite deposits (***Figure 1***, left). Most of these battery mineral deposits are small to medium-sized. However, large deposits (*e.g.*, Kevitsa, Sakatti, Aitalompi), and world-class deposits, such as the Ni-Zn-Cu-Co Sotkamo deposits (previously known as Talvivaara), also occur in Finland (***Figure 1*** and ***Table 1***). Nickel, copper and cobalt often occur together in polymetallic deposits, with Ni and Cu concentrations

Table 1: List of active battery raw material mines and projects in Finland with estimated total mineral resources (measured + indicated + inferred) and reserves (proved + probable), when available, obtained from company annual reports or website.

Operation Name	Deposit type	Main Commodities	Tonnage (Mt)	Grade (%)					Contained Metal (kt)					Current Owner	Stage
				Co	Ni	Cu	Li_2O	TGC[a]	Co	Ni	Cu	Li_2O	TGC[a]		
Sotkamo	Shale-hosted	Ni, Zn, Cu, Co	1525.0	0.02	0.25	0.14	-	-	290	3813	2135	-	-	Terrafame	Active
Sakatti[b]	Magmatic	Cu, Ni, Co, PGE	44.4	0.05	0.96	1.90	-	-	20	426	845	-	-	Anglo American	Project
Kevitsa	Magmatic	Ni, Cu, Co, PGE	297.5	0.01	0.23	0.33	-	-	31	695	977	-	-	Boliden	Active
Suhanko[b]	Magmatic	PGE, Au, Ni, Cu, Co	208.5	n/a	0.10	0.22	-	-	n/a	202	468	-	-	Suhanko Arctic Platinum	Project
Kaustinen area	Pegmatite	Li	23.6	-	-	-	1.04	-	-	-	-	246	-	Keliber Oy	Project
-Syväjärvi	Pegmatite	Li	4.8	-	-	-	1.17	-	-	-	-	56	-	Keliber Oy	Project
-Rapasaari	Pegmatite	Li	14.0	-	-	-	0.99	-	-	-	-	138	-	Keliber Oy	Project
-Länttä	Pegmatite	Li	2.4	-	-	-	0.97	-	-	-	-	24	-	Keliber Oy	Project
-Outovesi	Pegmatite	Li	0.5	-	-	-	1.27	-	-	-	-	6	-	Keliber Oy	Project
-Emmes	Pegmatite	Li	1.9	-	-	-	1.13	-	-	-	-	22	-	Keliber Oy	Project
Kylylahti[c]	VMS	Cu, Au, Zn, Ni, Co	0.5	0.16	0.25	0.33	-	-	1	1	2	-	-	Boliden	Closing
Hautalampi	VMS	Ni, Cu, Co, Au	5.4	0.10	0.44	0.38	-	-	5	24	20	-	-	Vulcan Hautalampi Oy	Project
Rompas-Rajapalot[b]	Orogenic (Hydrothermal, Metamorphic)	Au, Co	4.3	0.04	-	-	-	-	2	-	-	-	-	Mawson Resources	Project
Juomasuo[b]	Orogenic (Hydrothermal, Metamorphic)	Au, Co	5.0	0.12	-	-	-	-	6	-	-	-	-	Latitude 66 Oy	Project
Aitolampi[d]	Metamorphic	Graphite	19.3	-	-	-	-	4.50	-	-	-	-	878	Beowulf Mining plc	Project

[a] *Total Graphite Carbon ("TGC")*
[b] *Total mineral resources only*
[c] *Mineral reserves only as Boliden planned the mine closure for autumn 2020. Previous estimate (2018): 8.2 Mt @ 0.16 %Co, 0.27 %Ni and 0.8 4%Cu*
[d] *Indicated+ Inferred mineral resources only*

being an order of magnitude higher than that of Co, thus explaining its by-product status in currently active mining operations. Despite the wide heterogeneity between the distinct Ni-Cu-Co-hosting deposit types, there is a relatively small number of minerals that currently are or historically have been mined for these metals, like pentlandite ($(Fe,Ni,Co)_9S_8$), chalcopyrite ($CuFeS_2$), cobaltite (CoAsS) but also pyrite (FeS_2) which may contain significant proportions of cobalt and nickel.

Today in Finland there are ten active mines and exploration projects, at various stages of development, three of which (*i.e.*, Sotkamo, Kevitsa and Kylylahti) produce nickel, copper and cobalt concentrates, which are mostly refined locally to supply the EU market. The Boliden Kevitsa and Kylylahti mineral processing plants rely mainly on froth flotation to produce nickel and copper concentrates, following a typical process for magmatic Ni-Cu sulphide ores (Boliden, 2018), while the Sotkamo process is based on one-of-a-kind bio-heap leaching process. The latter is a unique and energy-efficient way to extract metals with about 40% less greenhouse gas emissions and 20% less energy consumption than the average for nickel production (Terrafame, 2018).

With four operating smelters and refineries (***Table 2***), Finland is the biggest nickel producer and the only country with its own cobalt production in the EU (European Commission, 2018). A range of battery materials is currently produced by these plants, notably nickel matte, cathodes, briquettes and salts, copper cathodes and cobalt chemicals. A Ni-Co sulphate plant is under construction by BASF in collaboration with Nornickel, while a lithium hydroxide plant is at the feasibility stage with Keliber Oy which will process concentrates from the company's own mines.

Although there have been efforts to attract large battery cell manufacturers to Finland, there is currently no large-scale battery cell fabrication plant in Finland

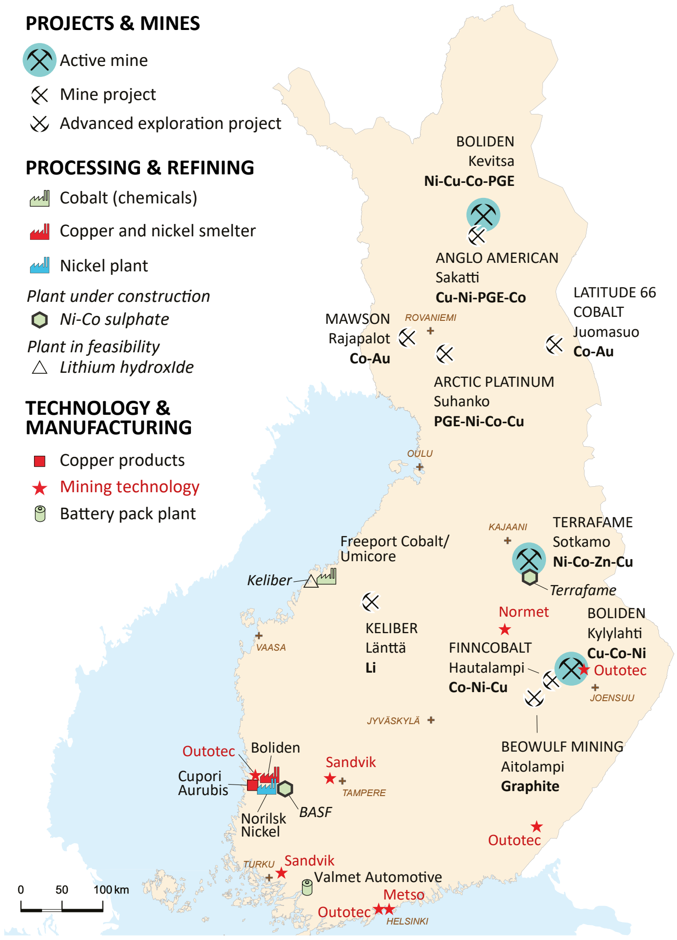


Figure 2: Overview of the Finnish battery ecosystem: battery mineral deposits, projects and mines, processing plants, smelters and refineries, as well as mining technology centres.

Table 2: List of active and future battery mineral refineries in Finland.

Industrial operation	*Main Commodity*	*Product(s)*	*Current Owner*	*Stage*
Kokkola	*Co*	*Cobalt chemicals and catalysts*	*Freeport/ Umicore*	*Operating*
Sotkamo	*Ni, Co*	*NiCoS mixed sulphide, Cu sulphide + Ni-Co sulphate*	*Terrafame*	*Operating + in extension*
Nornickel Harjavalta	*Ni, Cu, PGMs*	*Ni cathodes, briquettes & salts, Co chemicals*	*Norilsk Nickel*	*Operating*
Boliden Harjavalta	*Cu, Ni, Ag, Au*	*Cu cathode, Ni matte*	*Boliden*	*Operating*
BASF Harjavalta	*Ni, Co*	*Ni-Co sulphate*	*BASF*	*Under construction*
Keliber project	*Li*	*Li hydroxide*	*Keliber Oy*	*In feasibility*

(the European Battery factory in Varkaus closed in 2013). However, a new Li-ion battery assembly plant was launched in 2019 in Salo by Valmet Automotive to produce battery pack systems for EVs and moving machinery applications.

Figure 2 shows an overview of the Finnish battery ecosystem with mineral resources, chemical manufacturing plants and mining technology company offices and research centres. In addition to the aforementioned key assets, the strong R&D knowledge and know-how in the mining, chemical, and recycling industry, with notable mining and processing machinery manufacturers (Outotec, Metso) and access to cheap sustainable energy make Finland a potential platform for rechargeable battery manufacturing (Finnish Mineral Group - FMG, 2018) and one of the top locations in the world for mining investments (Stedman *et al.*, 2019). According to the FMG, Finland has the potential to meet the material needs of one large electric vehicle battery (EVB) factory, producing precursor and active cathode materials for the batteries of over 500,000 EVs annually.

Geometallurgy to improve the battery raw material value chain

Geometallurgy: What and why?

Geometallurgy is a multi-disciplinary approach that links geological, mining and metallurgical information to improve resource management, optimise process performance, and reduce technical risks (Lund and Lamberg, 2014). Geometallurgy systematically integrates planning practices to maximise resource efficiency of future or existing mining operations to create a spatial model for production planning and management (Dehaine *et al.*, 2019; Michaux and O'Connor, 2020). It also incorporates the principles of process mineralogy and material characterisation as tools for predictive metallurgy (Bowell *et al.*, 2011). Geometallurgy is an evolutionary step forward in mineral processing, where the process behaviour of minerals can guide engineering design. The competitive edge that geometallurgy provides is related to the dynamic relationship between different ore types and the target process response. The outcome is an understanding as to what minerals control which process response, and why poor recovery might happen. This allows more proactive planning in design and operation.

There are three main methods used for battery minerals extraction - physical separation (gravity, magnetic); flotation and hydrometallurgy. The processes involved and the flowsheets employed are typically unique to each deposit and ore type. Mineralogy is the main, if not the most important, geometallurgical ore property, as it drives the ore processing requirements (e.g. leaching vs flotation, leaching agent, flotation collector, etc.). However, mineralogy is not the only characteristic of interest. Indeed, there are other geometallurgical ore properties that influence process performance, such as: physical properties of the ore (hardness, grindability, and particle size), which control comminution behaviour and ore reactivity; gangue mineralogy, which

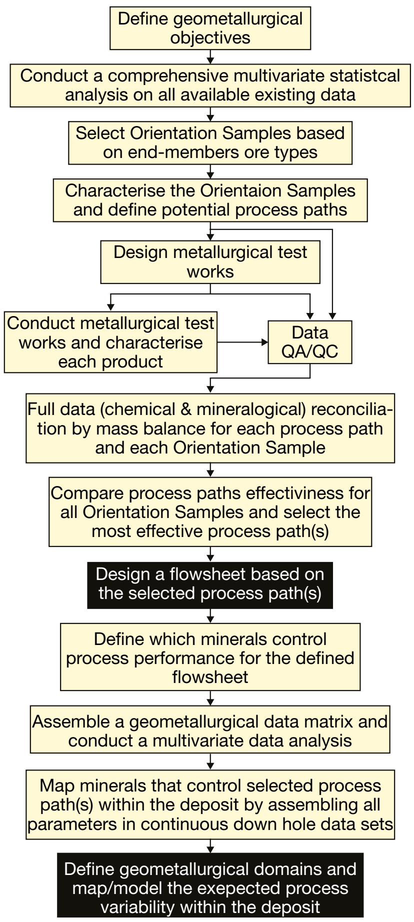


Figure 3: Simplified BATCircle geometallurgical program workflow.

influences acid consumption and flotation performance; mineral associations and liberation of metal-bearing minerals, which control their susceptibility to leaching and flotation; and the amount of impurities, which may reduce final product quality. These geometallurgical properties can be the determining factor for the selection of the processing route (flotation vs leaching) since they directly affect operating costs and recoveries of hydrometallurgical projects.

BATCircle: A geometallurgical program for battery mineral deposits

As mentioned before, the BATCircle project has been designed to be based around the concept of a Circular Ecosystem of Battery Metals. One main task of the project is the development of a geometallurgical program for battery mineral resources of Finland for which two case studies have been selected, the Rompas-Rajapalot Au-Co and Suhanko PGE-Au-Ni-Cu-Co projects. A concept or protocol was developed for each deposit type, set of geological and mineralogical characteristics, and acquired raw material specification requirements (***Figure 3***).

The basic experimental procedure for the geometallurgical programs is structured as follows:

1. **Define geometallurgical objectives** and assess all the available data from the deposit to date in terms of geology, mineralogy and process test characterisation. **Conduct a comprehensive multivariate statistical study** on all available data.
2. **Select a number of samples that show end-member ore types** (Orientation Samples). These samples should reflect the variety of mineralogy and textures encountered within the deposit at their extremes. This means that any other ore sample could be in theory regarded as a combination of these extreme ore types as far as their metallurgical response is concerned.
3. **Characterise each Orientation Sample** in terms of commercial chemistry (target metal grades, penalty elements) and mineralogy (mineral grades, grain sizes, liberation and associations). **Define potential process paths** based on characterisation results.
4. For each Orientation Sample, **conduct a series of metallurgical tests** (gravity separation, flotation, leaching) that could be made up into several parallel process paths. **Characterise the products of each test** with the same methods used to characterise the process test products in context of the relationship between the Orientation Study and the following Mapping Study.
5. For each Orientation Sample, and for each process path, a **full data reconciliation is done**. This includes **a mineralogical reconciliation** to determine what minerals separated into what product stream. This will establish the mineralogical controls over process behaviour for each separation process.
6. Then **compare all the process separation methods and all process paths for all Orientation Samples**. Assess which process path is the most effective in the context of multiple target metals. Trade-off comparisons between polymetallic recovery process paths can then be made in engineering and economic contexts, where mineralogy defines the outcome. **Select the best process paths** that yielded the best performance and that would recover the most economical combination of target elements. Of these process paths, select the one considered to be the final best result to design the process flowsheet.
7. For the Orientation Samples, **define what minerals controlled the most effective process paths**. These minerals will form the basis of the Mapping Study.
8. **Assemble all the available geological, mineralogical and metallurgical data in a geometallurgical data matrix** and **conduct a multivariate data analysis**, focusing on the target minerals from Step 7. Assess the statistical structures and relationships for each target mineral. Then assemble all parameters that control and influence the selected process paths into a continuous down-hole setting on individual drill cores into one single data matrix.
9. **Use cross-correlation of different data types to define domains of process behavior.** In doing so, **geometallurgical domains can be defined** and process response variability can be quantified.

For each case study, the above geometallurgical program will provide (i) an understanding of what mineralogy controls process separation behaviour of battery minerals, (ii) an estimate of the best engineering process path for each target valuable mineral/metal in each ore type, and then for all ore types together, (iii) an estimate of the best engineering process path for several valuable minerals/metals and (iv) a geometallurgical experimental procedure to study battery minerals.

Overall, the expected outcomes of the BATCircle project are:

- A comprehensive assessment of Finnish battery metal deposits, including polymetallic (e.g. Ni-Co-Cu), lithium and graphite deposits, not limited to tonnage and grades but including mineralogical and geometallurgical information with an emphasis on mineralogical properties that have a significant effect on the processing methods;

- A geometallurgical experimental and analytical procedure, a decision making methodology for battery mineral ores, and a geometallurgical library for the tested deposit types that can later be expanded;
- A strategic development plan for the development of Finnish battery mineral resources in a complete battery ecosystem. This can be used as a tool to support planning e.g., government initiatives supporting the ecosystem or business development planning.

Responsible sourcing

Ensuring sustainability all along the raw materials value chain has been a growing concern for the mining industry in recent years, especially in Europe. Achieving competiveness through sustainability is one of the key potential advantages of Europe. Raw materials traceability along the supply chain – from exploration, discovery, mining, to downstream uses – is a prerequisite to sustainability certification and compliance.

Currently, the vast majority of the world's cobalt supply is produced in the Democratic Republic of Congo (DRC) as a by-product of copper. According to the Government's own estimates, 20% of the cobalt currently exported from the DRC comes from artisanal mining in the southern part of the country, which often involves child labour (Amnesty International, 2016). Through independent traders this cobalt is then sold on to larger China-based companies via their local subsidiaries, which then supply some of the world's leading electronics companies, making cobalt likely to become a conflict mineral in the foreseeable future. Hence, fingerprinting battery raw materials, cobalt in particular, throughout the value chain would help improve their traceability and thus their responsible sourcing.

The BATTRACE project, currently in development, is exploring options for improving the traceability of battery raw materials at various stages of the value chain (from ore to product) using mineralogical and geochemical fingerprints (***Figure 4***). In terms of potential solutions that could help improve traceability of battery raw materials, a number of projects using digital technologies such as Blockchain or QR codes to control provenancing are being explored (RCS Global, 2017). However, these approaches are costly in terms of computing power and face technical challenges related to corruptible data input, with complex points of aggregation, mixing and processing, thus making the control of material flows challenging. Geochemical and mineralogical fingerprints, on the other hand, cannot be easily corrupted as they are often unique and inherent to the ore deposit type and location. For example, intrinsic mineralogical, geochemical and trace element contents in minerals can be used to discriminate between ore deposit types (Dupuis and Beaudoin, 2011). However, these fingerprints become less distinctive once mineral processing, metallurgy and other downstream steps of the supply chain proceed. In archaeometallurgy, for example, provenancing of raw materials used to manufacture tools can be established using trace elements patterns and lead isotopes ratios (Pernicka, 2014). Regardless of the processes involved in the treatment of ores (roasting, smelting, alloying or dissolution), the isotopic composition remains constant, making it an ideal fingerprint for metal sourcing. Such an approach has been successfully applied to conflict minerals in Africa (coltan, tin) but limited to ores and concentrates, i.e., upstream supply chain (Melcher *et al.*, 2008).

The battery minerals resources of Finland offer a source of sustainable and responsible battery raw materials that could reduce the dependence of the EU on importation for some battery raw materials. However, for those raw materials that cannot be produced in sufficient amounts, there is clearly an urgent need to embrace these ideas and move towards more transparent and traceable raw materials flows along the battery raw material value chain. In this context, the BATTRACE project is being developed to improve the traceability of battery raw materials and therefore enhance sustainability and responsibility issues connected to their production and gain a competitive advantage.

Conclusion

Finland, with its available mineral resources (battery mineral deposits and operating mines), metallurgical industry (processing plants, smelters, refineries), and its technical expertise (know-how, automation, low-price clean energy), has the ideal ecosystem to tackle the challenge of improving the battery raw materials supply chain and securing a sustainable, conflict-free, source for Europe.

From battery mineral hosting rocks to a final battery product (*e.g.*, cathodes) different types of materials (*e.g.*, ores, minerals, metals) flows are treated all along the value chain, and each of these materials is characterised by key different properties (***Figure 4***). Quantifying the relationships between these properties at the different stages of the

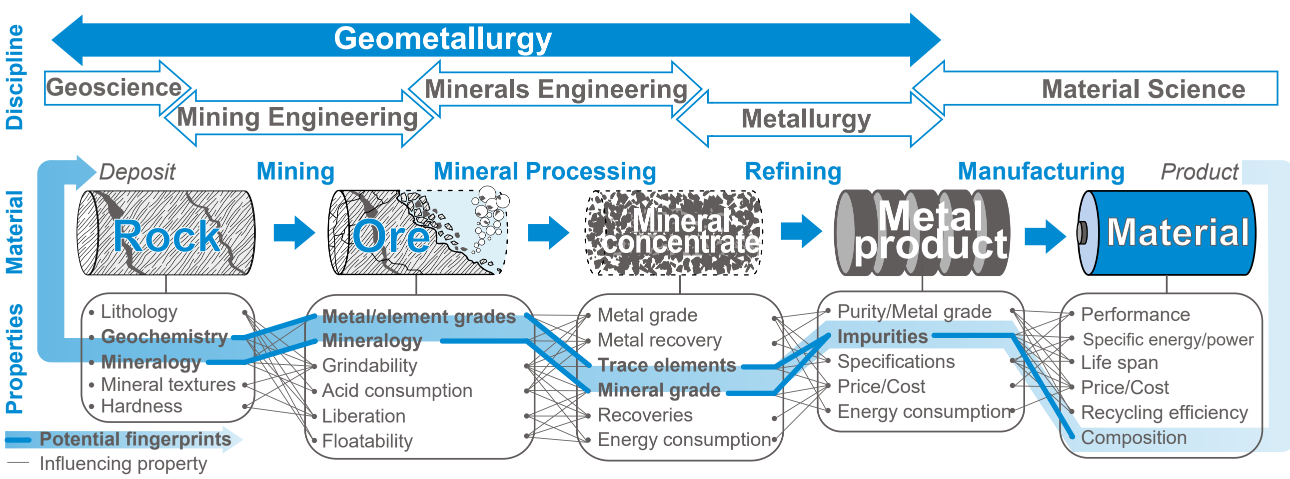


Figure 4: Geometallurgy: an integrated approach for optimisation and traceability along the battery materials value chain.

value chain through the application of an integrated geometallurgical approach will allow the optimisation of the whole mine value chain and the battery materials supply chain. Some of the properties (*e.g.*, trace elements, isotopes) may have the potential to be used as fingerprints to trace the origin of the battery materials at different stages of the value chain. Ongoing projects like BATCircle and BATTRACE seek to apply this integrated approach to optimise the battery supply chain using the Finnish ecosystem. This will support efficient as well as sustainable and responsible production through tracing battery materials all along the value chain.

Acknowledgments

This research has been undertaken as part of the Finland-based circular ecosystem of battery metals consortium (BATCircle) project [Grant No. 4853/31/2018] funded by Business Finland (website: ***https://www.batcircle.fi***) as well as the Business Finland Co-Innovation project BATTRACE on battery raw materials traceability [Grant No. 1019/31/2020].

References

Amnesty International, 2016. This is what we die for: Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt. Amnesty International. URL ***https://www.amnesty.org/download/Documents/AFR6231832016ENGLISH.PDF***

Boliden, 2018. Boliden Summary Report, Kevitsa Mine. URL ***https://www.boliden.com/globalassets/operations/exploration/mineral-resources-and-mineral-reserves-pdf/resources-and-reserves-kevitsa-2018-12-31.pdf***

Bowell, R.J., Grogan, J., Hutton-Ashkenny, M., Brough, C., Penman, K., Sapsford, D.J., 2011. Geometallurgy of uranium deposits. *Minerals Engineering* 24, 1305–1313. DOI: 10.1016/j.mineng.2011.05.005

Dehaine, Q., Filippov, L.O., Glass, H.J., Rollinson, G.K., 2019. Rare-metal granites as a potential source of critical metals: A geometallurgical case study. *Ore Geology Reviews* 104, 384–402. DOI: 10.1016/j.oregeorev.2018.11.012

Dupuis, C., Beaudoin, G., 2011. Discriminant diagrams for iron oxide trace element fingerprinting of mineral deposit types. *Mineralium Deposita* 46, 319–335. DOI: 10.1007/s00126-011-0334-y

Eilu, P., 2012. Mineral deposits and metallogeny of Fennoscandia, Geological Survey of Finland Special Paper 53. Geological Survey of Finland, Espoo, Finalnd.

European Commission, 2018. Report on Raw Materials for Battery Applications, Commission Staff Working Document.

Finnish Mineral Group, 2018. Finland & battery production [WWW Document]. Finnish Mineral Group website. URL ***https://www.mineralsgroup.fi/battery-mining-ecosystem/finland-battery-production.html*** (accessed 3.10.20).

Lund, C., Lamberg, P., 2014. Geometallurgy – A tool for better resource efficiency. *European Geologist* 37, 39–43. DOI: 10.1039/C4SM02815E

Melcher, F., Sitnikova, M.A., Graupner, T., Martin, N., Oberthür, T., Henjes-kunst, F., Gäbler, E., Gerdes, A., Brätz, H., Davis, D.W., Dewaele, S., Groves, D.I., 2008. Fingerprinting of conflict minerals: columbite-tantalite ("coltan") ores. *SGA News* 23, 1–13.

Michaux, S., P., O'Connor, L., 2020. How to Set Up and Develop a Geometallurgical Program, GTK Open Work File Report 72/2019, ISBN 978-952-217-409-3

Mudd, G.M., Weng, Z., Jowitt, S.M., Turnbull, I.D., Graedel, T.E., 2013. Quantifying the recoverable resources of by-product metals: The case of cobalt. *Ore Geology Reviews* 55, 87–98. DOI: 10.1016/j.oregeorev.2013.04.010

Pernicka, E., 2014. Provenance Determination of Archaeological Metal Objects, in: Roberts, B.W., Thornton, C.P. (Eds.), *Archaeometallurgy in Global Perspective: Methods and Syntheses.* New York: Springer- pp. 239–268. DOI: 10.1007/978-1-4614-9017-3

RCS Global and ICMM. 2017. Blockchain for Traceability in Minerals and Metals Supply Chains: Opportunities and Challenges. London. URL ***https://www.icmm.com/blockchain-in-minerals-and-metals-supply-chains***

Stedman, A., Yunis, J., Aliakbari, E., 2019. Fraser Institute Annual Survey of Mining Companies 2019. Fraser Institute. ***https://www.fraserinstitute.org/sites/default/files/annual-survey-of-mining-companies-2019.pdf***

Terrafame, 2018. Production methods. Terrafame website. ***https://www.terrafame.com/production-methods.html*** (accessed 3.10.20).

USGS, 2020. Mineral Commodity Summaries 2020. United States Geological Survey. DOI: 10.3133/mcs2020

The Zinnwald Lithium Project: Transferring legacy exploration data into new mineral resources

Thomas Dittrich[1], Matthias Helbig[2], Kersten Kühn[2], Wolf-Dietrich Bock[3] and Armin Müller[1]*

The Erzgebirge represents one of the most important metallogenic provinces in Europe and was mined for various metals (i.e. Ag, Sn, U) over centuries. All mining activities were abandoned in the early 1990s, but recent technological and geopolitical developments have brought the Erzgebirge back into the focus of the raw material sector. The leucogranite hosted greisen deposit Zinnwald, historically mined for Sn and W, was systematically explored between 1945 and 1989. Despite the massive presence of the lithium mica Zinnwaldite, its raw material potential remained unused. The combination of legacy data and results of recent exploration (2012-2019) demonstrates that the deposit hosts significant Li resources (35.5 Mt averaging 3,500 ppm Li) and thus has the potential to contribute substantially to the domestic production of Germany.

La région d'Erzgebirge qui représente l'une des provinces métallogéniques les plus importantes d'Europe a fait l'objet de travaux miniers pendant des siècles, pour l'exploration de différentes substances métalliques (i.e. l'Argent, l'étain, l'uranium). Toutes les activités minières ont cessé au début des années 1990 mais de récents développements technologiques et géo-politiques ont réactivé le secteur des matières premières. Le leucogranite qui hébergeait l'ancien gisement de Zinnwald, historiquement exploité pour l'étain et le tungstène, fut alors exploré systématiquement entre les années 1945 et 1989. Malgré la présence massive du mica à lithium (Zinnwaldite), son potentiel en matières premières est resté inutilisé. La mise en commun des données d'exploration, historiques et récentes (2012-2019), montre que le gisement renferme des ressources de lithium significatives (35.5 MT avec en moyenne une concentration de 3 500 ppm de lithium) et donc capables de contribuer de manière substantielle à la production nationale allemande.

El Erzgebirge representa una de las provincias metalogénicas más importantes de Europa en la cual se extrajeron varios metales (Ag, Sn, U) durante siglos. Todas las actividades mineras fueron abandonadas a principios de la década de 1990, pero los recientes desarrollos tecnológicos y geopolíticos han llevado al Erzgebirge nuevamente al foco del sector de las materias primas. El leucogranito greisen alojado en el depósito Zinnwald, históricamente extraído para la obtención de Sn y W, fue explorado sistemáticamente entre 1945 y 1989. A pesar de la presencia masiva de la beta de litio Zinnwaldite, su potencial como materia prima no llego a ser explotada. La combinación de los datos heredados y los resultados de la exploración reciente (2012-2019) demuestra que el depósito alberga importantes reservas de Li (35,5 Mt con un promedio de 3.500 ppm de Li) y, por lo tanto, tiene el potencial de contribuir sustancialmente a la producción nacional de Alemania.

Introduction

Mining in the Erzgebirge has a long tradition and can be traced back to the Bronze Age (Tolksdorf *et al.* 2019). The region hosts numerous ore deposits that were important raw material sources for Fe, Sn, Ag, Cu, Co and later also Zn, Pb, and U in Saxony and the entire Central German region for several centuries (Baumann *et al.* 2000). During this time span the mining industry went through six main mining periods, whose new technological developments led to a change in the demand for individual commodities and thus to greenfield and brownfield exploration with the discovery of new deposits or the reactivation of existing ones. This was also the case in the Eastern Erzgebirge. Historically, the known greisen ore deposits of this region (e.g. Zinnwald/Cínovec, Altenberg, Sadisdorf) were initially an important source for Sn (1300-1800) (Schilka 1991). In the course of the development of the steel industry (19th century), W became increasingly important. Both metals remained the principal mining targets until the beginning of the 1990s, when economic conditions led to the shut down and closure of all ore mines within the region (Schilka 1991; Baumann *et al.* 2000).

However, recent trends show unequivocally that usage of renewable energy is an energy-, climate- and socio-political necessity. The resulting demand for battery storage capacity triggered by the growth of electromobility was the key driver for a very strong increase in demand of lithium (***Figure 1***) (SignumBox 2019). Lithium supply is currently dominated by the four

[1] Deutsche Lithium GmbH, Am St. Niclas Schacht 13, 09599 Freiberg
[2] G.E.O.S Ingenieurgesellschaft mbH, Schwarze Kiefern 2, 09633 Halsbrücke
[3] Consulting Geologist, Berliner Strasse 112, 79211 Denzlingen
[*] thomas.dittrich@deutschelithium.de

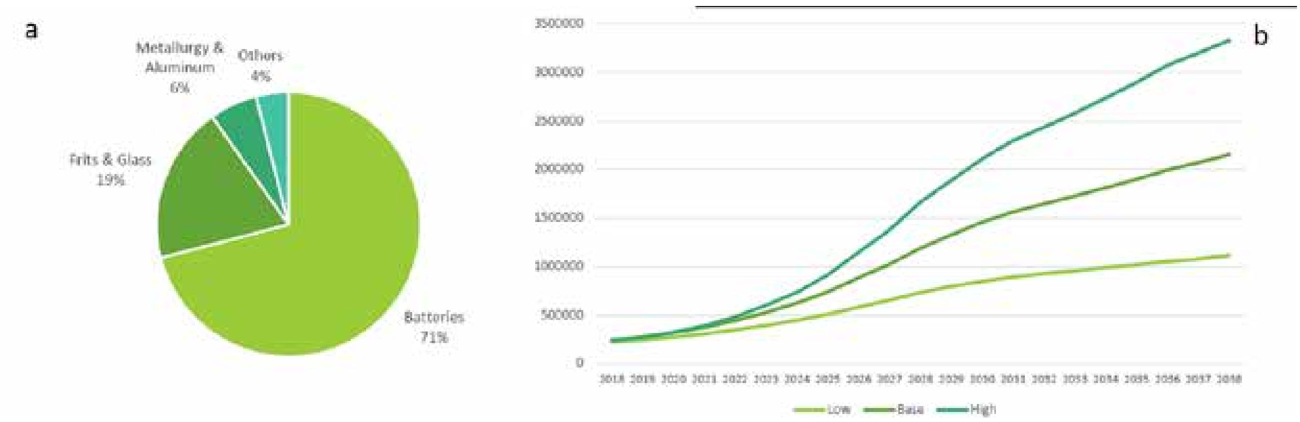


Figure 1: Lithium market. a: Lithium consumption by application in 2018. b: Estimation of total lithium demand, t/LCE (SignumBox 2019).

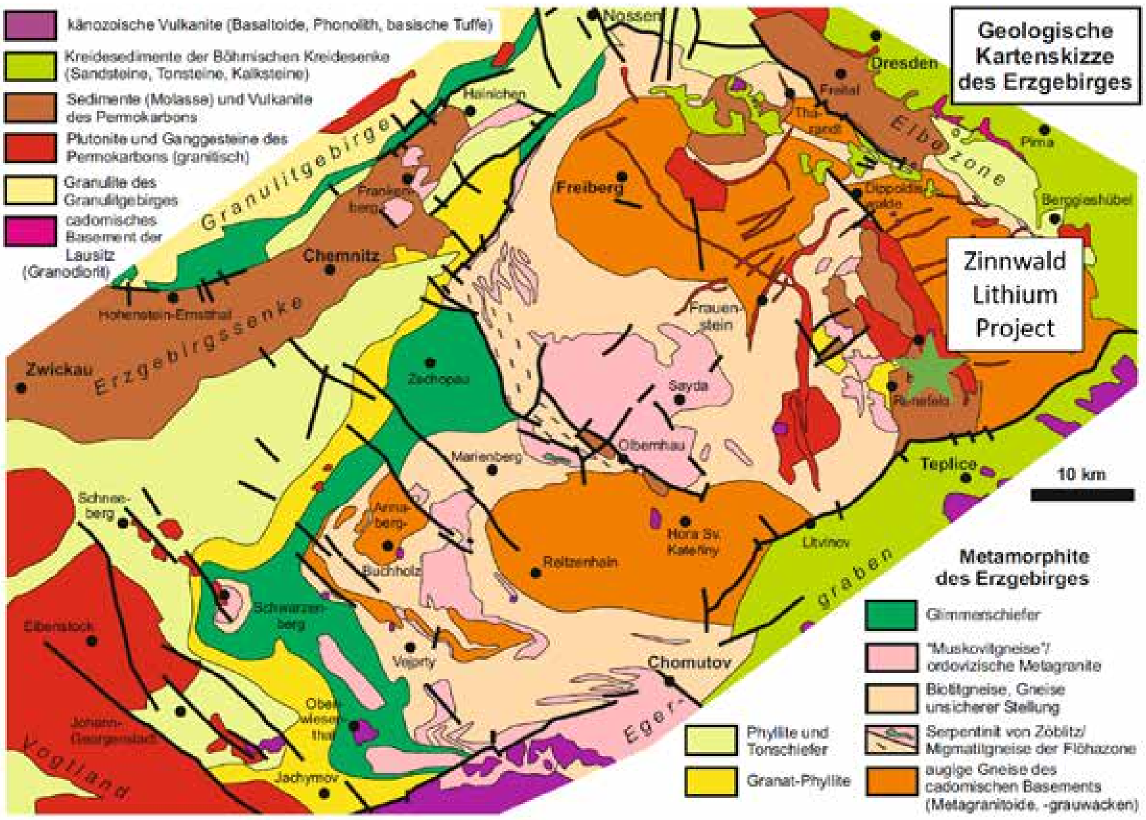


Figure 2: Schematic geological map of the Erzgebirge (modified after Sebastian 2013).

producers Tianqi, SQM, Albermale and FMC, who jointly account for an estimated 56 % of forecast global lithium production in 2019. Due to the current oligopolistic market and the simultaneous rapidly increasing demand for lithium compounds, a stable and secure supply from the free market cannot be guaranteed.

This possible supply shortfall can be filled either by expanding existing capacities or by commissioning new deposits. However, with regard to other unforeseen influences, such as the breakdown of supply chains due to political crises (e.g. trade disputes, wars) or the spread of unknown infectious diseases (e.g. coronavirus), closing this supply gap poses major challenges for a country's industry. In order to mitigate the latter effects, it can be an advantage if a part of the demand can be met by local raw materials that are accessible at all times.

The Eastern Erzgebirge is a region with well-developed infrastructure, services, facilities and access roads. Beside cassiterite and wolframite, as major sources of Sn and W, lithium mica minerals like zinnwaldite as the principal host of Li are essential components of the leucogranitic greisen ore deposits within the Eastern Erzgebirge. Consequently, the region has again become a focus of exploration.

Intensive exploration work in the second half of the 20th century was primarily focused on the economically important Sn; lithium mica mineralisations were discovered as by-product. Neither a final assessment of the exploration data in order to estimate the overall lithium potential of the region nor the estimation of Li mineral resources and reserves were undertaken at that time. However, although the area of the Eastern Erzgebirge must be considered as

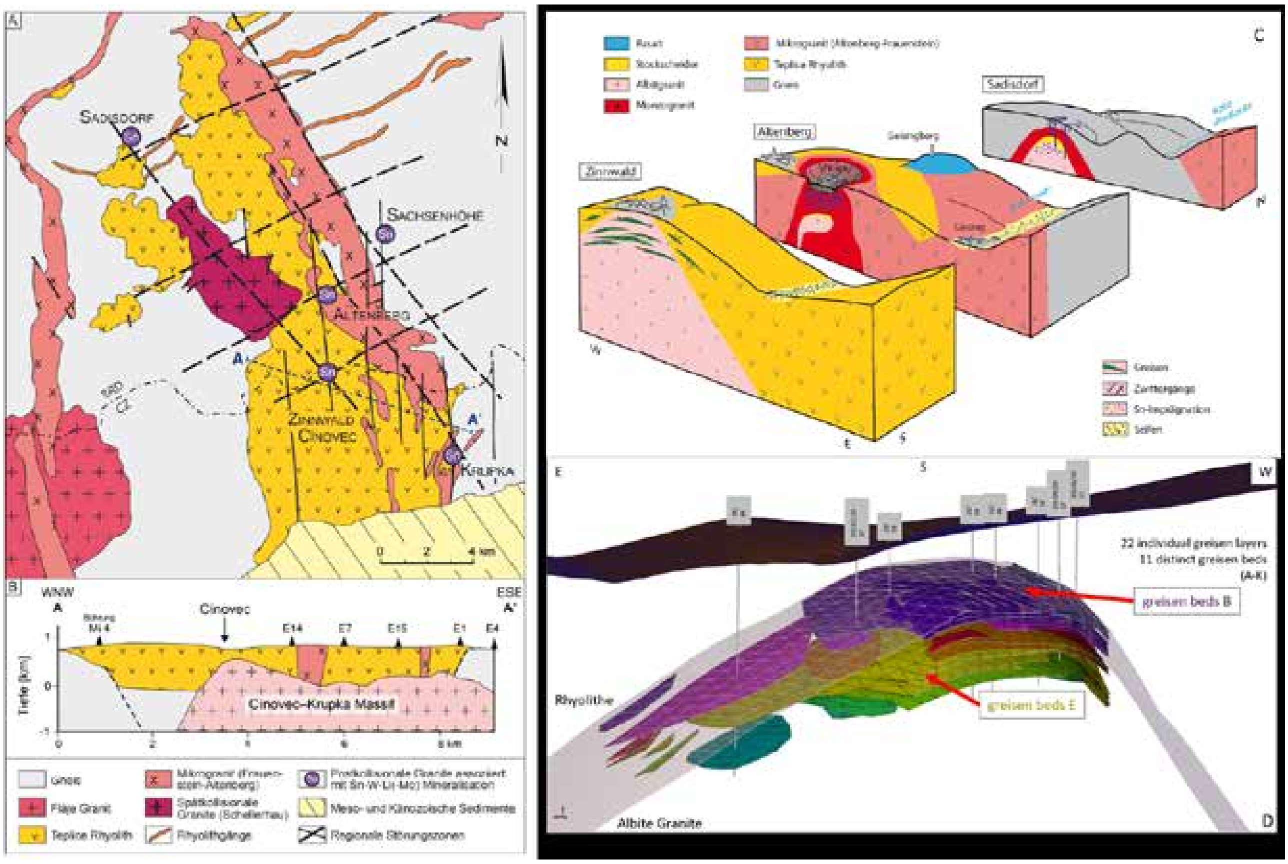


Figure 3: Geology and structures of the Li-Sn-W deposit Zinnwald. A) Schematic geological map of the south-eastern Eastern Erzgebirge (Altenberg-Teplice-Caldera, modified from Neßler et al. 2017 according to Seifert and Kempe 1994). B) Geological section along the line A-A' (modified by Neßler et al. 2017). C) Schematic E-W sections through the tin deposits of the Eastern Erzgebirge (modified after Sebastian 2013). D) Spatial location of the individual greisen ore bodies (Bock et al. 2020).

underexplored with regard to Li and needs to be re-evaluated, it shows considerable potential to serve as a domestic source for Li.

Among the known sites, the border crossing albite granite dome of Zinnwald/Cínovec is one of the most promising Li-Sn-W greisen ore deposits. Historic underground mining activities on Sn have been reported since the second half of the 15th century.

Based on a Li research network project at the TU Bergakademie Freiberg (Seifert and Gutzmer 2010) in 2010 Solarworld Solicium GmbH (SWS) and from 2017 its legal successor Deutsche Lithium GmbH (DL) carried out an in-depth exploration of Li in the German part of the deposit Zinnwald/Cínovec. The aim of the exploration was the estimation of mineral resources that meet the requirements of modern internationally accepted standards such as the Canadian NI43-101 standard. This paper addresses the evaluation of legacy data sets and their combination with new exploration data with a view to present a resource estimate that meets the required standards of resource reporting.

The Eastern Erzgebirge lithium province

The Li-Sn-W greisen deposit Zinnwald/Cínovec is located in the Eastern Erzgebirge/Krušné hory. This crustal unit represents the northernmost extension of the Bohemian Massif, which was formed as a result of the collision of Gondwana and Laurussia during the Variscan Orogeny (***Figure 2***) (Sebastian 2013). Its geological structure is characterised by a crystalline basement comprising Proterozoic and Palaeozoic lithologies which were intruded by various pulses of post-kinematic magmatites belonging to the Erzgebirge/Krušné hory Batholiths. This late Variscan magmatism was accompanied by widespread volcanic activity, of which the formation of the Altenberg-Teplice Caldera is one of the most important events. The Altenberg Teplice Caldera is a large elliptical collapse structure (approx. 35 by 22 km wide) that hosts a thick volcanic succession and several phases of granitic intrusions. The model of deep fault zone-related small intrusions of Li-F granites and associated Sn-W-Mo-Li ore deposition in the (eastern) Erzgebirge (see ***Fig. 3a***) discusses also the influence of mantle-derived magmatic pulses (Seifert and Kempe 1994; Seifert 2008).

At or near intersections of these tectonic zones the crystalline basement in the Eastern Erzgebirge is intruded by different late-Variscan acidic melts. The first major magmatic pulse (330-324 Ma) formed a stock-like intrusion with steep flanks (e.g. Niederbobritzsch Granite, Flajé Granite) and immediately was followed by a second major pulse at 324–318 Ma. However, as these melts represent low temperature melts (Helbig *et al.* 2019) they are not highly differentiated, as is evident from a geochemistry exhibiting only low contents of Sn, W, and Li.

In contrast, high temperature melts that were not able to penetrate the gneissic basement could fractionate and thus were enriched in Sn, W and Li and other granitophile elements. Those melts were trapped below the basement until its collapse at 320–318 Ma and the formation of the Altenberg-Teplice Caldera. The highly fractionated melts then could ascend along the resulting fault network into the overlying crust, where they formed small dome or pipe-like intrusions (e.g., Schellerhau

Table 1: Summary of bore holes from exploration campaigns in the German part of the deposit.

Campaign	*Number of drill holes*	*Total length*
1917-1918	*2*	*345 m*
1930-1945	*75*	*1,903 m*
1951-1960	*27*	*5,973 m*
1977-1978	*2*	*1,216 m*
1988-2989	*8*	*3,148 m*
2012-2013	*10*	*2,564 m*
2017	*15*	*4,455 m*
Total	*139*	*19,604 m*

Table 2: Resource estimate of historic Lithium exploration (summarised by Neßler et al. 2017)

Resource Estimation	*Resource Classification*	*Ore Volume [m³]*	*Ore Tonnage [t]*	*Mean Grade [ppm]*		
				Li	*Sn*	*W*
1960	*C_1*	*4,000,000*	*10,700,000*	*3,100*		
	C_2	*1,000,000*	*2,800,000*	*3,200*		
	Δ	*200,000*	*500,000*			
		Total C_1 +C_2	*Total C_1 +C_2*		*prognostic*	*prognostic*
		5,000,000	*13,500,000*	*3,000*	*500*	*200*
1978	*none*	*5,980,000*	*16,100,000*	*3,000*	*not calculated*	

Granite). These late-stage granites show monzo- to syeno- and alkali feldspar granitic compositions and are usually formed in this order (e.g. Altenberg, Sadisorf). The major Sn and W mineralisation phase is related to the monzogranitic stage, whereas the final alkali feldspar stage is accompanied by major Li and minor Sn and W mineralisation (Helbig *et al.* 2019).

Pneumatolitc fluids enriched in HF, CO_2, HCI, and H_2S accompanied the emplacement of highly fractionated melts and led to autometasomatic processes within the crystallising and consolidating granite or the post-magmatic metasomatic alteration of the crystallised granite and host rocks (e.g. Teplice Rhyolite, gneiss). The first process is typical for Li-mica bearing leucogranites (e.g.Zinnwald/Cínovec, Schenkenshöhe), where massive greisen bodies up to 44 metres in thickness were formed.

The second mechanism caused stockwork-like greisen or greisen veins. Examples for this metasomatic alteration type are sub-horizontal greisen veins and accompanying greisen at Zinnwald/Cínovec, the Morgengänge (sub-vertical veins) at Zinnwald / Cínovec and the greisen stockworks at Altenberg and Sadisdorf (outer granite).

In addition, the metasomatic lithium-mica (zinnwaldite, polylithionite etc.), cassiterite and wolframite mineralisation is accompanied by subordinate to minor topaz, fluorite, arsenopyrite, molybdenite, native bismuth and bismuthine mineralisations.

The Li-Sn-W Greisen deposit of Zinnwald/Cínovec

With regard to Li, Zinnwald is the most explored and richest among the known greisen ore deposits in the Erzgebirge. The deposit is located about 3 km south of Altenberg and is divided into a smaller German (Zinnwald, containing about one third of the deposit) and a larger Czech part (Cínovec) along the German-Czech border. The geological structure of the deposit is relatively simple and is mainly determined by the rocks of the Zinnwald albite granite intrusion that is hosted by the Teplice Rhyolite (***Figure 3***) (Neßler *et al.* 2017).

The major part of Li-Sn-W mineralisation occurs as greisen beds and veins within the granite (endocontact) and only to a lesser extent in the surrounding Teplice Rhyolite (exocontact). The albite granite (***Figure 3***) is a small-scale granitic intrusion that forms an ellipsoidal surface outcrop of about 1,300 m in length (N-S) and about 300 m in width (E-W; Baumann *et al.* 2000). It exhibits a pale yellow to greenish colour, has a weakly porphyritic to poikilitic texture and consists essentially of plagioclase, quartz, orthoclase, Li-Fe-F mica (zinnwaldite) and sericite (Neßler *et al.* 2017). In addition to progressive evidences of greisenisation (in particular decomposition of feldspar, quartz and zinnwaldite metablastesis), albite granite is also affected by argilitisation and hematitisation.

Based on style, orientation, extent and mineral inventory, the greisen- and vein-type mineralisations are divided into different ore types (e.g., Neßler *et al.* 2017).

- Massive greisen beds, that follow with subparallel dip the morphology of the granites' surface
- Massive greisen stockworks, associated with NW-SE striking faults
- Sub-horizontal dipping quartz-greisen veins (called "Flöze")
- Sub-vertical dipping veins (called "Morgengänge").

Among those, the massive greisen beds represent the volumetrically dominant mineralisation type and the largest resource for Li in Germany (Bock *et al.*, 2020) The mineralogical composition of the massive greisen beds is relatively simple and consists predominantly of quartz (70-80 %), zinnwaldite (20-30 %) and also contains minor topaz and remnants of feldspar. These mineralisations form flat, lenticular, irregular ore bodies and are developed in the upper part of the granite dome as well as along its flanks. Individual greisen bodies have a lateral extent of up to several hundred metres at thicknesses of <1 m to 30 m and at several locations of up to 50 m. Their frequency and thicknesses decrease with increasing depth (Neßler *et al.* 2017).

The sub-horizontally dipping quartz greisen veins are the host for the major part of the Sn-W mineralisation in the upper part of the intrusion and therefore were the basis of historic mining activities. These greisen veins also follow with subparallel dip the morphology of the granite' surface. In contrast to the massive greisen beds they can extend in the exocontact. Due to their flat packing and high lateral continuity they were referred as "seams" ("Flöze") as this appearance resembles a stratiform mineralisation. The most common type of veins is represented by quartz-zinnwaldite-veins, where the zinnwaldite rests as irregular nests or bands within the quartz gangue (Nessler *et al.* 2017). Cassiterite typically forms small nests, which consist of many small single grains that are intergrown with large (up to 15 cm) wolframite crystals and massive white to milky quartz.

Sub-vertically dipping veins are only a subordinate mineralisation in the deposit. Their mineralogical composition is similar to that of shallow dipping veins. Their thickness is usually around 10 to 20 cm and does not exceed 1 m (Neßler *et al.* 2017).

Zinnwaldite is only a minor constituent of this mineralisation style and occurs as disseminated crystals or rosettes in a compact core of quartz.

In addition to the Li mineralisation, the deposit also contains subordinate to minor mineralisations of Sn(-W)-mineralised albite granite, feldspatites, Sn-(In)-Zn-Cu-Pb sulphide ores as well as barite(-fluorite) mineralisation (Neßler *et al.* 2017).

Historic mining and exploration

The Zinnwald/Cínovec deposit is one of the most important greisen-type ore deposits of the Central European Variscan Orogen. It is not possible to reconstruct the exact date of the first mining activities, but it is estimated to be the end of the 13th century (Schilka 1991). Starting from the first discovery, the main focus for around 400 years was the extraction of tin ore (cassiterite). It was not until 1880 that the tungsten mineral wolframite became the main product of ore extraction. The first production of lithium-mica is reported from 1890 (Schilka 1991). After the end of the Second World War mining in the Saxon part of the deposit was abandoned.

The first core drillings were performed in 1917-18, with further drillings following between 1936 and 1945. Systematic exploration of the Sn and Li reserves began in 1930. The deposit was explored in detail by surface and underground bore holes during several campaigns (***Table 1***). In addition, the accessible parts of the underground mine were sampled. The results of the Li reserve estimations in the German part of the deposit for historic exploration campaigns prior to 1990 are summarised in ***Table 2***.

In the course of economic and political developments, the exploration was stopped at the beginning of the 1990s.

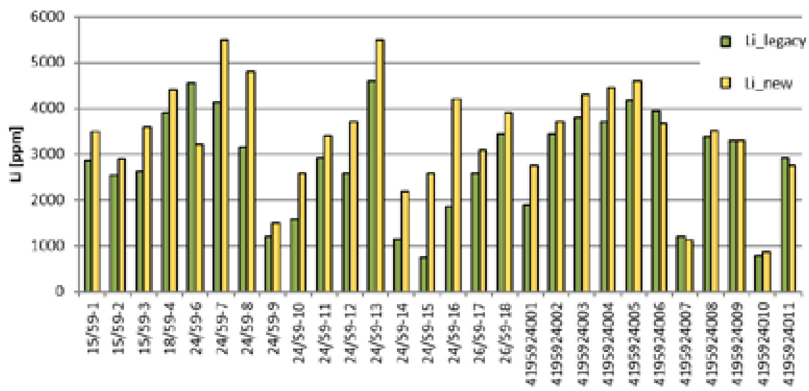


Figure 4: Comparison of Li-grades from legacy and new analysis (Neumann et al. 2014).

Table 3: Lithium resource estimation of the 2011-2014 exploration campaign (Neumann et al. 2014).

Resource classification "Ore Type 1" - greisen beds, vertical thickness ≥ 2 m, cut-off Li = 2,500 ppm	*Ore Volume [m³]*	*Ore Tonnage [t]*	*Mean Li Grade [ppm]*
Demonstrated *(Measured+Indicated)*	*9,840,000*	*26,570,000*	*3,620*
Total *(Measured+Indicated+Inferred)*	***13,495,000***	***36,437,000***	***3,643***

Table 4: Mineral inventory of the Zinnwald Lithium Deposit, German part below 740 m a.s.l. (Bock et al. 2020).

Mineral inventory "Ore Type 1"	*Volume [m³]*	*Tonnage [t]*	*Mean Li Grade [ppm]*
Total	*19,900,000*	*53,800,000*	*3,100*

5. 2011-2014 Exploration

In 2011 and 2012 SWS acquired two exploration licenses in the Zinnwald area. SWS initially focused its exploration activities in the central Zinnwald area as well as underground in the accessible parts of the abandoned mine. Exploration consisted of 10 surface drill holes (9 DDH and 1 RC DH) completed during the years 2012 to 2014 with a total length of 2,484 m. An underground sampling campaign was conducted in the year 2012, which provided a series of 88 greisen channel samples from the sidewalls of the adits (Neßler *et al.* 2017). In addition, a 20 t bulk ore sample was taken for processing test works.

Another important information source consisted of various kinds of datasets from prior exploration campaigns. These include exploration reports and assay tables in printed form, but also drill cores and retained sample materials from old geochemical analyses (Neßler *et al.* 2017).

Table 5: Lithium resource of the Zinnwald Lithium Deposit, German part below 740 m a.s.l. – Base Case "Ore Type1" Summary (Bock et al. 2020).

Resource Classification "Ore Type 1" Greisen Beds	*Ore Volume [m³]*	*Ore Tonnage [t]*	*Mean Li Grade [ppm]*	*Ore Volume [m³]*	*Ore Tonnage [t]*	*Mean Li Grade [ppm]*
	Vertical Thickness ≥ 2 m, cut-off Li =2,500 ppm			*Vertical Thickness ≥ 2 m, cut-off Li = 0 ppm*		
Measured	*6,855,000*	*18,510,000*	*3,630*	*8,954,000*	*24,176,000*	*3,246*
Indicated	*6,296,000*	*17,000,000*	*3,399*	*8,046,000*	*21,725,000*	*3,114*
Inferred	*1,802,000*	*4,865,000*	*3,549*	*2,675,000*	*7,224,000*	*2,995*
Demonstrated (Measured+Indicated)	*13,152,000*	*35,510,000*	*3,519*	*17,000,000*	*45,901,000*	*3,183*
	Internal Dilution					
Total (Measured+Indicated+Inferred)	*4,722,000*	*12,749,000*	*2,001*			

To check the accuracy of the geological data, the first two drill holes in 2012 were executed as twin holes of historic drillings. Results demonstrated a good match in both geology and geochemistry. In order to further validate the results from chemical analysis of these former campaigns, a reassessment of the assayed values was conducted (***Figure 4***). This work included the geochemical analysis and comparison of about 53 historic samples from drill cores at certified analytical labs. After thorough and careful evaluation and interpretation, a large part of the legacy data sets could be implemented and used for geological modelling and reserve estimations.

Thus, a potential lithium resource (***Table 3***) was confirmed applying the European PERC reporting standard and published in a prefeasibility study (Neumann *et al.* 2014).

6. 2017-2019 exploration

In February 2017, Bacanora Lithium plc. acquired 50 % of SWS and the 50:50 joint venture company was renamed Deutsche Lithium GmbH. Consequently, the further exploration work had to be conducted according to the Canadian NI43-101 reporting standard.

Infill and verification drilling was resumed and completed in 2017 by Deutsche Lithium consisting of 15 surface DDH with a total length of 4,458.9 m. In addition, another 100 t bulk ore sample was taken for pilot plant scale processing test works.

The geological and geochemical results were fully integrated in the database and used to update the geological model and resource estimation. QA/QC procedures were carried out for due diligence purposes during both exploration campaigns (2011–2014 and 2017–2019) and were verified by external qualified persons. The results confirmed the careful sampling and reasonable accuracy and precision of the assays.

Thus, exploration within the Zinnwald property has confirmed the presence of several lithium bearing greisen ore bodies with dimensions of around 1 km from north to south and of around 1 km in east-west direction. Intersected thicknesses range between a minimum of 0.1 m and a maximum of 43.7 m. The deepest exposure of greisen ore was encountered at a depth of 416 m below surface.

The general mineral inventory of lithium (***Table 4***) estimated from the block model on the basis of a zero cut-off and without a constraint of minimum thickness of the ore bodies accounts to 53.8 Mt ("Ore Type 1") with a rounded average grade of 3,100 ppm Li.

Modifying factors for eventual economic extraction (vertical thickness ≥ 2 m, cut-off = 2,500 ppm Li) applied to the mineral inventory result in a demonstrated (measured and indicated) lithium resource of 35.51 Mt of greisen ore with an average lithium grade of 3,519 ppm Li (***Table 5***).

The potential of Sn, W and K_2O have been estimated for the greisen beds as mean grades for "Ore Type 1" of the deposit and below 740 m a.s.l. at a total volume of rounded 15 Mm^3 and a tonnage of 40 Mt, the overall mean grades for Sn, W and K_2O account to 500 ppm, 100 ppm and 3.1 wt.%, respectively.

8. Summary and outlook

The Zinnwald Li mineral resources have been established on a solid data basement and with the use of modern estimation methodology. Through careful and accurate treatment, it was possible to combine legacy and new data, which led to a robust resource estimation in accordance with internationally recognised standards.

In summary, the resources (***Table 5***) were found to double those estimated in the prior 1990 results (see ***Table 2***). In addition, it was demonstrated that due to the particular tectonic situation along the western flank of the intrusion, the mineralisation remains open beyond the expected limits of the deposit towards the northwest.

Another result of metallogenetic and possibly economic importance is the discovery of a continuous mineralised zone with disseminated Sn-W mine ralisation along the eastern flank at the footwall section of the main greisen ore bodies. A corresponding core interval of 20 m in length resulted in average grades of 0.26 wt.% Sn and 0.06 wt.% W (Neßler *et al.* 2015, 2017).

Both commodities need to be investigated in more detail by further field exploration during mining of the deposit.

In April 2017, a mining permit was applied for by Deutsche Lithium GmbH (DL), which was approved for the field "Zinnwald" in October 2017. The mining permit covers 2,564,800 m^2 and is valid up to the end of 2047. In addition, DL holds two other exploration licenses (Falkenhain, Altenberg-DL) within the area that have the potential to significantly increase the lifetime of the project.

Following mine development and construction of the processing and chemical plant, which will take a period of 18-20 months, DL plans to mine around 500,000 to 600,000 tonnes of ore per year to produce 5,000 tonnes of battery grade LiF or other Li-salts (e.g. $LiOH \cdot H_2O$, Li_2CO_3).

The results of the exploration campaigns were published by DL in a feasibility study in April 2020 (Bock *et al.* 2020). Based on this, a financing package is currently under way. In parallel, the higher-level approval procedures (i.e. optional framework operating plan) are underway. Depending on positive results of both, the project can be executed.

Due to the still weak demand for lithium as a result of a generally weakening lithium market, the acquisition of capital for the implementation of the project has become significantly more complex. However, it is assumed that in the coming years (2020-2022) the demand for lithium compounds will continue to increase sharply due to the expansion plans for electromobility.

In addition to its location in a region with well-developed infrastructure, services, facilities, and access roads, the short distances to the end-users of the lithium compounds are another essential advantage of the project. Furthermore, all social and economic standards are met. The Zinnwald deposit thus has the potential to cover part of the domestic lithium demand.

References

Baumann, L., Kuschka, E., Seifert, T. 2000: Lagerstätten des Erzgebirges (Mineral deposits of the Erzgebirge Mountains). Stuttgart: Enke im Thieme-Verlag.

Bock, W-D., Kühn, K., Gowans, R. 2020. Zinnwald Lithium Project, Technical Report on the Feasibility Study for the Zinnwald Lithium Project, Germany, NI 43-101 Technical Report, effective date 15.04.2020, prepared for Deutsche Lithium GmbH, Freiberg, G.E.O.S Ingenieurgesellschaft mbH, Halsbrücke, Germany, Micon International Ltd., Toronto.

Grunewald, V. 1978. Neueinschätzung Rohstoffführung Erzgebirge, Gebiet Osterzgebirge – Metallogenie und Prognose Zinnwald, Teil 1: Metallogenie (Reassessment of resource base of the Erzgebirge Mountains, Eastern Erzgebirge Mountains District - metallogeny and forecast for Zinnwald, part 1: Metallogeny). Unpublished report, Zentrales Geologisches Institut der DDR, Berlin.

Helbig, M., Kahnt, R., Becker, L., Gabriel, A. 2019. Verbundprojekt GEM Granitgebundene Erze strategischer Metalle – Bildungsbedingungen und Ableitung innovativer Suchkriterien für verborgene Erzkörper. Arbeitspaket 4 – Wärmetransportmodellierung und geochemische Modellierung (Joint project GEM, granite-bound ores of strategic metals: conditions of formations and derivation of innovative search criteria for hidden ore bodies. Work package 4 - heat transport modeling and geochemical modelling). Unpublished report. G.E.O.S. Ingenieurgesellschaft mbH Halsbrücke / Germany, 31.12.2018.

Neßler, J., Seifert, T., Gutzmer, J. 2015. New Sn-W potential at the Zinnwald/Cínovec deposit, eastern Erzgebirge, Germany. "Mineral Resources in a Sustainable World", 13th SGA Biennial Meeting 2015, Nancy. Proceedings, Volume 2, 2819-2822.

Neßler, J., Seifert, T., Gutzmer, J., Müller, A. 2017. Beitrag zur Erkundung und metallogenetischen Charakteristik der Li-Sn-W-Greisenlagerstätte Zinnwald, Osterzgebirge, Deutschland (Contribution to the exploration and metallogenetic characteristics of the Li-Sn-W Greisen deposits Zinnwald, Eastern Erzgebirge Mountains, Germany). *Freiberger Forschungshefte* C 552. Freiberg: TU Bergakademie Freiberg.

Neumann, M., Bachmann, T., Hartsch, J., Henker, J., Helbig, M., Kahnt, R., Kühn, K., Morgenstern, S., Müller, A., Neßler, J., Zernke, B. 2014. Zinnwald Lithium Project, Report according to PERC Standard on behalf of SolarWorld Solicium GmbH. G.E.O.S. Ingenieurgesellschaft mbH, Halsbrücke, Germany in collaboration with TU Bergakademie Freiberg, 01.10.2014.

Schilka, W. 1991. Zinnwald. Die Geschichte eines osterzgebirgischen Bergbauortes (Zinnwald: The history of a mining site in the Eastern Erzgebirge Mountains). Gemeindeverwaltung Zinnwald-Georgenfeld.

Schilka, W., Baumann, L. 1996. Metasomatische Prozesse im Schellerhauer Granitmassiv (Osterzgebirge) (Metasomatic processes in the Schellerhauer granite massif) . *Freiberger Forschungshefte*, C467. 151-176.

Sebastian, U. 2013. *Die Geologie des Erzgebirges (The geology of the Erzgebirge Mountains)*, Berlin: Springer Spektrum. DOI: 10.1007/978-3-8274-2977-3

Seifert, T. 2008. *Metallogeny and Petrogenesis of Lamprophyres in the Mid-European Variscides – Post-Collisional Magmatism and Its Relationship to Late-Variscan Ore Forming Processes (Bohemian Massif)*. Amsterdam: IOS Press BV.

Seifert, T., Gutzmer, J. 2010. Li-reiche Sn(-W-Polymetall)-Greisenlagerstätten im Freistaat Sachsen (Li-rich Sn(-W-polymetallic) deposits in Saxony). In: Voigt, W. (ed), Freiberger Forschungsforum: 61. Berg- und Hüttenmännischer Tag, FK 3: "Lithium for Li-Ion Batteries - Resources and Recovery", abstracts volume.

Seifert, T., Kempe, U. 1994. Zinn-Wolfram-Lagerstätten und spätvariszische Magmatite des Erzgebirges (Tin-tungsten deposits and late Variscan magmatites from the Erzgebirge Mountains). *Beihefte zum European Journal of Mineralogy*, 6(2). 125–172.

Signumbox 2019. Lithium Fluoride Market Study – Final. signumBox, Santiago, Chile, 11.03.2019.

Tolksdorf, J. F., Schröder, F., Petr, L., Herbig, C. 2019. Evidence for Bronze Age and Medieval tin placer mining in the Erzgebirge mountains, Saxony (Germany). *Geoarchaeology* 35. 198–216. DOI: 10.1002/gea.21763

How can universities and students increase domestic raw material knowledge to help production? Possibilities through examples

Máté Zs. Leskó[1], Lívia Majoros[1], Gábor Jakab[1], Richárd Z. Papp[1] and Ferenc Kristály[1]*

The European Union is one of the world's largest raw material consumers; however, the EU's share in global mineral raw material production is small. This creates a risk, because the economy depends on other countries/regions. To avoid this situation the EU encourages its members to increase exploration for and better exploitation of mineral resources. There are many historical and abandoned mining areas across Europe that could have high economic potential in the future. In this paper we would like to present through examples a method demonstrating how universities and students can provide data and new aspects for prospective research, governments and exploration companies. Our study shows that students with an interest in economic geology during their education could give us new perspectives and possibilities for supporting the national economies and the EU, as well.

L'Union Européenne (UE) est l'une des organisations mondiales les plus consommatrices de matières premières ; cependant, la part européenne au niveau production de matières premières est faible. Cela est source de risque parce que l'économie dépend alors d'autres pays/régions. Pour éviter cette situation, l'UE pousse ses membres à accroitre les travaux d'exploration pour une meilleure exploitation des ressources minières. Il existe, à travers l'Europe, de nombreux secteurs miniers, historiques et à l'abandon, qui pourraient se révéler, dans le futur, comme des sites potentiels de haute valeur économique. Dans cet article, nous aimerions présenter, à partir d'exemples, une méthode démontrant comment les universités et les étudiants sont capables de fournir des données et une nouvelle approche pour de futures recherches en impliquant les instances gouvernementales et les compagnies d'exploration. D'après notre étude, les étudiants intéressés par l'aspect économique de la géologie pendant leur cursus pourraient nous gratifier de nouvelles perspectives et de moyens pour aider les économies nationales ainsi que l'UE.

La Unión Europea es uno de los mayores consumidores de materias primas del mundo; sin embargo, la participación de la UE en la producción mundial de materias primas minerales es pequeña. Esto crea un riesgo, porque la economía depende de otros países/regiones. Para evitar esta situación, la UE alienta a sus miembros a aumentar la exploración y a una mejor explotación de los recursos minerales. Hay muchas áreas de minas históricas y abandonadas en toda Europa que podrían tener un alto potencial económico en el futuro. En este documento nos gustaría presentar a través de ejemplos un método que demuestre cómo las universidades y los estudiantes pueden proporcionar datos y nuevos aspectos para la investigación prospectiva, empresas de exploración y gobiernos. Nuestro estudio muestra que los estudiantes interesados en geología económica, durante su educación también podrían brindarnos nuevas perspectivas y posibilidades para apoyar a las economías nacionales y a la de la UE, por consiguiente.

Introduction

The raw material supply-and-demand system in the world economy and in the manufacturing industry always has trends and these depend on many factors. This has accompanied mankind throughout history: people always looked for the best raw materials applicable: flint (in the Stone Age), copper (Copper Age), tin and copper (Bronze Age), iron (Iron Age), and now rare earth elements in our age. Cultural evolution through millennia has created an ever rising trend especially since the industrial revolution in the 18th century accelerated and diversified the raw material demand. The strength of a country or a community (e.g. the European Union) depends on many factors: financial stability, industrial development, education, military, politics, etc. These factors form a complex interlinked system, where they affect each other.

[1] Institute of Mineralogy and Geology, University of Miskolc, Hungary
* askmate@uni-miskolc.hu

Raw materials within the borders

There are many thousands of abandoned mines and mining areas in Europe or more specifically in the European Union. The mining activity may have occurred in ancient times or the mine may have been closed only a few years ago. Exploration and extraction of raw materials are processes that have been determined by demand and supply during the history of the mankind. Chert (flint) was essential to Stone Age man to survive, therefore to find and mine chert was a matter of life or death. They dug shafts several metres deep to reach the silicolite strata. Ignatius von Born (mineralogist and metallurgist) wrote in the 18th century in his travel letters about how important the financial return is during mining activity (von Born, 1774).

Most of the abandoned mines were closed because the mining grade of the ore did not reach the actual cut-off grade, or the mining method was not economical: e.g. open pits or drifts stopped because the gangue/ore ratio was too high. Until the Medieval Ages most mined materials were utilised only locally, since the transportation possibilities were cumbersome. Some rare, strategic or expensive minerals, such as rock salt or lapis lazuli, could be transported to larger distances. With the discovery of the New World's continents and technological advancement, a lot of minerals and metals were shipped to Europe. In the globalised world of today it is frequently possible to buy and transport raw materials worldwide more cheaply than mining them in a European country. In some cases a country can grow into a significant metallurgical supplier without having supporting mineral resources. For example, Iceland is a large aluminium producer (USGS, 2020), although it does not possess any bauxite –cheap electricity and low cost sea transportation makes shipped bauxite processing profitable. The European Union is one of the major and important world economic focus points alongside North America and East Asia. It has a significant share of the world's manufacturing industry, but its raw material demand is much higher than its internal production; the EU produces around 4 % of the global mineral output but consumes 35 % of the products exported from the world market.

Importing products (especially raw materials) from the world market has supply risks. During history there were episodes when a country could not obtain the required raw material (quantity or quality): wars, politics (e.g. cold war) or embargos. In our society today there are only few countries that are isolated from the global market (e.g. North Korea).

In the past the market-influencing factors acted far more slowly than they do today: to prepare for a war the governments and people had to stockpile goods and minerals to survive. The conflicts escalated more slowly and lasted longer. The markets in the global society today (demand-supply system) can be influenced very rapidly by different news or events: military intervention/terrorist act; political decisions, pandemics, new technological developments or the discovery of giant deposits.

The production of raw materials seems uninterrupted in the European Union, unlike in some other parts of the world (those suffering from wars or in political/financial crisis). Nowadays the raw material production and use ratio in the EU is not optimal, so the EU has to face the effects of the world market: fluctuating trends and price changes. The negative effect of the China's REE embargo from 2011 had serious consequences: countries where the main raw material supply is from the world market realised their economy and industry depended on other countries. In response to the situation the EU established a list in 2011 (COM (2011) 25), where the critical raw materials were listed. This list is upgraded every three years: in 2011 it contained 14 elements, in 2014 it had 20 and from 2017 there are 27 elements on the list (COM(2017) 490). The next upgrade is expected in 2020. Most of the elements on the list are imported in more than 50% (even 100% as well) of the quantity used and their lack may have a serious impact on technologies and create a supply risk. One of the biggest problem is that most of these materials cannot be recycled with today's technology (COM(2017) 490).

The EU supports exploration and reconsideration of abandoned mines in its territory to mitigate these negative effects and to protect its industry and economy.

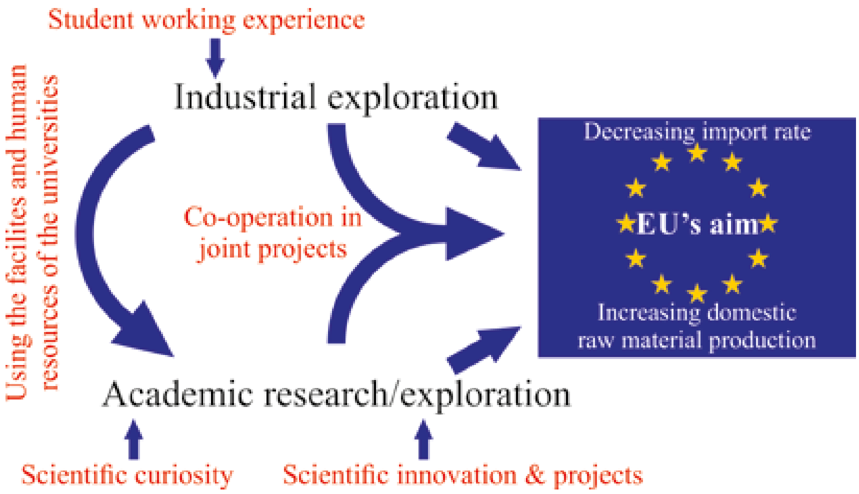


Figure 1: Possibilities of universities and their students to support the EU's aim.

The importance and possibilities of the universities and the students

Today there is no continuously operating ore mine in Hungary anymore. The last one in Úrkút, a manganese-ore mine, was closed in 2016. The last periodically operating ore mine is located in Bakonyoszlop (coal and bauxite; it is also the last underground mine) but its production is negligible. In the last two decades there have been only a few explorations, which were carried out by small companies. Although there seems little chance for opening ore mines in Hungary in the next few years, the universities and the students can provide available new data for everybody. The data and knowledge could be useful now or in the future as well. For instance, in the second half of the 20th century an assistant geologist investigated microfossils as a hobby, and those data are used today to know the age of the sedimentary rocks during hydrocarbon exploration.

Several generations of geology students have been working to understand our environment better and getting familiar with the raw materials under the surface, and this knowledge will assist in the future's exploration and mining. Universities and their students are capable of contributing to the EU's directive in multiple ways (*Figure 1*):

- Basic and applied research in the universities
    - Re-evaluation of abandoned mines closed decades or centuries ago.
    - Translation and data mining of old local-language exploration reports to connect to international scientific and industrial world.
    - Participation in national and international project teams
- Industrial and academic cooperation
    - Joint projects: BSc, MSc, and PhD theses
    - R&D contracts with industrial companies
        - Analytical measurements (SEM, XRD, XRF, etc.)
        - Competence in certain topics, special domains

We would like to demonstrate with a few examples from Hungary that universities and their students can provide new valuable data and knowledge that can lead towards the principal aim: increasing the domestic (and EU) commodity supply.

Figure 2: Sample collection: graphite-bearing rocks in NE Hungary.

Graphite re-evaluation from archive data

From the mid-1950s till the early 1990s (in the Soviet era) in Hungary there were numerous explorations because of the "planned economy"[1]. A significant amount of data piled up from those explorations.

Some 30–40 years ago there were preliminary graphite explorations revealing interesting local showings which had not been followed up on. Their re-evaluation started a few years ago at the University of Miskolc (***Figure 2***). With the new instrumental technologies that were commercialised in the last 3–4 decades, we can investigate these occurrences more accurately (SEM with higher resolution, Rietveld method in XRD, Raman spectroscopy, etc.), which can give us reliable quantitative results. Thus, the graphite-bearing rocks in NE Hungary were analysed. The graphite deposit type was identified and the graphite was classified into international industrial groups (Majoros *et al.*, 2019). Most of the Hungarian exploration reports were re-evaluated and results were disseminated in different international conference presentations and scientific papers.

A new barite deposit

In NE Hungary there is a major shear zone, the Darnó shear zone, alongside which are located several ore-bearing zones, with the Recsk porphyry copper at its southernmost exposure. There are many iron-rich metasomatic zones and Rudabánya was the largest iron-ore mine. Iron-ore mining in Rudabánya ceased in 1985, but ever since Cu, Pb, Zn and barite exploration have been taking place in this area. There are at least 6 different ore forming processes represented here, starting from the early Triassic until the Pliocene (Szakáll, 2001).

Martonyi is located in the far NE part of the Darnó shear zone. It had an active iron mine until the early 20th century. The early explorations for iron ore did not recognize its base metal and barite potential. In 2011 and 2018 MSc students worked on a mineralogical investigation in Martonyi (***Figure 3***) and detected base metal and barite assemblages. In a later thesis (Jakab, 2019) almost all of the ore forming processes were identified which are also recognised in Rudabánya. Among the different ore forming processes, barite accumulation could be the most interesting part. This has led us to more investigations and hopefully our results will lead to a follow-up professional exploration, as well.

Rare metals

Although there are several indications of tantalum, niobium, cobalt, gallium and indium in Hungary, systematic exploration with modern analytical work had not been carried out. Within the CriticEl project (2012-2014; ***http://kritikuselemek.uni-miskolc.hu/index_en.php***) student projects were set up to investigate such geological formations. In 2016 a master's student investigated In and other trace element content of sphalerite and related sulphides from the Recsk polymetallic mineralisation for his thesis study (Csámer, 2016). In addition to In, Ga, Ge and Te were detected at levels below 1000 ppm, with occasional enrichment of Se in galena and pyrite. The occurrence of these metals is linked to hydrothermal mineralisation produced by intermediary magmatic intrusions in tertiary sediments. Indium is mainly trapped in sphalerite, associated with Cu anomalies, suggesting coupled substitution or In-bearing chalcopyrite inclusions.

REE in bauxites and red mud

Another topic in CriticEl was the REE content of bauxites, investigated at the level of an MSc thesis (Márkus, 2014) and scientific publication (Szabó *et al.*, 2014). The work is being continued in a more recent project, REEBAUX (***http://reebaux.gfz.hr/about/***).

CHPM2030 project

The CHPM2030 (Combined Heat, Power and Metal extraction; ***https://www.chpm2030.eu/***) Horizon 2020 project involves industry and academia and aims at developing a fluid state extraction technology for ultra-deep ore deposits with a single process of combined ore, heat extraction and power (electricity) generation (Hartai *et al.*, 2019). It is a very innovative program initiated from the academic sector that supported student work, as well. A new geological model of the deep-seated Recsk porphyry copper deposit was created during the research linked to an MSc thesis (Miklovicz, 2017), indicating the deep intrusive root of the porphyry copper complex.

Figure 3: Sample collection in Martonyi.

1 The "planned economy" was characteristic for the socialist countries. The economy was not controlled by the market but by the government. The government prescribed what and how many goods should be produced regardless of whether it was economical or not.

Co-operation between industry and universities

During the exploration phase companies often turn to universities. They order different investigations (e.g. XRD, XRF, SEM, fluid inclusion thermometry) for their samples. If the relationship between the company and the university (or professors) is good, the measurements can be carried out by students as a thesis project: the company that leads the active barite exploration in Rudabánya gave a chance to a student to join the project. The student's work was used during the exploration.

An operating mine often has co-operation with the nearest university. A small mine has its goods investigated there, because it is cheaper than establishing its own laboratory, or it can validate its own measurements. During the mining activity problems and tasks may turn up that can frequently be solved by students as their thesis projects: for instance, in the Úrkút manganese ore mine (underground) the old pneumatic load-haul-dump (LHD) machines were changed to diesel engine varieties. A student was given the task to investigate whether the ventilation in the mine was sufficient or if the owner needed to improve it.

Conclusion

One aim of the European Union is to increase raw material (mainly critical raw materials) exploitation within the European Union borders. This could decrease raw material imports and mitigate the occasional negative effects of the world market. This aim is actively supported by universities and students, who can seek for and provide valuable data and knowledge to academic and industrial professionals in several ways:

- Scientific interest, which may lead to important deep knowledge about deposits
- Within national and international projects
- Within academic-industrial co-operation.

Technological development is continuous, which means today's knowledge could be tomorrow's treasure.

Acknowledgment

The described article was carried out as part of the EFOP-3.6.1-16-2016-00011 “Younger and Renewing University – Innovative Knowledge City – institutional development of the University of Miskolc aiming at intelligent specialisation” project implemented in the framework of the Széchenyi 2020 program. The realisation of this project is supported by the European Union, co-financed by the European Social Fund.

References

COM(2011)25: Communication from the Commission to the Institutions Tackling the Challenges in Commodity Markets and on Raw Materials. Brussels: European Commission.

COM(2017) 490: Communication from the Commission to the Institutions on the 2017 list of Critical Raw Materials for the EU. Brussels: European Commission.Csámer Á. 2016: Indium and other trace elements in the sphalerite dominant base metal mineralizations from Recsk Ore Complex. MSc thesis, Institute of Mineralogy and Geology, University of Miskolc, Hungary.

Hartai, É., Madarász, T. and the CHPM2030 TEAM. 2019. Co-production of clean energy and metals – the CHPM concept. *European Geologist*, 47, 10–14

Jakab, G. 2019. A Martonyi vasércesedés ásványtani és geokémiai vizsgálata (Mineralogical and geochemical investigation of the Martonyi iron deposit). MSc thesis, Institute of Mineralogy and Geology, University of Miskolc.

Majoros, L. Kristály, F., Szakáll, S. 2019. ÉK-magyarországi, potencionálisan grafittartalmú feketepalák vizsgálata (Investigation of potentially graphite-bearing blackschists in NE-Hungary.) *Publications of Earth Science Engineering*, Miskolc, 88/2, 134–139.

Márkus I. R. 2014. A halimbai és nyirádi bauxitok technológiai célú összehasonlító ásványtani és geokémiai vizsgálata (Mineralogical and geochemical comparative investigation of Halimba and Nyírád bauxites for technological characterization.) MSc thesis, Institute of Mineralogy and Geology, University of Miskolc,

Miklovicz T. 2017: Application of predictive 3D geomodelling on the Recsk Ore Complex vertical extent, and overview of Combined Heat Power and Metal extraction technology at Recsk. MSc thesis, Institute of Mineralogy and Geology, University of Miskolc,

Szabó, C., Mádai, V., Márkus I. 2014. Rare earth elements in the bauxites of the Transdanubian Range. In Szakáll, S. (Ed.), *REE-s in Hungarian geological formations*. CriticEl Monography 5, pp. 131–159. Milagrossa: Miskolc.

Szakáll, S. 2001. Rudabánya ásványai (Minerals of Rudabánya). Kőország Kiadó, Budapest, p. 176

von Born, I. 1774. Úti levelek az 1770-es bánsági, erdélyi, felső- és alsó-magyarországi ásványtani utazásról (Travel letters about Mineralogical Traveling in Banat, Transylvania, and Upper and Lower Hungary in 1770). 2014. Milagrossa: Miskolc. (Translated from German to Hungarian by Péter Fuchs)

USGS. 2020. Mineral commodity summaries 2020: United States Geological Survey. https://doi.org/10.3133/mcs2020

Considerations for financing and encouraging successful exploration within the EU

*Eamonn F. Grennan**

This paper outlines the challenges attached to the exploration for a wide range of metals and minerals. It addresses a number of factors amongst the general public in regard to the differences between exploration, mining, refining and product manufacture. The fact that the exploration philosophy employed in one resource industry differs significantly from another resource industry and that the attitude of the players is extremely different is one of the reasons why there has been a dearth of new discoveries in Europe, especially in regard to the 'emergent metals' required for the low carbon economy. Most people are unaware of the very high element of risk at the commencement of the exploration phase. Since Europe has only a very small indigenous mining industry, the only way to restart it is by way of direct financial investment channelled through SMEs, which are known in the industry as "junior" minerals exploration companies. In respect of metals this, along with social acceptance, is the key challenge for our basic industries.

Cet article met en relief les défis associés à l'exploration d'un large éventail de substances métalliques et de minéraux. Il traite d'un certain nombre de facteurs à l'usage de « monsieur tout le monde » concernant les différences entre l'exploration, l'extraction du minerai, son raffinage et le produit manufacturé. Le fait que la philosophie de l'exploration utilisée pour un type de minerai industriel diffère significativement de celle mise en œuvre pour un autre type et que l'attitude des protagonistes est très différente, représente l'une des raisons qui expliquent pourquoi il y a eu pénurie de nouvelles découvertes en Europe, en particulier pour ce qui concerne les métaux émergents, nécessaires à une économie pauvre en carbone. La plupart des gens ignore le caractère éminemment risqué qui accompagne le début de la phase d'exploration. Depuis que l'industrie minière proprement européenne est très réduite, la seule façon de la relancer est possible grâce à un investissement financier direct canalisé à travers des SMEs, qui sont répertoriées dans le domaine industriel en tant que compagnies « juniors » d'exploration minière. Pour ce qui est des métaux stratégiques, cela, en même temps qu'une acceptation sociétale, représente le défi central de nos industries de base.

Este documento describe los desafíos relacionados con la exploración de una amplia gama de metales y minerales. Aborda una serie de factores para el público en general con respecto a las diferencias entre exploración, minería, refino y fabricación de productos. El hecho de que la filosofía de exploración empleada en una determinada industria de recursos difiere significativamente de las otras, y que la actitud de las partes implicadas es extremadamente diferente; son razones por las que ha habido una escasez de nuevos descubrimientos en Europa, especialmente en lo que respecta a 'metales emergentes' necesarios para la economía baja en carbono. La mayoría de las personas desconocen el elevado riesgo al comienzo de la fase de exploración. Dado que Europa tiene una industria minera autóctona muy reducida, la única forma de reactivarla es a través de una inversión financiera directa canalizada a través de las PYME, que se conocen en la industria como compañías de exploración minera "junior". Con respecto a los metales, esto, junto con la aceptación social, es el desafío clave para nuestras industrias básicas.

Overview of European Commission (EC) policy

Last year in a presentation to the European Investment Bank Maroš Šefčovič, a vice president of the European Commission, made the point that, *"Without undertaking its own exploration, the EU will have no mining projects. This, in turn, means no refineries and, without refining capacity, the EU will continue to be in great part dependent on foreign supplies of high-quality materials"* (Šefčovič, 2019a).

This is one of the rare occasions when it has been explicitly pointed out that raw material policy formulation must not begin with extraction, as is exemplified by ***Figure 1a***, but has to start with exploration, as in ***Figure 1b***.

Šefčovič (2019b) also stated, *"If the European Battery Alliance has taught us one thing it is that top-down approach does not work. We need to understand …. what is needed to accelerate this transition and mitigate its impact"*. In other words, 'business as usual' is no longer an option. He goes on to make the point that we need to finance exploration.

The ERA-MIN roadmap (2013) recognised this and listed five key areas, *"exploration, extraction, mineral processing, metallurgy, and mine closure and rehabilitation"*. This is one of the few EC documents that actually highlights the need for exploration and the fact that *"exploration in the EU lags far behind that of most developed countries" and further notes that its development "depends on clear enabling public policies"*.

Introduction

When supra- or inter-governmental bodies such as the UN, the EC or the World Bank discuss the supply of metals, exploration is often not even mentioned, as it is usually conflated with "mining". Thus, the initial phase and the highest risk activity involved in the raw material supply spectrum, the exploration phase, is omitted from consideration. The fact is that exploration and mining are two very distinct albeit related industries. Thus, for proper policy formulation it is essential to understand the difference and how the companies involved in the discovery of raw materials are struc-

* eamonn.grennan@outlook.ie

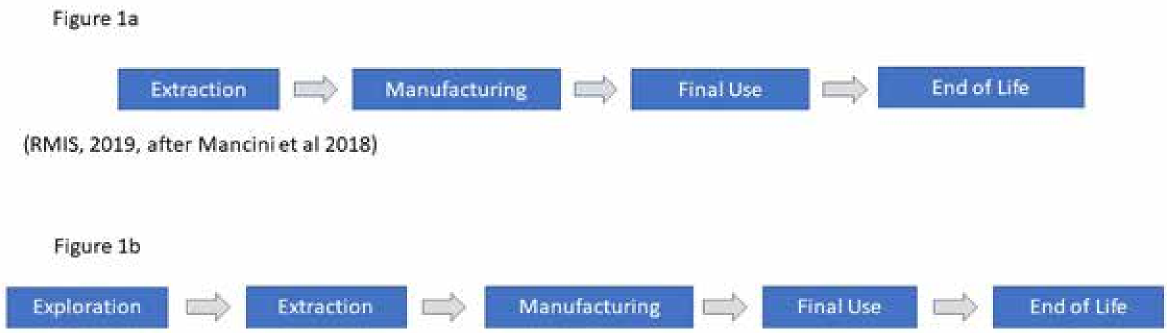


Figure 1: Two approaches to raw material policy formation (RMIS, 2019, after Mancini et al. 2018).

tured. Unless the composition of the metals discovery and supply industries is understood, the problem of supply will worsen. This is particularly true in any discussion relating to the discovery and securing the supplies of critical raw materials.

There are three types of mining companies, each with different exploration strategies. Furthermore, the corporate structure within the metals exploration industry is very different from that of the oil & gas industry and both contrast with exploration for "industrial minerals" and similar activity within the "Command Economies". Unlike oil & gas companies and large-scale producers of industrial minerals, metals companies, with exceptions such as aluminium and iron, are often not vertically integrated. It is not a one- size-fits-all scenario. Each structure has its own set of corporate governance requirements, and, most importantly its own different philosophies and targets.

Corporate structure of exploration companies

Major multinational oil & gas companies

These companies are amongst the largest corporations in the world and until the advent of the tech and social media companies, inevitably filled most of the Top 10 slots of the largest stock exchanges in the world. Nearly all of the major oil companies have at some stage during the past 30 years become involved in minerals exploration, notable mainly for their lack of success. There is clear evidence that whilst a cross-sector transfer of specific exploration technologies is important, such as the increasing application of seismic technologies in mineral exploration, the exploration targeting is distinctly different.

Within the oil & gas industry there are many smaller companies which are usually part of an exploration consortium exploring or who for investment reasons are sharing the profits of a producing field. They are much smaller than the major oil & gas companies, but have a much larger capitalisation than the junior mineral exploration companies. Their governance tends to be more akin to that of the major multi-national oil & gas companies. They may occasionally become involved in minerals exploration, but like the majors their impact on minerals exploration is almost negligible.

"Junior" mineral exploration companies

The junior mineral exploration companies are at the other end of the financial spectrum, as the oft-quoted investment phrase puts it, "investment in them is not for widows and orphans." Indeed, the risk of failure is so great that there are only a limited number of stock exchanges around the world that trade in the shares of such companies, which operate within special rules. The main Exchanges which trade these shares are in Canada, Australia, South Africa, and the London AIM exchange. The term "SME" (small and medium-sized enterprise) truly describes these companies.

The key aspect is that they are not "mining" companies at all, they are solely involved in minerals exploration, and possibly some early-stage development. These companies rarely have any operating income. The companies tend to have a short life; few last longer than 10–15 years. They are usually set up by someone with an entrepreneurial mindset and a technical or administrative background in another exploration company or an established mining company.

Initially these companies will self-finance, building-up a portfolio of prospects and/or 'properties', particularly those that have some known mineralisation within them or close-by, and strive to enhance the prospectivity of their ground holdings as a prelude to floating a company on the stock exchange. In order to survive, a characteristic of these companies is their ability to rapidly change their exploration commodity focus, as metal prices increase or decrease, or indeed their location in response to regulatory hurdles or discoveries elsewhere. On upgrading the prospect, or making a "discovery", financing to advance the project will then often be sought from a major. During this phase the junior company often retains management of the exploration programme. Inevitably, as the project advances into feasibility studies, management will devolve to the major with the junior retaining a minority share.

Distinction between metal mining and industrial minerals companies

Historically the difference between mining companies and industrial minerals companies was that the former mined metalliferous ores, and typically sold the product to third parties on the global markets whilst the latter mined 'industrial minerals' for their own internal, often local requirements. With the rise of "specialty metals", such as chromium, titanium and lithium, this distinction is no longer clear cut.

As a result of this basic difference the exploration funds available to mining companies are mobile and will seek out the best opportunities in whatever jurisdiction, whereas industrial mineral companies focus on areas close to their own production plants and/or local markets, confirming the old adage that, 'Mining companies are into mining because they want to be, whilst Industrial Minerals companies are into mining because they have to be'. This goes a long way in explaining why Europe has a well-developed industrial minerals industry and a metalliferous mineral supply problem.

Mining companies

Every mining company started life as an exploration company, and to a greater or lesser degree, continues to have Exploration Divisions dedicated to the discovery of new deposits. Some have become so large that prior to the 'Tech Revolution' they were amongst the largest capitalised companies in the world; the term multinational is appropriate to apply to such entities.

These divisions often have their own corporate structure, principally because the working environment and ethos are very different from those within a mine. The exploration arm varies from one company to the next, but there are three basic scenarios.

(A) In some companies, especially the very large mining corporations, it acts primarily as a 'listening service'. During the course of a discovery by other (smaller) companies, they will seek to join forces, by offering financial and technical advice. Together they will attempt to expand the size of the deposit and bring it into production.

(B) Over time, the very large mining companies with the small exploration divisions realised that their mergers and acquisitions system was not working and that in particular they were having to pay 'over-the-odds' prices to acquire good prospects and/or deposits. As a result, their business model evolved into a system of financing junior exploration companies to act as their exploration arm, particularly in grass-roots exploration in frontier areas. Whilst the latter were paid for their services, they were also given the promise of a share of any mining company that would emanate from the project.

(C) The third system applies mainly to mid-size mining companies. Their exploration division tends to be more active in grass-roots exploration, where it can also move faster if a junior company makes a discovery. The exploration division will have its own budget. It is generally accepted that the more independent that it is from the mining operation(s), the more likely it is to be successful. However, the downside to this independence is that in times of financial austerity it will be the first part of the company to have its budget reduced. By and large these exploration divisions tend to be successful.

The actual mining operation, whatever the origin of the discovering company, usually carries out some processing on site. The concentrate is then transported and sold to a third party, usually a smelting company for further processing and refining. Some mining companies may own and operate smelters, the products and by-products of which are then sold on to a wide variety of end users. There will rarely be a corporate linkage between the junior company and the smelting company or between the mining company and the user(s) of the metal(s). There are exceptions, such as single metal (e.g. aluminium and iron) companies, which tend to be very large vertically integrated corporations, with exploration arms, mining operations, smelters/refineries and a sales office. In this way they resemble the oil & gas companies.

Industrial minerals companies

Industrial minerals companies vary enormously depending on the ultimate product. Diamond producing companies often have exploration divisions, mainly as a "listening system", comparable to Type (A) mining companies described above. Gypsum companies tend to be more actively engaged in exploration, particularly in areas close to a gypboard or plaster producing plant, and are therefore somewhere between Types (A) and (C). On the other hand, companies producing talc-based products, for example, are unlikely to have an exploration arm or a mining division and tend to buy the raw product from a long-term supplier.

The specialty metals companies, which are often only interested in small quantities of that metal, are most likely to purchase the metal as a by-product from a large metal smelting operation. Then there are metals such as chromium which may be discovered by 'accident' or design by a metals exploration company which may then join forces with a mainstream production (and sales) company, and proceed to extract the chromite ore, with the probability that it has reached an off-take agreement with a user for its product. In 2010, the EC emphasised that the supplier base for such products (that is, industrial minerals) is in many cases highly concentrated (EC, 2010).

Many of the industrial minerals companies are usually vertically integrated in a manner that would be unusual in the metals mining industry. If they are mining the raw material, their operations tend to have a life of >50 years, hence exploration is not a big consideration. They are typically legalistic, monopolistic, stock-market conscious and blue-chip companies.

With the increasing use of specialty minerals, such as rare earths, cobalt and lithium and their presence within the Critical Raw Materials framework of the EU, the structure of the companies involved in the exploration for, the development of mining projects and the processing of these materials is quite diverse. It spans the spectrum of junior exploration companies, metal mining companies and industrial mineral processing companies. These distinctions have become central to the continuing development of European industry and will be further examined below.

Resource exploration and extraction in command economies

The author notes that it was very difficult to obtain information on the exploration philosophy of entities within the Command Economies. Effectively the only data available is from "economics-centred" papers. However, based on personal experience in Kazakhstan, additional comments from Duncan Large and from colleagues who have carried out work in the former CIS during the past 20 years, the following is a brief commentary.

Basically, in the twin industries of exploration and mining, a central authority issues a command to identify particular raw materials to meet the demand requirement of the economy. Large, centrally controlled exploration teams are mobilised with a single focus to conduct multi-annual programmes. These teams made discoveries, which were then brought into production, often irrespective of their economics, the only criteria being that the essential needs of the overall economy be met.

With the collapse of the communist regimes in the 1980s, a transition to "western" style exploration ensued and major "western" mining companies prepared for the "Great Leap" eastwards. Unfortunately, it turned into a weak-kneed limp (Large, pers comm). Amongst the reasons for this failure is that many of the philosophical legacies of the communist era remain deeply embedded in the economic systems. Today in Eastern Europe another Command Economy entity, China, is playing a major role in resource development.

Discussion

According to ERA-MIN (2013) *"The EU currently imports between 60 and 100% of all metals used by its industry, with attendant penalties for the continent's balance of payments and security of supply"*, thus *"One of Europe's challenges is to secure sustainable supply of raw materials, increasingly from European sources."* As noted earlier, minerals exploration is often not even mentioned and it is usually conflated with "mining". Since exploration is a fundamental pre-requisite to resource production, this paucity of reference lies at the heart of Europe's failure to encourage and facilitate a successful minerals exploration industry and its knock-on effect of a sustainable mining industry. Securing an indigenous and sustainable supply of raw materials can only be achieved if it is recognised that a separate minerals exploration industry is required, and this cannot be done without specifically incentivising exploration.

Minerals exploration and mining are two distinct sectors. Exploration is a faith-based risk: does the deposit being sought even exist? Mining has huge financial risks. Within centrally controlled economies and most of the non-English speaking countries in the EU, exploration risk is undertaken either by a state agency or a state-controlled mining company. The true cost of exploration and the very high risk attaching to it have been hidden.

At present there is much emphasis on deep deposits to the detriment of looking for medium-near surface (50–300m) deposits. Such deposits should be easier to find and are most likely to be found by cost-efficient minerals exploration SMEs, which will identify not only new deposits but provide excellent clues in the search for deeper deposits. Indeed, *"In the past 2-3 years, renewed interest in the minerals sector has led to an expansion of mining, particularly around the fringe of Europe, from Ireland through Scandinavia and eastern and southern Europe to Portugal"* (Grennan and Clifford, 2018). One of the long-term goals of the EC is that exploration activity is spread out throughout Europe.

Currently China, a major command economy, is dominating the supply of raw materials, particularly those indispensable to carbon-neutral renewable energy technologies. As Šefčovič (2019a) said: *"we cannot sit idle while China is taking control of all the supply"*. He continued *"So, we need to invest strategically into both primary (exploration, extraction and refining) and secondary raw materials (recycling)"*. This will only happen with the recognition that minerals exploration is a very high-risk business. The ad-hoc Group (EC, 2010) recommended that there should be policy actions which would improve the fair treatment of the extraction industries and to develop *"a more streamlined permitting system"*. The ERA-MIN roadmap (2013) is one of the few EC documents that highlights the need for exploration. It notes that within the EU exploration is lagging far behind most developed countries, and that its facilitation is dependent on *"clear enabling public policies"*. A further recommendation from ERA-Min (2013) includes the formulation of appropriate actions that "include the development of exploration programmes co-financed by the public and private sector in Europe and the host country".

Conclusion

The evidence suggests that the best and most efficient way to find a deposit is to allow small exploration companies to flourish, whereby they can raise high risk finance and/or obtain exploration funding from major mining companies. Both systems have enjoyed success. The exploration and research goals must seek to develop a cradle-to-gate (from geological resources to the marketed minerals and materials) as a public good. SMEs within the minerals exploration sector have a very good track record.

However, thus far many of the grant aid programmes are highly bureaucratic. Small companies cannot afford the time and lack the administrative resources to apply. There needs to be a grant level below which the administrative procedures are relaxed. The EU has been one of the foremost supporters and promoter of SMEs and within the EU, the requirement to have at least two partner countries should be retained. It is hereby recommended that grants of up to €500,000 (with no minimum) per annum, for a minimum of five years, be made available to SMEs who have matching equivalents, and that national tax legislation to encourage exploration investment (similar to other jurisdictions) be adopted. This would have the double effect of being attractive to SMEs and attractive, indirectly, to major mining and industrial companies.

The importance of mining for rural development is self-evident, if only because 'a mine is where you find it', it cannot be moved. As the EU does not have a self-sustaining Critical Raw Materials mining industry, the only way to restart it is with SMEs, known in the industry as "Junior Companies". Given the EC's onus on the development of the SME sector, the supply of indigenous raw materials for European industry provides a wonderful chance for the development of a symbiotic relationship between EC funding, junior mineral exploration companies and ensuring security of supply of raw materials.

Acknowledgements

I wish to acknowledge and thank Emer Blackwell and John Clifford for the many positive suggestions and their editing expertise.

References

ERA-MIN (2013). The first ERA-MIN joint call on sustainable and responsible supply of primary resources. Accessed in 2013 and March 2nd 2020.

European Commission, (2010). Critical raw materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials. Brussels.

Grennan, E.F. and Clifford, J.A. (2017). Resource sustainability – Geology is the solution. *European Geologist* 44, 28¬–31.

Mancini, L. Benini, L. and Serenella, S. (2018). Characterisation of raw materials supply based on supply risk indicators for Europe. *The International Journal of Life Cycle Assessment*, 23, 726–738. DOI: 10.1007/s11367-016-1137-2

RMIS (2019). RMIS Newsletter no. 1 (November 2019). Joint research centre (JRC), Raw Materials Information System. European Union.

Šefčovič, M., (VP European Commission) (2019a), Presentation to the European Investment Bank (June 2019). Accessed August, 2019.

Šefčovič, M., (VP European Commission) (2019b). Towards a green industrial policy for the EU. Presentation in Brussels at the Ambrosetti Club Europe (July 9th) on EU Industrial Policy. Accessed August 2019.

The Italian Database GeMMA: from monitoring production to cataloguing mining wastes, a starting point for recovering critical raw materials from abandoned mines?

Mauro Lucarini, Roberta Carta, Fiorenzo Fumanti, Lucio Martarelli and Monica Serra*

The Geological Survey of Italy (ISPRA) is developing the GeMMA geodatabase by collecting all relevant information (e.g. activities, resources/reserves, production figures, and mining wastes) on Italian extractive sites from available sources. Attention is also given to extractive waste from closed or abandoned storage facilities – usually heaps or ponds – that can contain recoverable raw materials. The main purpose of the database is to define the situation of both active and historical extractive resources from mines and quarries, including geological, environmental, cultural and economic aspects. GeMMA aims to become a valid tool for developing national and regional policies oriented towards the sustainable mining/quarrying of primary mineral resources, in a circular economy perspective, considering also the exploitation potential of any secondary resources produced.

Le Département des Etudes Géologiques d'Italie (ISPRA) développe la Base de données GeMMA en recueillant des informations pertinentes (activités concernant les ressources et réserves minières, les volumes de production et les déchets miniers) provenant des données disponibles pour les gisements italiens en exploitation. Une attention particulière est prêtée également aux déchets d'exploitation stockés en des lieux confinés ou abandonnés – habituellement sous forme de terrils ou en bassins – qui peuvent renfermer des matières premières récupérables. L'objectif principal de cette Base de données est de préciser la situation des ressources d'exploitation, à la fois actuelles et anciennes, produites par les gisements miniers ou les carrières, en incluant les volets géologique, environnemental, culturel et économique. L'objectif de GeMMA est de devenir un outil reconnu pour le développement des politiques nationales et régionales orientées vers les ressources minérales primaires, renouvelables, extraites de gites miniers et de carrières, dans le cadre d'une économie circulaire, en tenant compte aussi de l'exploitation potentielle de toutes les ressources secondaires produites.

El Servicio Geológico de Italia (ISPRA) está desarrollando la base de datos geológicos GeMMA mediante la recopilación de toda la información relevante (por ejemplo, actividades, recursos / reservas, cifras de producción y desechos mineros) en sitios de extracción italianos provenientes de fuentes disponibles. También se presta atención a los desechos extractivos de instalaciones de almacenamiento cerradas o abandonadas, generalmente rellenos o balsas, que pueden contener materias primas recuperables. El objetivo principal de la base de datos es definir la situación de los recursos extractivos activos e históricos de las minas y canteras, incluidos los aspectos geológicos, ambientales, culturales y económicos. GeMMA apunta a convertirse en una herramienta válida para desarrollar políticas nacionales y regionales orientadas hacia la extracción minera sostenible de recursos minerales primarios, en una perspectiva de economía circular, considerando también el potencial de explotación de cualquier recurso secundario producido.

Raw materials in Italy: a general overview

The production and supply of mineral raw materials from mines and quarries are of strategic importance for the economy, both for the European Union and on a national scale. Although the EU has an important role in the world production of construction minerals and industrial minerals, for many raw materials, whose demand is continuously increasing, the European industry remains heavily dependent on imports, even from countries where mining/sourcing is not always taking place responsibly and sustainability is often poorly addressed. Europe, including Italy, therefore needs to better manage its untapped mineral resources, including the implementation of more efficient recovery and recycling strategies. In this sense, we are moving towards addressing the challenging opportunity of combining the economic competitiveness of production with a socially acceptable impact on the environment through "sustainable mining" (Carvalho, 2017; Careddu *et al.*, 2018).

Geological Survey of Italy (ISPRA), Via Vitaliano Brancati 48, 00144 Rome, Italy
* mauro.lucarini@isprambiente.it

In Italy, despite the obvious decrease in production recorded since 2008, the extractive industry of non-energy mineral resources remains an important economic sector (***Figure 1***), in particular for industrial and construction minerals. Thus, at national level, Italy should take on the task of launching a shared strategy between the state and the regions, in compliance with their respective skills, which can maintain and strengthen the competitiveness of country's mining industry with a view to sustainable management and development, based on resource-efficient value chains and related increased reuse and recycling capacity.

Figure 1: Active quarry in the Apuan Alps (Carrara Marble District, Tuscany).

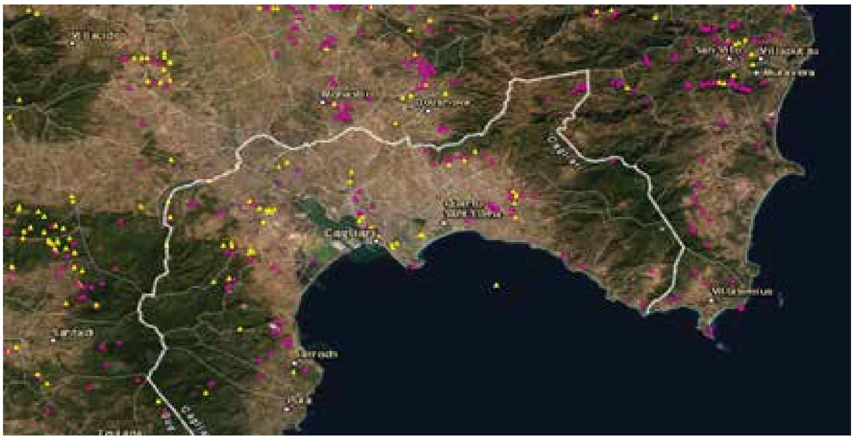


Figure 2: Output of the preliminary GeMMA geodatabase showing the closed and active mining sites for non-energy minerals in the southern Sardinia. Since information is derived from different databases, a cross-check of the site location was performed. The verified and harmonized sites have been reported in violet, the undefined and not still verified sites are in yellow. The off-shore site is a marine sand extractive site for beach nourishment.

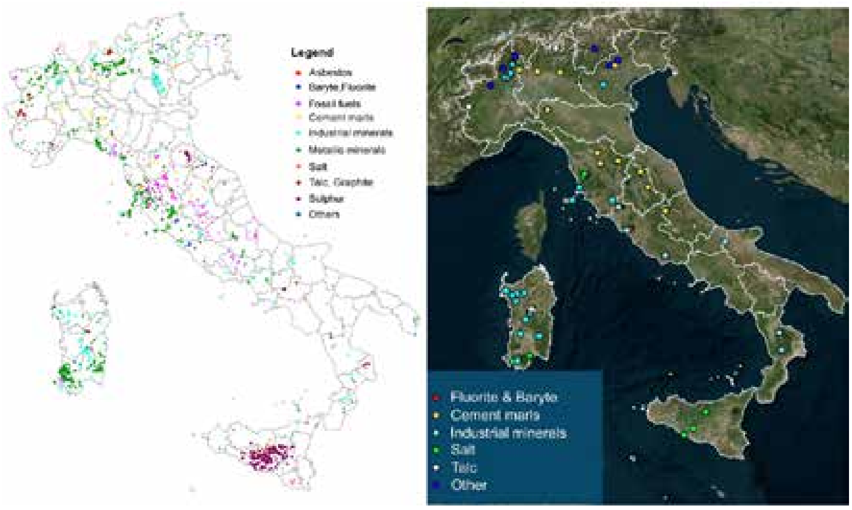


Figure 3: Distribution of mines operating between 1870 and 2018 (left), and current mining concessions (right).

Table 1: Mines production (tons) in Italy between 2015 and 2017.

	2015	2016	2017
Cement marls	5185	5537	5980
Industrial minerals (Kaolin, Feldspar, Bentonite, Clays)	5223	5703	6186
Salt	2081	2085	2147
Others (Talc, Baryte, Fluorite, Olivine, Magnesium salts)	1490	345	510
TOTAL production (t*1000)	**13980**	**13671**	**14823**

Legislative framework in Italy

The mining legislation in Italy still dates back to Royal Decree No. 1443/1927, which distinguishes the extractive industries of strategic minerals (first category, mines) and those of minerals with less economic impact (second category, quarries and peat bogs). The mines are state-owned and subject to a concession procedure, while the quarries fall under private law and are subject to an authorization procedure (Carta *et al.*, 2017a).

Nowadays the administrative and technical skills relating to the extraction of non-energy minerals have been transferred, at different times, to the regions (quarries: Presidential Decree 24 July 1977 No. 616; mines: Legislative Decree March 31, 1998 No. 112 and Legislative Decree June 22, 2012 No. 83); in addition, at different times, all regions have legislated on the matter. The absence of national guidelines has generated diversified regional planning and heterogeneous databases in terms of data quality and data completeness. This situation requires the collection and harmonisation of the available data and their organisation in a dedicated IT structure to obtain an organic framework at national level. Italy is one of the few European countries that still does not have a national inventory of ceased, active and operating not-energy mining activities.

The mineral resources database of Italy (GeMMA)

Taking into account the Italian mineral data fragmentation, the Geological Survey of Italy (ISPRA) is building a *Geological, Mining, Museum and Environmental Database* (***Figure 2***) to collect all relevant information from national and regional/provincial public and private sources. Based on the Minerals4EU Project (refinanced in 2018 through GEOERA by the Mintell4EU Project, which ISPRA is a partner of) the PostgreSQL database is being designed with an INSPIRE-compliant architecture and contains the geographic and documentary information of mining sites (quarries and mines: active, closed or abandoned and restored) of the entire Italian territory (Carta *et al.*, 2017b). It responds to the need to harmonise information with the participation and sharing of the regions through shared projects.

The main purpose is to define the national situation of mining and quarrying, including geological, environmental, economic and cultural aspects, with particular attention to the sustainability of extraction practices and to the potential exploitation of the decommissioned or abandoned mining assets, including mining wastes piled up over time.

To each coded mining site has been associated information related to data sources, type of mining site, state of activities, type of extracted ore, type of management, presence of park/museum and environmental conditions. So far, all the active quarries and mines within the national territory have been identified and georeferenced. About 90% of the mines opened since 1870 have been located too.

Mines in Italy

Italy has a long history of mining extending back to the Pre-Roman times. It is our intention to identify all of the ancient mining sites. At present, more than 3,000 sites have been identified in the period since 1870 (Unification of Italy) to 2018 (***Figure 3***). Exploitation of metallic minerals (now zeroed out) was widespread in the Alps, Tuscany, Calabria and Sardinia. Sulfur mines (also zeroed out) were operating in Sicily and to a lesser extent, in Marche and Romagna. Until 1950, Sicily was the world's largest sulfur producer. Coal (mainly lignite) was exploited along the alluvial plain of central Italy. Currently, 107 mining concessions are active but only 67 mines are operating with the extraction of industrial minerals, mainly for ceramic industry, cement marls and salt (***Table 1***). None of the operating mines involves extraction of metallic minerals. The Pb-Zn-Ag Gorno mines (Lombardy), which ceased operation in 1980, are scheduled to return to production in 2020-21. Several prospecting permits for metallic minerals (Ni, Pb, Zn, Co, Au, Ag, Cu) have been granted in the Alpine region (Piedmont and Lombardy) (Carta *et al.*, 2017b; ISPRA, 2019).

Quarries in Italy

Because of Italian geological complexity and lithological diversity, the exploitation of aggregates and dimension stones from quarries concerns a wide range of rocks. All active quarries sites have been georeferenced with an evaluation of the state of activity by means of regional data or remote sensing analyses (***Figure 4***). At the end of 2017, 4,368 quarries were authorised but, due the sectorial economic crisis, only 2,630 were operating. Of the authorized sites, 67% concern the extraction of "sand, gravel and debris" (1,321 sites) and "limestone, marl and chalk" (1,646 sites) (***Figure 5***). Sand and gravel quarries are widespread throughout the national territory along the valleys and plains, with an obvious concentration in the Po Plain. At a national level, limestone, most of it crushed for aggregate production, is the most exploited lithology in Apulia, in the central Apennine, in western Sicily, northern Lombardy and in Veneto and Friuli-Venezia Giulia regions. This category includes also travertine, intensely extracted mainly in the district of Guidonia-Tivoli, near Rome. Sandstone extraction takes mainly place in the Northern Apennine. The exploitation of effusive igneous rocks is developed in Sicily and Campania active volcanic areas, in the Pleistocene Latium volcanoes (tuff, basalt, pozzolana) and in the Permian of Trentino-Alto Adige (porphyry). Intrusive igneous rocks mainly characterise quarrying in Sardinia (granite). Metamorphic rocks are intensively exploited in the Alpine arc, especially in Piedmont (gneiss), in the Apuan Alps (Carrara Marble) and in Liguria (slate) (Carta *et al.*, 2017b; ISPRA, 2019).

Figure 4: Distribution of authorized quarries in 2017.

Mining waste from a circular economy perspective

Extractive industries (mines and quarries) have provided, and currently provide, mineral raw materials that are essential to related downstream industries and economic sectors, but at the same time they have generated huge quantities of mining wastes. These wastes may include waste rocks (e.g. overburden or wall-rock), mineral processing wastes (e.g. tailing sand) and exploration/resource drilling wastes (e.g. drill cuttings/chips) and they may still contain a fraction of valuable and potentially recoverable mineral (***Figure 6***). The above-mentioned wastes may represent potential secondary resources of critical and other mineral raw materials, which are currently in growing demand and for which the EU depends on imports.

After numerous accidents caused by the inadequate management of extractive wastes, the EU Commission issued the Extractive Waste Directive (D 2006/21/EC) in order to limit their production and to prevent or reduce, as far as possible, any adverse effects on the environment or on human health. This Directive states that in active mine areas the extractive waste is subject to a *management plan* for the treatment, recovery and disposal with maximum utilisation of the extracted waste resource (Article 5); while for closed or abandoned mine areas the extractive waste is subject to the *inventory* of waste facilities which cause serious negative environmental impacts or human health (Article 20).

Concerning Italian mining sites, attention is given to extractive waste catalogued according to Article 20 of 2006/21/EC Directive. These are wastes produced in the past and contained in closed or abandoned storage facilities. The term closed means a

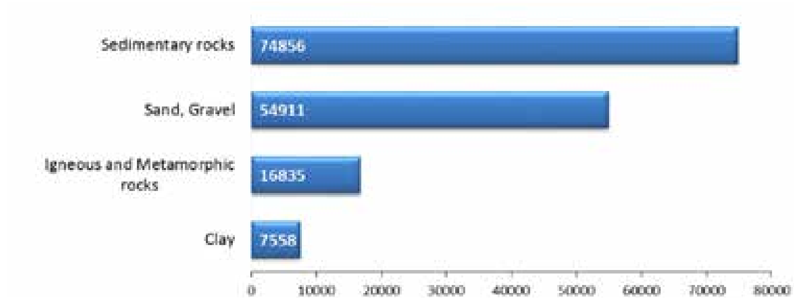


Figure 5: Quarrying production in 2017 (tons).

Figure 6: Extractive Waste Facilities. On the left Monteponi Mine red muds, on the right Masua Mine tailings pond.

Table 2: Comparison between CRM (EU CRM list, 2017) and Italian inventory of extractive waste closed/abandoned facilities (art.20 of Legislative Decree, 2008).

storage facility that no longer receives waste, stockpiled in historical time and before the adoption of the Mining Waste Directive (2006/21/EC), usually disposed of in heaps and ponds.

Each Member State has implemented the directive in its own legal system and, for Italy, Legislative Decree No. 117/08 was issued prescribing the realisation of "the Inventory of Extractive Waste Facilities" (Legislative Decree 117/08, Article 20). The information catalogued in it, in some cases, may point out wastes potentially containing critical raw materials (CRMs) in relevant quantities and concentrations (e.g. indium or germanium in zinc mineral processing tailings or gallium in wastes related to bauxite mining), thus allowing the evaluation of their possible recovery. Particular attention should be given to those facilities (closed or abandoned) that are assessed as having high potential amounts of CRMs and other valuable minerals and/or metals on the basis of the previous extractive activity or analytical sampling data.

Currently, no database, neither in the EU nor in Italy, reports the volumes, mineral resources and related metal grades of the extractive waste deposits (for closed/abandoned and active mines), classified on the basis of the main mineral commodities primarily exploited, the types of waste, and the volumes and compositions of the different waste streams produced across mineral value chains. Nevertheless, from a circular economy perspective, extractive wastes are considered to be a potential source of valuable minerals and/or metals, including CRMs, that may be targeted for recovery. In fact, increased recovery of CRMs from extractive wastes can 1) reduce the amount of storage and stockpiled extractive waste, and mitigate or even minimise the associated environmental impacts and 2) lead to adjustments in primary mining by contributing to securing the growing supply needs of minerals (Mathieux *et al.*, 2017; Eco-Efficiency *et al.*, 2019a).

So far, the recovery of CRMs from extractive waste is rather low (e.g. <1% for rare earths, In, Ge), but old mines often focussed on the production of one or few commodities, while recent technological progress increasingly allows the production of additional co-products and by-products. Thus, it is possible that associated minerals and/or elements, not known, poorly detected or not exploited during past mining activities are still present (and potentially exploitable) in the old extractive waste facilities. Furthermore, low-grade ores with concentrations below the cut-off grade at the time of mining may become extractable and their recovery may become economic due to technology changes, growing demand and elevated market prices for the minerals and metals contained in the ore.

The aim of the circular economy is to boost economic growth by promoting the implementation of resource- efficient practices and creating many opportunities for the rational use of raw materials. The European Commission recognises the importance of the circular economy and is developing and implementing an action plan outlining new product requirements and new principles for assessing environmental performance using the life cycle assessment method (Ghisellini & Ulgiati, 2019). At the same time the EC promotes the application of a circular economy in assessing the mineral resource and metal recovery potential of old/historical extractive wastes, considering it as best practice in extractive waste management plans (Eco Efficiency *et al.*, 2019a; 2019b). The dimension of the circular economy in Italy, in terms of added value, is worth just under 1.5% of the national added value. In 2014, there were 47,487,404 tonnes of mining wastes deriving from extractive activities (processing wastes), representing a percentage of 37% of the total wastes volume in Italy (CONAI, 2018).

In fact, available analytical data of several extractive wastes show elevated contents of metals which are also included in the latest European list of CRM (updated every three years) (***Table 2***), enabling them as potential resources of valuable minerals and metals. Those that were previously wastes have become new sources of raw materials for other production cycles and well-designed new products that enter the sustainable revolution that the circular economy wants to model (Moschini & Bompan, 2017). Recovery and reuse may become an integral part of the processes, together with all those measures aimed at reducing production costs, less dependence on critical raw materials, a dynamic contribution to the growth of job opportunities, and the containment of pollution from waste and emissions during the production process.

Finally, even in the extractive field, the circular economy represents an extraordinary opportunity to bring about the desired revolution in optimising the use of natural resources and sustainable waste management, limiting the number and size of landfills, and increasing the recovery rate from wastes.

Conclusions

The many aspects and issues linked to the extraction of non-energy mineral resources are, at the Italian national level, uneven and incomplete. Up until now there has been no national IT structure shared between the state and the regions that is dedicated to the integration of the geological, mining, environmental, cultural and management aspects of the extractive activities.

By means of the creation of the GeMMA database, the Geological Survey of Italy (ISPRA) intends to share available, harmonised and INSPIRE-compliant mineral information with the European Union Raw Materials Knowledge Base (EURMKB). In addition to the basic data coming from other existing databases, the database is also designed for gathering a series of information related to environmental restoration of the sites, the management of mineral waste, and recycling plants for construction and demolition materials.

The database testing period will be carried out in collaboration with the Regional Geological Surveys and with the Regional Agencies for Environmental Protection, also trying to promote agreements between the various regional offices, including those responsible for extractive activities. An advanced version will then be shared with ISTAT (Italian National Institute of Statistics) and with the Raw Materials Laboratory, as well as with the concerned ministries and regions, in order to achieve a participatory, integrated and comprehensive result.

In other words, it is deemed necessary, in compliance with the specific skills of the various territorial levels, to create flexible conditions for dialogue and convergence governed by the principle of loyal and equitable collaboration. Within these challenging discussions, the Geological Survey of Italy hopes that GeMMA will become a valuable support tool for the development of national and regional policies oriented towards sustainable production and the efficient use of primary and secondary mineral resources, addressing and targeting the implementation of the circular economy.

References

Careddu, N., Dino, G.A., Danielsen, S.W., Přikryl, R., 2018. Raw materials associated with extractive industry: An overview. *Resources Policy*, 59. 1-6. DOI: 10.1016/j.resourpol.2018.09.014.

Carta, R., Dacquino. C., Di Leginio, M., Fratini, M., Fumanti, F., Lettieri, M.T., Lucarini, M., Patanè, A., Serra, M., 2017a. Verso l'inventario geominerario e ambientale delle risorse minerarie solide Italiane (Towards the geomineral and environmental inventory of Italian solid mineral resources). Rapporto Ambiente-SNPA 01/2017, Ambiente in Primo Piano.

Carta, R., Dacquino, C., Di Leginio, M., Fumanti, F., Lettieri, M.T., Lucarini, M., Patanè, A., Serra, M., Vittori, E., 2017b. La Banca Dati Geologico Mineraria Ambientale (GeMMA) (The Geological, Mining and Environmental Database (GeMMA)). *Patrimonio industriale (Rivista AIPAI),* 1.(17-18). 44-57.

Carvalho, F. P., 2017. Mining industry and sustainable development: Time for change. Food and Energy Security, 6 (2). 61–77. DOI: 10.1002/fes3.109

CONAI, 2018. L'Economia Circolare in Italia: Executive Summary (The Circular Economy in Italy: Executive Summary). Consorzio Nazionale Imballaggi. URL: ***http://www.cial.it/wp-content/uploads/2018/11/economia-circolare_executive-summary_novembre-2018.pdf***

Eco Efficiency Consulting and Engineering Ltd., WEFalck, Kertész, B., Pöyry Finland Oy, CRS Ingenería, Directorate-General for Environment (European Commission), 2019a. Development of a guidance document on best practices in the extractive waste management plans. Circular economy action – Study. 59 p., DOI: 10.2779/061825

Eco Efficiency Consulting and Engineering Ltd., WEFalck, Kertész, B., Pöyry Finland Oy, CRS Ingenería, Directorate-General for Environment (European Commission), 2019b. Study supporting the elaboration of guidance on best practices in the Extractive Waste Management Plans. Final Report. DOI: 10.2779/842100

Ghisellini, P., and Ulgiati, S., 2019. Circular economy transition in Italy. Achievements, perspectives and constraints, *Journal of Cleaner Production*, Volume 243, Article No. 118360. DOI: 10.1016/j.jclepro.2019.118360.

ISPRA, 2019. Annuario dei Dati Ambientali. Istituto Superiore per la Protezione e la Ricerca Ambientale, Rome.

Mathieux, F., Ardente, F., Bobba, S., Nuss, P., Blengini, G., Alves Dias, P., Blagoeva, D., Torres De Matos, C., Wittmer, D., Pavel, C., Hamor, T., Saveyn, H., Gawlik, B., Orveillon, G., Huygens, D., Garbarino, E., Tzimas, E., Bouraoui, F. and Solar, S., 2017. Critical Raw Materials and the Circular Economy – Background report. JRC Science-for-policy report, EUR 28832 EN, Publications Office of the European Union, Luxembourg. DOI:10.2760/378123

Moschini, P., Bompan, E., 2017. Circular Economy as a Key for Environmental Regeneration. 27 September. ***https://medium.com/@ECONYL/circular-economy-as-a-key-for-environmental-regeneration-207ea34d21f3.***

Hidden graphite resources in Turkey: a new supply candidate for Europe?

Alp İlhan[1], Ramazan Sarı[2] and Yonca Yıldırım[3]*

Natural resources always have critical and strategic importance for emerging countries. The EU's Raw Materials Initiative has developed strategies for 27 critical raw materials, one of which is graphite. Turkey has a graphite mining history of more than 30 years; however, production limits have stayed below economic benefits due to lack of exploration knowledge and technological background to increase ore grades. As a first step, investment in systematic exploration of graphite resources is necessary to increase the supply of resources and then R&D to develop the technology to produce higher grade graphite ore. This paper aims to show the potential graphite mineralisation with new ore discoveries and its geoeconomic importance to both Turkey and surrounding European countries.

Les ressources naturelles ont toujours une importance critique et stratégique pour les pays émergents. L'Initiative EU concernant les matières premières a développé des stratégies spécifiques pour 27 matières premières, critiques, l'une d'entre elles étant le graphite. La Turquie possède, pour le secteur minier du graphite, une expérience historique supérieure à une trentaine d'années ; cependant, les contraintes de production n'ont pas permis d'atteindre un niveau de bénéfice économique en raison du manque de compétence en exploration et d'expérience technologique pour produire un minerai de haute qualité. Au titre d'un premier pas, un investissement en exploration systématique des ressources de graphite est nécessaire pour augmenter les réserves de minerai et ensuite, grâce aux activités de R&D, développer la technologie pour produire un minerai de graphite enrichi. Le but de cet article est de montrer les potentialités du graphite avec la découverte de nouveaux gisements et son importance économique pour, à la fois, la Turquie et les pays européens.

Los recursos naturales siempre tienen una importancia crítica y estratégica para los países emergentes. La iniciativa europea de materias primas ha desarrollado estrategias para 27 materias primas críticas, una de las cuales es el grafito. Turquía tiene una historia minera del grafito de más de 30 años; sin embargo, los límites de producción se han mantenido por debajo de los beneficios económicos debido a la falta de conocimiento de exploración y tecnología para aumentar las leyes del mineral. Como primer paso, la inversión en la exploración sistemática de los recursos de grafito es necesaria para aumentar la oferta de recursos y luego en I + D para desarrollar la tecnología para producir mineral de grafito de mayor ley. Este documento tiene como objetivo mostrar la potencial mineralización de grafito con nuevos descubrimientos de mineral y su importancia geoeconómica tanto para Turquía como para los países europeos circundantes.

Introduction

Graphite is one of the most essential non-metallic minerals, with a wide variety of applications. Its physical-chemical properties and its high resistance to heat make it an excellent thermal and electrical conductor. It is used in steel manufacturing and for coating the foundry moulds of the metal industry; engine parts, mechanical seals, anti-corrosive paint, lithium-ion and alkaline batteries, small electronic devices such as smartphones, electrical cars are the major industry branches that consume graphite minerals. Graphite is listed as one of the critical raw materials for the European Union (EU).

Graphite is a natural form of carbon (C) and is characterised by hexagonal tabular lattice layers. Thermal conductivity is anisotropic, very high in the direction parallel to the plane of the layers and low in the perpendicular direction. It is soft, flexible and sectile but not elastic. Commercial sources of natural graphite are commonly classified as flake, vein or amorphous.

Flake graphite is associated mostly with high-grade metamorphic rocks where organic carbon deposited within sediments was transformed into graphite by pressure typically exceeding 5 kilobar and temperatures above 700 °C. Graphite-bearing rocks include orthoquartzite and marble, but more commonly are quartz–biotite schist and gneiss. The graphite is often present as flakes or elongated patches aligned with the schistosity or banding to form lenses. High purity flake graphite can be produced by flotation without chemical purification. Flakes are flexible and can be rolled into very small potato shapes for use in battery anodes. Product grades change between 85-97 %Cg (total carbon grade in graphite form).

Vein graphite occurs as fracture-fill vein or pipe-like bodies where graphitic carbon and/or carbon-rich fluids have migrated and precipitated as graphite masses. High-grade, vein-style graphite is known of in several countries, but at present is produced only in Sri Lanka. Product grades range between 90-99 %Cg.

Amorphous graphite is produced mostly from anthracitic coal seams that have undergone variable graphitisation during contact or high pressurised regional meta-

[1] Soner Temel Mühendislik İnş. ve Tic. A.Ş., İstanbul
[2] Altınordu Madencilik San. Tic. A.Ş, Ankara
[3] Lidya Madencilik San. ve Tic. A.Ş., Ankara
* ramazansari@geologist.com

Table 1: Major graphite producers and production numbers between 2011 and 2019. Sources: [1] Jara et al., 2019; [2] Statista, 2019; [3] USGS, 2020

Year of Production	2011 [1]	2012 [1]	2013 [1]	2014 [1]	2015 [1]	2016 [1]	2017 [1]	2018 [2]	2019 [3]	Total Production (t)	Reserves (t) [3]
China	800.000	800.000	750.000	780.000	780.000	780.000	780.000	630.000	700.000	6.800.000	73.000.000
India	150.000	160.000	170.000	170.000	170.000	170.000	150.000	35.000	35.000	1.210.000	8.000.000
Brazil	73.000	110.000	95.000	80.000	80.000	80.000	95.000	95.000	96.000	804.000	72.000.000
Canada	25.000	25.000	20.000	30.000	30.000	21.000	30.000	40.000	40.000	261.000	
North Korea	30.000	30.000	30.000	30.000	30.000	30.000	6.000	6.000	6.000	198.000	2.000.000
Madagaskar	4.000	4.000	4.000	5.000	5.000	8.000	7.000	46.900	47.000	130.900	1.600.000
Russia	-	-	14.000	15.000	15.000	15.000	19.000	25.200	25.000	128.200	
Turkey	**10.000**	**5.000**	**5.000**	**29.000**	**32.000**	**32.000**	**4.000**	**2.000**	**2.000**	**121.000**	
Mexico	7.000	8.000	7.000	22.000	22.000	22.000	4.000	9.000	9.000	110.000	3.100.000
Ukraine	6.000	6.000	6.000	5.000	5.000	5.000	15.000	20.000	20.000	88.000	
Norway	2.000	2.000	2.000	8.000	8.000	8.000	8.000	16.000	16.000	70.000	600.000
Pakistan	-	-	-	-	-	14.000	14.000	14.000	14.000	56.000	
Zimbabwe	-	6.000	4.000	7.000	7.000	7.000	6.000	2.000	2.000	41.000	

morphism. This form of graphite is typically massive and has comparatively high levels of fine-grained impurities that are not easily separable from the graphite. Commercial grades typically range from 75% to 85 %Cg. Synthetic graphite is made by heating amorphous carbon materials, such as calcined petroleum coke of suitable crystalline quality, in a reducing environment at temperatures between 2,300 and 3,000 °C to convert it to graphite.

In the economic evaluation of graphite deposits, the following factors are important: a) type, size, grade and tonnage of the ore bodies, and b) the grain size and distribution of the graphite flakes in the ores. Commercial graphite is a relatively expensive industrial mineral and to obtain good quality graphite concentrates, beneficiation is essential.

World graphite demand and Turkey's position

Worldwide consumption of graphite has steadily increased since 2011. Natural graphite production to date is about 1 million tonnes annually and amorphous graphite comprises about 60% of the total production. The demand for graphite is expected to increase by approximately 4% in the coming years (Jara *et al.*, 2019). Between 2011 and 2019, China produced 6.8 million tonnes of graphite, which equals about 10% of its country reserves and approximately 5% of the world's graphite reserves. China was followed at a distance by Brazil and India (***Table 1***).

Amorphous graphite is mainly used in traditional markets and mostly consumed in the steel and refractory industry. Signs of a rise in demand for steel will also trigger graphite demand, but it is not certain that there will be enough amorphous graphite to support this demand. Countries where the global amorphous graphite reserves are concentrated – such as China, Turkey, India and Brazil – will play an important role in this supply/demand chain.

In terms of graphite production of Turkey, it is not competitive on the world's graphite market, and in fact domestic need is usually met by importing from other countries. There are around 11,000 tons of graphite imports – equivalent to USD 10 million per year in the official figures of our country (***Table 2***). All of these imports are from European countries and China. The imported graphite is used in casting, paint, pencil manufacturing, refractory industries and mineral oils in our country. In graphite mining in the world, especially in developed countries, they can work with much lower grades, and even occurrences similar to those of Turkey can be operated and enriched. It is also a well-known fact in the mining community that Turkish graphite imported by European countries generally returns to Turkey at very high prices.

There is only one active graphite mine, located in the Kutahya district, Western Turkey. The facility in Kutahya-Altıntaş is designed to produce 22,000 tonnes of raw graphite and 8,000 tons of enriched graphite per year if working at full capacity (Ergin, 2014).

Table 2: Turkey's Graphite Export and Import Values by years (source: TUIK, 2018).

Years	Imports		Exports	
	Quantity (kg)	Value (US$)	Quantity (kg)	Value (US$)
2010	11,191,006	8,360,945	220,431	182,214
2011	13,138,032	18,037,589	761,016	983,449
2012	8,170,666	11,268,434	766,132	1,011,839
2013	11,774,936	12,421,665	835,604	1,270,338
2014	8,796,160	8,578,088	662,930	960,505
2015	9,097,408	8,302,168	618,081	758,679
2016	10,846,233	8,824,929	862,167	613,900
2017	13,512,528	11,330,838	1,291,397	966,720
2018	11,093,698	11,839,649	1,624,141	1,291,450

Geology and graphite ore potential of Turkey

Turkish graphite deposits and occurrences have been recorded in Paleozoic high-grade amphibolitic metamorphic rocks in the Menderes Massif, Istıranca Massif, Akdagmadeni Massif, Sultandag Massif (Konya) and Eastern Bitlis Massif. New graphite discoveries are also situated in fine grained material (clays, schists) and carbonate rocks, and mostly found in the vicinity of granitic masses or massifs as well as nearby regions whose with high thermal-gradient-forming main tectonic zones.

The main discovered graphite deposits of the country are; Balıkesir-Susurluk, Kastamonu, Bingöl-Genç, Adıyaman-Sincik, Muğla-Milas, Kütahya-Oysu, Kahramanmaraş-Göksun, Konya, Yozgat-Akdağmadeni and Kırklareli. Aside from these deposits, there are still many undiscovered occurrences, as well as some meta-anthracite deposits which have been under the effect of young volcanic activities located in Mid-Anatolia still in the processes of unfinished graphitisation (Toprak, 2017) (*Table 3* and *Figure 1*).

Turkey's active flagship **Kutahya-Oysu graphite deposit** is located in the southern part of the Kutahya district, Western Turkey (*Figure 1*). Mining operations started in the early 1990s and were suspended for economic and technological reasons between 1993 and 2004. After 2004, increasing demand for graphite resulted in re-establishing the graphite flotation process at the Oysu deposit (*Figure 2*).

Graphite mineralisation in Oysu deposit is presented in the Upper Paleozoic Emirgazi Formation consisting of amphibolite gneiss, schist, quartzite and marble, repre-

Table 3: Graphite deposit and occurrences in Turkey. Sources: [1] Karabacak Madencilik, [2] Malayoğlu et al.,1999, [3] MTA 2017.

Name	Location	Type	Resource/ Reserve	Host Rock	Stage
Oysu	Kütahya	Amorphous	7.2 Mt with 20 %Cg	Metamorphic	Active Mining[1]
Milas	Muğla	Amorphous	500 Kt with 10 %Cg	Metamorphic	Historic Mine[2]
Susurluk	Balıkesir	Crystalline	unknown resource	Metamorphic-Intrusive	Occurrence
Tire	İzmir	Amorphous	350 Kt with <10 %Cg	Metamorphic	Occurrence
Sincik	Adıyaman	Amorphous	30 Kt with 45 %Cg	Metamorphic	Occurrence
Akdağmadeni	Yozgat	Crystalline	100 Kt with 45 %Cg	Metamorphic	Occurrence
Anday	İnebolu	Amorphous	60 %Cg, unknown resource	Metamorphic	Occurrence
Derbent	Konya	Amorphous	unknown resource	Metamorphic	Occurrence
Doğanyurt	Kastamonu	Amorphous	unknown resource	Metamorphic	Exploration[3]
Göksun	Kahramanmaraş	Amorphous	unknown resource	Metamorphic	Exploration[3]

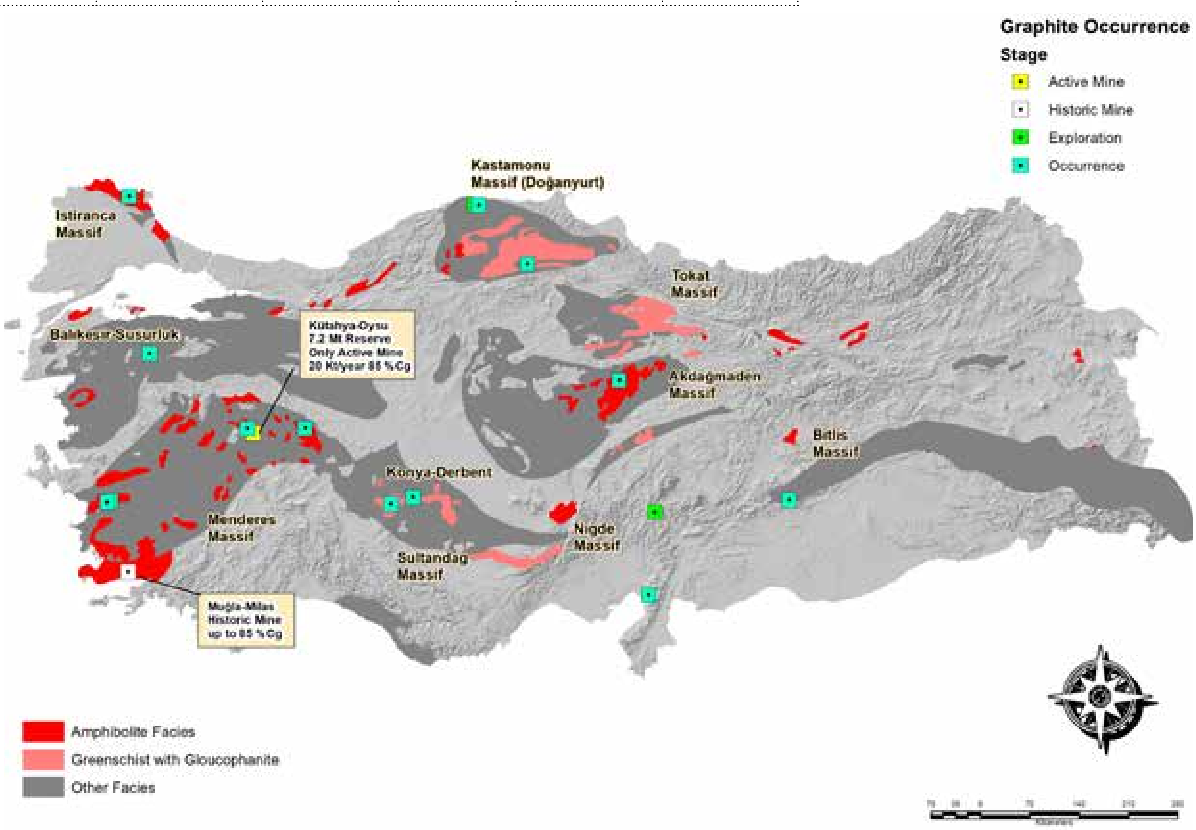


Figure 1: General distribution of graphite occurrences and deposits in Turkey and their lithological relationship with metamorphic terrain.

Figure 2: a) Kırklareli Istranca Massif graphite occurrence (MTA, 2017), b) graphite outcrop sample from Mersin District (Uysal, 2012), c) active graphite mine, Kütahya-Oysu Deposit (Karabacak Company Presentation), d) Muğla-Milas graphite occurrence (Uysal, 2012), e) core drill, Kastamonu Doğanyurt graphite occurrence (MTA, 2017).

senting high temperature and high pressure conditions. Amorphous graphite is seen as disseminated ore along the metamorphic layers. Due to strong tectonic deformation, ore zones are generally discontinuous and the thickness of the ore varies between 5-10 metres (Tufan and Batar, 2015) The deposit comprises 7.2 million tonnes of graphite ore (JORC based) and has 125 million tonnes of graphite upside potential. It has been owned by a private Turkish company since 1992, which has reported that graphite mineralisation is still open at depth (over 225 m) and 15 years of mine life are expected (***http:www.karabacakmaden.com.tr***).

The Mugla-Milas property is also another graphite deposit located within the Menderes Massif and hosted by similar amphibolite gneiss and schist units. The deposit was mined by a private Turkish company in the early 1990s (***Figure 2***).

The Kastamonu-Doğanyurt property is an early stage graphite property defined by the National General Directorate of Mineral Research and Exploration (MTA) Department in 2017. A drilling program has identified several graphite-rich layers within gneiss, granitic gneiss and granodiorite. The feasibility of the property is still being evaluated (***Figure 2***) (MTA, 2017).

Konya-Derbent graphite mineralisations are located 30 km north of the Konya city center. The deposit is presented in high pressure greenschist facies with glaucophanite and sillimanite-rich metamorphic rocks. These types of metamorphic terrains are seen along the Sultandag massif, Kastamonu massif and Tokat massif. The graphite occurrences in the Konya Derbent area are grouped by their geographical and lithological distribution into the Tepeköy, Meydanköy and Tatköy occurrences. At the north of the Tepeköy, there are four types of graphite. The first type of graphite mineralisation occurs within quartzite unit and the thickness of veins varies between 20 cm and 30 cm. The second and fourth types of graphite mineralisations occur mostly in the calc-schist and crystallised limestone. Their thickness ranges from 1 to 5 m. The third type of graphite mineralisation occurs as intercalations with phyllite and its thickness is about 1 m. At the east of the Tatköy, the graphite bearing zone, which is 50 cm to 2 m thick, occurs in metasandstone-phyllite of the Bağrıkurt formation. The graphite layers are laminated and cleaved by deformation and metamorphism. One km NW of the Meydanköy, there are two types of graphite, The first type occurs between phyllite and metasandstone and its thickness varies between 1 cm and 20 cm, The second type occurs over the phyllite-metasandstone and metaquartz conglomerate and its thickness varies between 2 m and 2.5 m. All types of graphite layers are parallel to the surrounding metamorphic rocks (Kurt and Eren, 2000).

Balıkesir-Susurluk graphite ores are of the coarse crystalline graphite type and have the best quality in Turkey. Graphite mineralisation is mostly related to granitic intrusions along the strongly deformed metamorphic rocks. Carbon grades are generally over 70 %Cg; however, the occurrence is located very close to the main Izmir-Bursa highway so that mining operations cannot be permitted. Furthermore, an abundance of coarse crystalline graphite occurrences in the Susurluk district increases the potential for a new discovery in the region (***Figure 2***). Numerous graphite occurrences over Paleozoic Amphibolitic Metamorphic rocks are still open to new discoveries. Recent graphite occurrences at the Eastern Turkey also indicate hidden potential of ore mineralisation. Menderes Metamorphic rocks in Western Turkey host one historic and one active graphite mine and could potentially have more graphite deposits that can be actively exploited (***Figure 1***).

Challenge: graphite beneficiation technology

The increasing demand for high-grade graphite products has resulted in the development of various approaches to remove impurities. Comminution, flotation, gravity separation, leaching and alkali roasting processes with several reagents are generally used to produce and enrich graphite products.

As the size and grade of graphite products are important parameters in their commercial application, it is best to maximise the amount of large flakes and minimise any processing problems that will reduce flake sizes. Liberated graphite is naturally hydrophobic and floatable, and it is well understood that to increase the recovery and grade, liberation has the most critical effect. Careful assessment of liberation and distribution of remaining impurities during beneficiation of graphite ore is needed to avoid overgrinding and to maximise flake size, product grade, and recovery. Comminution flow sheets depend highly on the type of ore to be treated, and liberation characteristics can be variable.

The biggest challenges of Turkey's graphite occurrences is that they exhibit as tiny forms and are disseminated within very small-grained inorganic materials similar to their grain sizes. Grinding is costly and the separation of the materials from each other seems very difficult at the currents technological facilities available in Turkey.

The critical inputs during the enrichment of the graphite samples with flotation are; the pH of flotation, the amount of depressant, the amount of the collector, the amount of the frother, the time of the flotation, the ratio of solid and the size of the particles. Dense media separation (DMS), used for coal cleaning worldwide, is the most efficient industrial gravity-based separator. Generally, the graphite with less gangue minerals but higher carbon content has lower density and tends to float in DMS. Specially produced reactive sets of a corporation for graphite ores have also been tested by several companies on samples from different properties.

Flotation is a generally widespread method applied in graphite ore enrichment process in Turkey. Acid-leaching or alkali roasting methods are also added to the flotation process. These methods were applied for some graphite occurrences such as Muğla-Milas (Malayoglu *et al.*,1999), Yozgat-Akdağmadeni (Kırbaş and Girgin, 2001), Kastamonu-İnebol, Konya-Derbent (Kaya and Canbazoglu, 2009), Balıkesir-Demirkapı (Cifci, 2006) and Kutahya-Oysu (Tufan and Batar, 2015).

Chemical purification by means of leaching is the most common technique to produce high-purity graphite after flotation (Chelgani *et al.*, 2016). Based on the remaining impurities, different acids, such as HCl, HF, H_2SO_4, and HNO_3, or a mixture of these, can be used. The alkali roasting method is an effective method to eliminate both silicates and sulfides from graphite concentrates. High temperature (over 500 °C) alkali roasting would be effective to remove sulfides from the graphite mineralisation.

Malayoğlu *et al.* (1999) investigated early applications of a collector in the flotation study of Muğla-Milas graphite ore. A fuel oil and kerosene mixture was used as a suppressor reagent while Na_2SiO_3 was used as a foaming agent. The experiments were carried out with basic flotation, three-stage cleaning and a single-stage sweep circuit. Flotation tests showed that Milas-Yaylıdere ore can be enriched with flotation and concentrates with 90-92 %Cg are produced.

Kırbaş and Girgin (2001) studied the enrichment of Yozgat-Akdağmadeni graphites using the two-liquid flotation method. Kerosene was used as collector and the effects of reagent dosage, pH, pulp density, flotation time and mixing speed parameters were also investigated. As a result of multistage tests, concentrates were obtained of 30.80 %Cg with 55.24 %Cg recovery at first extraction stage and of 67.71 %Cg with 11.62% recovery at second stage.

In the experimental studies carried out by the MTA at the Konya Derbent Coraklıdere and Mülayimköy graphite occurrences (Civelekoğlu *et al.* 2001). Na_2SiO_3 was used as a silicate suppressor adjusted to Ph:9 conditions with $CaCO_3$, FeS_2 as suppressor, quebracho as collector and MIBC as foamer. Enrichment studies in the Mülayimköy sample found that sufficient yield and carbon grade could not be achieved. In the Coraklıdere sample a concentration of 13.40 %Cg was obtained. In order to increase the grade in the flotation, liberalisation was increased by applying surface abrasion at 65, 70 or 75 pulp densities for 20 minutes, and the constant carbon content reached 18.96 %Cg.

Kaya (2006), studied graphite ores from Kastamonu-İnebolu, Yozgat-Akdağmadeni, Balıkesir-Demirkapı, Konya-Coraklıdere and Kütahya-Altıntaş. Flotation preconcentrates obtained under optimum conditions by applying flotation to the samples were enriched in two stages. In the first stage, enrichment studies with heavy medium were carried out, and in the second stage, direct acid leaching and roasting with NaOH, followed by water and acid leaching. In flotation experiments, kerosene was used as a collector, sodium silicate (Na_2SiO_3) as a suppressant, pine oil was used as a foamer. The effects of pH, solid ratio and grain size were investigated extensively. Results showed that acid leaching and alkali roasting process resulted in partial grade yield, whereas the heavy medium method was not successful.

Ciftci (2006) investigated the enrichment of Balıkesir-Demirkapı graphite ore by applying abrasive mixing and flotation. Kerosene was used as a collector to suppress gangue minerals while pine oil was used as frother and sodium silicate was used as suppressant. The author concluded that 84.43% of total carbon grades can be obtained at 97.27% efficiency.

In a recent study aimed at improving the flotation parameters of Kütahya-Oysu active mine, the effects of ore grain size, ambient pH value, collector, suppressor and foaming amounts were examined. As a result of experiments, it was determined that the optimum ore grain size is -300 microns for efficient flotation of graphite ore; under this size, graphite is plastered on the surface of the gangue minerals and causes a drop in the concentrate grade. Flotation experiments conducted in laboratory conditions after cleaning and sweeping obtained 71.59% flotation yield and 76.89% organic carbon content in the final concentrate (Tufan and Batar, 2015). In addition, a series of leaching operations were applied on the graphite ore of Anamur-Bozyazı region. The experiments were based on enrichment of graphite by dissolving gangue minerals, mostly $CaCO_3$ in graphite. HCl concentration, solid ratio, grain size and leaching time are effective parameters and the effects of these parameters were investigated (Tufan and Batar, 2015).

Results and discussion

World natural graphite demand is directly linked to industrial applications, including refractories, automotive, batteries and lubricants. Refractories for the steel industry remain the dominant market for natural graphite consumption and graphite production has tended to follow global steel production, although hi-tech applications such as battery anodes are driving demand for the mineral. This is potentially one of graphite's fastest growing markets due to interest in electric vehicles, portable electronics and large-scale domestic and commercial energy storage. The major primary producing and exporting countries are China, North Korea and Brazil. Importing countries include the US, China and the EU.

Furthermore, due to the shortage of the available graphite resources, the supply-demand mismatch will be a future global challenge. Both deposit reconnaissance in natural graphite exploration districts and developing compatible purification methods for impurities in graphite are critical (Jara *et al.*, 2019).

Turkey has a long graphite and coal mining history, and geographically it is very close to Europe, which makes it a candidate for the supply of different versions of graphite (natural, synthetic or graphene). Due to recent technology developments to increase carbon grades and produce nanographene technology, along with amorphous-dominant graphite ores that are supported with new exploration targets and concepts (i.e. proximity to igneous rocks), the future graphite potential of the country looks promising.

Recent developments in ion-batteries commercialisation show that amorphous graphite is a suitable resource. Turkey, with a considerable amount of amorphous graphite resources, will be an important candidate for being a key graphite producer. New technologies and R&D studies will change the graphite production challenge into a great chance in the coming years.

References

Chelgani, S. C., M. Rudolph, R. Kratzsch, D. Sandmann & Gutzmer J. 2016. A Review of Graphite Beneficiation Techniques. *Mineral Processing and Extractive Metallurgy Review* 37(1), 58-68. DOI: 10.1080/08827508.2015.1115992

Civelekoglu, S., Erdem, A., Gülmez, A., Sahin, N. 2001. Konya-Derbent-Coraklıdere ve Mülayimköy Grafitlerinin Zenginleştirme Calışmaları (Graphite Enrichment Applications for Konya-Derbent-Coraklıdere and Mulayimkoy Deposits). Ankara, Maden Tetkik ve Arama Genel Müdürlüğü,.

Cifci, F. 2006. Balıkesir-Demirkapı Grafit Cevherinin Aşındırmalı Karıştırma ve Flotasyonla Zenginleştirilebilirliğinin Araştırılması (The Investigation Of Concentration Of Balıkesir-Demirkapı Graphite Ores Using Scrubbing and Flotation). MSc Thesis, Cumhuriyet Üniversitesi Fen Bilimleri Enstitüsü, Sivas.

Ergin Y. 2014. Kayaclar Endustriyel Hammaddeler (Industrial Raw Materials). ***https://www.betonvecimento.com/category/teknik-yayinlar/kayaclar*** (last accessed 2020)

Jara A., Betemariam A., Woldetinsae G., Kim J., 2019. Purification, application and current market trend of natural graphite: A Review. *International Journal of Mining Science and Technology* 29, 671–689. DOI: 10.1016/j.ijmst.2019.04.003

Karabacakmaden, 2012. Oysu Graphite Deposit, ***http://www.karabacakmaden.com.tr*** (last accessed 2020)

Kaya Ö. 2006. Grafit Zenginleştirme Yöntemleri ve Zenginleştirmeye Etki Eden Parametrelerin Araştırılması (Methods of Graphite Enrichment and research of the Parameters Influencing Enrichment). PhD Thesis, Cumhuriyet Üniversitesi Fen Bilimleri Enstitüsü, Sivas.

Kaya, O. and Canbazoglu, M. 2009. Chemical demineralization of three different graphite ores from Turkey. *Minerals & Metallurgical Processing*, 26(3), 158–162. DOI: 10.1007/BF03402229

Kırbaş H. and Girgin İ. 2001. Yozgat-Akdağmadeni Grafitlerinin İki-Sıvı Ekstraksiyonu Yöntemi İle Zenginleştirilmesi Olanaklarının Araştırılması (Investigation of Enrichment of Yozgat Akdagmadeni Graphites by Two-Liquid Extraction Method). The 4th Industrial Raw Materials Symposium, Izmir, pp. 45–52.

Kurt, H. and Eren, Y. 2000. Graphitization of Metasedimentary Rocks In The Western Konya, Journal of Enginnering Sciences, 6(1) 97–100.

Malayoglu U. Cicek T. And Akar A. 1999. Mugla-Milas Grafit Cevherinin Flotasyon Yöntemi İle Zenginleşebilirliğinin Araştırılması (Investigation of Enrichment of Mugla-Milas Graphite Ore by Flotation Method). The 3rd Industrial Raw Materials Symposium, Izmır. pp. 109-113.

MTA. 2017 Activity Report. General Directorate of Mineral Research and Exploration, Turkey. ***https://www.mta.gov.tr/v3.0/sayfalar/kurumsal/belgeler/faaliyet_raporu_2017.pdf***

Toprak, S. 2017. Graphite Presentation, MJD Event.

Statista (2020) Major countries in worldwide graphite mine production from 2015 to 2019. ***https://www.statista.com/statistics/267366/world-graphite-production/*** (last accessed 2020)

Tufan B. and Batar T. 2015. Oysu Grafit Cevheri Flotasyon Parametrelerinin İyileştirilmesi (Improvement of Oysu Graphite Ore Flotation Parameters).Suleyman Demirel University, *Journal of Institute of Science*, 19(3), 17–25.

TUIK, 2018. Turkey Export and Import Statistics, ***http://www.tuik.gov.tr***

USGS, 2020. Graphite Statistics and Information. United States Geological Survey. ***https://www.usgs.gov/centers/nmic/graphite-statistics-and-information*** (last accessed February 2020)

Uysal, S. 2012. Kritik Hammaddeler: Grafit (Critical Raw Materials: Graphite). Mining Turkey Newsletter, Ankara.

Are the pan-European seas a promising source for critical metals supply? The project GeoERA-MINDeSEA

Javier González[1], Teresa Medialdea[1], Henrik Schiellerup[2], Irene Zananiri[3], Pedro Ferreira[4], Luis Somoza[1], Xavier Monteys[5] and the MINDeSEA Team*

Covering 15,000,000 km^2, the pan-European seas represent a promising new frontier for the exploration of mineral resources and an enormous challenge in terms of research, technological innovation, environmental protection, spatial planning and social acceptance. The GeoERA-MINDeSEA project is an ERA-NET action (Horizon 2020) a transnational cooperative network of 12 geological surveys and marine institutes for investigation and exploration of seafloor mineral deposits in pan-European seas. MINDeSEA is producing cartography, datasets, genetic models and case studies to help the EC, stakeholders and society assess possibilities. These are based on detailed studies and compiled data on geology, geochemistry, mineralogy, and environmental and regulatory issues. Strategic and critical metals are being investigated in several seabed mineral deposits, looking for alternative sources to land-based mined deposits. MINDeSEA's task is to identify areas for sustainable resourcing and information to support decision-making on management and marine spatial planning in pan-European seas as part of its core activities.

Avec une surface de 15 000 000 km2, les mers pan-européennes constituent une nouvelle frontière prometteuse pour l'exploration de ressources minérales et un énorme défi en termes de recherche, d'innovation technologique, de protection environnementale, de gestion de l'espace et d'acceptation sociale. Le projet GeoERA-MINDeSEA représente un plan d'action ERA-NET (Horizon 2020), un réseau transnational entre 12 Bureaux d'Etudes géologiques et Instituts marins de recherche et d'exploration de gisements miniers des fonds marins, au sein des mers pan-européennes. MINDeSEA élabore des cartes, des ensembles de données, des modèles génétiques et des études de cas pour aider la Commission Européenne, ses parties prenantes et ses potentialités, fonction de l'évaluation des données sociales. Tout cela est basé sur des études de détail, de données compilées concernant la géologie, la géochimie, la minéralogie et l'environnement ainsi que des questions de régulation. Les minéraux stratégiques et critiques font l'objet de prospection au sein de plusieurs gisements miniers des fonds marins, à la recherche de sources alternatives aux gisements terrestres. L'objectif des travaux MINDeSEA et l'essentiel de ses activités visent à l'identification de secteurs de ressources renouvelables et de données d'information pour appuyer la prise de décision au niveau de la gestion et des programmes d'occupation de l'espace marin, au sein des mers pan-européennes.

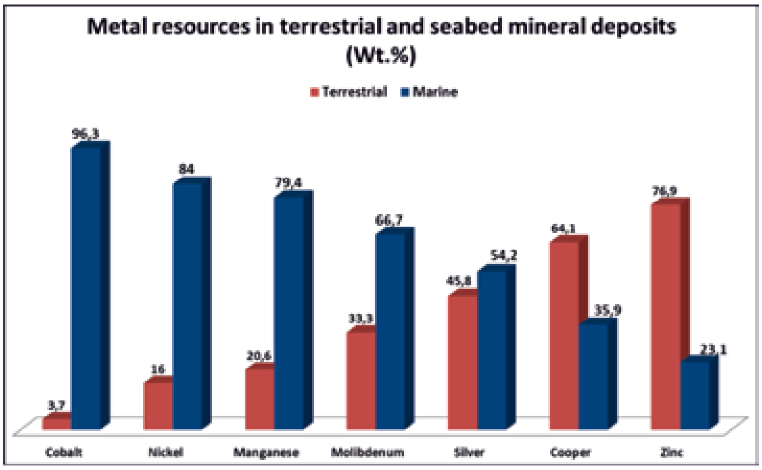
Con una superficie de 15,000,000 km^2, los mares paneuropeos representan una nueva frontera prometedora para la exploración de recursos minerales y un enorme desafío en términos de investigación, innovación tecnológica, protección ambiental, planificación territorial y aceptación social. El proyecto GeoERA-MINDeSEA es una acción ERA-NET (Horizonte 2020), una red cooperativa transnacional de 12 institutos geológicos y marinos para la investigación y exploración de depósitos minerales del fondo marino en mares paneuropeos. MINDeSEA está produciendo cartografía, conjuntos de datos, modelos genéticos y estudios de casos para ayudar a la CE, las partes interesadas y la sociedad; a evaluar las posibilidades. Estos se basan en estudios detallados y datos compilados sobre geología, geoquímica, mineralogía y cuestiones ambientales y regulatorias. Se están investigando metales estratégicos y críticos en varios depósitos minerales del fondo marino, buscando fuentes alternativas a los depósitos minerales terrestres. La tarea de MINDeSEA es identificar áreas con recursos sostenibles para la toma de decisiones sobre gestión y planificación del territorio marino en aguas paneuropeas como parte de sus actividades principales.

Introduction

A major element in Europe's long-term economic strategy is to ensure security of supply for strategic and critical metals as part of the Blue Growth Strategy, developing sectors that have a high potential for the creation of sustainable jobs and growth as seabed mining. Marine aggregates mining (sand and gravel) is one example of a long established activity in Europe (e.g., Germany, the United Kingdom, Belgium and the Netherlands) and represents more than 1900 deposits with 834 licenses for either exploration or extraction (European Commission, 2019a).

Covering more than 70% of the planet, seas and oceans represent a promising new frontier for the exploration and exploitation of mineral resources. Deep-sea deposits span a large diversity of environments and resource types, from hydrothermal deposits to crusts and nodules, and are particularly attractive for their polymetallic nature with high contents of rare and critical metals. Moreover, shallow-water resources such as marine placer deposits represent another source of many industrial materials, critical metals, and gems. The seabed mineral

[1] Marine Geology Dv, Geological Survey of Spain (IGME), C/ Ríos Rosas 23, 28003 Madrid, Spain
[2] Geological Survey of Norway (NGU)
[3] Hellenic Survey of Geology & Mineral Exploration (HSGME), Greece
[4] National Laboratory of Energy and Geology (LNEG), Portugal
[5] Geological Survey Ireland (GSI)
* fj.gonzalez@igme.es



2017 CRMs (27)			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

Figure 1: Above: comparison between the terrestrial and marine resources for critical and strategic metals. Below: the European Commission 2017 CRM list with metals enriched in the marine deposits marked in blue.

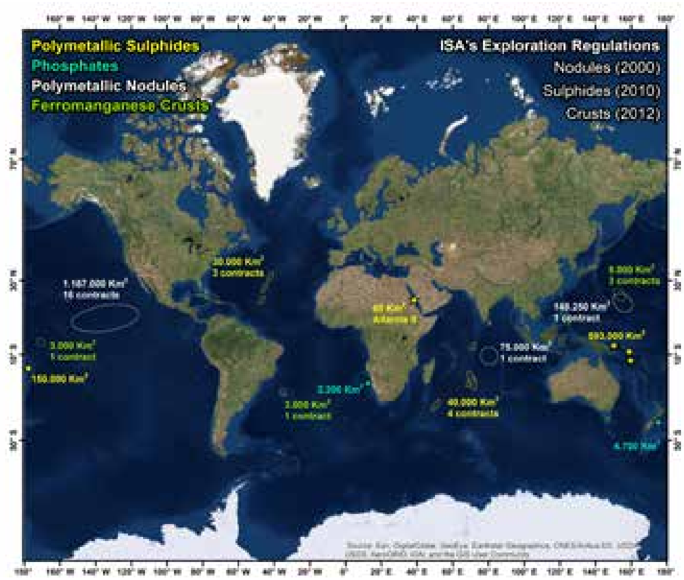


Figure 2: Global map of seabed minerals exploration present status. The stars represent areas under national jurisdiction. Modified from Hein et al. (2013).

resources host the largest reserves on Earth for some metals like cobalt, tellurium, manganese, and the rare earth elements (Hein *et al.*, 2013), critical for industry and required for a transition from a carbon-based to green-energy-based world (Sovacool *et al.*, 2020) (***Figure 1***). The EC's Blue Growth strategy estimated that "By 2030, 10% of the world's minerals, including the sources for cobalt, copper and zinc could come from the ocean floor. Global annual turnover of deep sea mining can be expected to grow from virtually nothing to €10 billion by 2030" (page 10, section 5.4, European Commission, 2012). In addition, materials from recycling seabed mining related wastes, like silica coming from ferromanganese deposit exploitation and processing, will contribute to the circular economy.

The global ocean can play a key role in the mitigation of climate change, but also in improving the sustainable use of mineral resources. These issues include judicious consideration among the fisheries and minerals industries, offshore wind production, and the preservation of aquatic environments and ecosystems in line with the UN Sustainable Development Goals (United Nations, 2020). Extracting minerals from the deep sea represents an enormous scientific and technological challenge for humankind, and one of the biggest challenges is to ensure the protection of the marine environment and its ecosystems.

Considerable improvement in our knowledge of the oceans and seas is necessary to develop a sustainable "Blue Economy" and in obtaining social license. But seabed geology and ecosystems are widely unexplored, and new geological and environmental studies are required to address the impacts of potential mining activities. New developments focused on new technologies for deep-sea exploration and mining will be required. In addition, a regulatory framework for minerals extraction and marine spatial planning is needed for the development of the seabed mining sector.

The International Seabed Authority (ISA) is working on exploitation regulations that will permit the extraction of minerals in areas beyond national jurisdictions, the so-called "Area" (***Figure 2***). Thirty contractors have entered into 15-year contracts with ISA for exploration for polymetallic nodules, polymetallic sulphides, and cobalt-rich ferromanganese crusts on the deep seabed of the Atlantic, Pacific, and Indian Oceans (ISA, 2020). Over the 15 years these exploration areas will be subject of relinquishment and will be smaller by the end of the contract (not more than 2500 km^2 in the case of polymetallic sulphides and not more than 1000 km^2 in the case of cobalt-rich ferromanganese crusts).

Recently, EU research programmes are funding projects to increase knowledge about seabed minerals in its waters, marine minerals exploration, extraction technologies, and environmental issues. One EU programme, GeoERA ("Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe") – an ERA-NET action under Horizon 2020 – funds transnational projects contributing to the best use and management of the subsurface (Gessel *et al.*, 2018). One GeoERA-funded project is MINDeSEA.

Contributing to pan-European seabed minerals knowledge: The MINDeSEA project

Eight GeoERA partners and four non-funded organisations with a common interest in exploration and investigation on seafloor mineral deposits have collaborated in the project GeoERA-MINDeSEA. The geological survey organisations of Spain, Germany, Greece, Ireland, Norway, Portugal, Sweden and Ukraine handle coastal, marine geological investigation and mineral resources studies and mapping in their respective countries. The non-funded participants – the Instituto Português do Mar e da Atmosfera; the United States Geological Survey; the All-Russia Scientific Research Institute for Geology and Mineral Resources of the Ocean; and the Geosciences Institute from Spain – maintain important databases and host internationally-known experts on seafloor mineralisation and hydrothermal systems.

The project focuses on an integrative metallogenetic study of the principal types of marine mineral resources (polymetallic sulphides, ferromanganese crusts, phosphorites, marine placers and polymetallic nodules) in the seabed under the jurisdiction of European coastal States (***Figure 3***). The geographical scope of the project includes all the regional basins around Europe comprising the Atlantic and Arctic Oceans, the Mediterranean Sea, the Baltic Sea and the Black Sea.

The MINDeSEA project is compiling data and genetic models for all of these deposit types based on extensive studies carried out previously, which include geophysical surveys, sampling stations, underwater photography and ROV surveys, and mineralogical, geochemical and isotopic studies. It builds on previously and currently developed pan-European and national databases and expands strategic and CRM knowledge through compiling mineral potential and metallogenic studies of CRW resources in pan-European seas.

The objectives of the project include characterising deposit types under the jurisdiction of European coastal and their trace element content, evaluating supply potential, developing harmonised mineral maps and datasets of seabed deposits, producing mineral potential and prospectivity maps, proposing pilot zones, analysing present-day exploration and exploitation status in terms of regulation, legislation, environmental impacts and future directions and extending state-of-the-art knowledge and information on submarine minerals, metallogenic studies, standards and technologies across the European community.

Seabed mineral deposits in the pan-European seas: an update

The pan-European seas cover about 15 million km^2 in the Arctic and Atlantic oceans and the Mediterranean, Baltic, and Black Seas, from shallow waters up to 6,000 m water depth. The preliminary MINDeSEA results show the potential of the pan-European seas for critical metals according to the criticality list of the European Commission (2017) (***Figure 3***) and the enormous gaps of information covering vast marine areas. More than 600 mineral occurrences and 1,045 individual analysed samples are reported in the MINDeSEA database. The dataset contains five principal levels of information with multiple attributes for each occurrence: geographical, metallogenic, economic, geochemical and environmental data. A reference database supports the mineral occurrences with more than 200 records, including peer-reviewed papers, oceanographic expedition reports, PhD theses, maps and datasets.

Seafloor polymetallic sulphides and metalliferous sediments precipitating from hot hydrothermal solutions and plumes are forming today offshore of the Azores Archipelago (Portugal) and in the Arctic (Norway, Denmark) and the Mediterranean volcanic arcs (Italy and Greece) (***Figure 3A***). They are among the most important marine resources for copper, zinc, silver, and gold. In addition, hydrothermal deposits may contain economic grades of tin, barium, indium, bismuth, tellurium, gallium, and germanium. Seamounts, submarine volcanoes and banks in the Macaronesia sector (Portugal and Spain) and the Arctic ridges (Norway, Denmark, Iceland) show high potential for Fe-Mn crusts, rich in energy-critical elements like cobalt but also tellurium, rare earth elements, and manganese. Fe-Mn crusts are accompanied by phosphorites on the seafloor of continental shelves and slopes along the western continental margins of Portugal and Spain (***Figure 3B***). These marine phosphorites concentrate rare earth elements and yttrium in addition to phosphate. Shallow-water concretions and nodules from the Arctic (Norway, Russia), Baltic (Sweden, Poland, Finland, Russia, Estonia, Germany), and Black Sea (Ukraine, Romania) represent potential

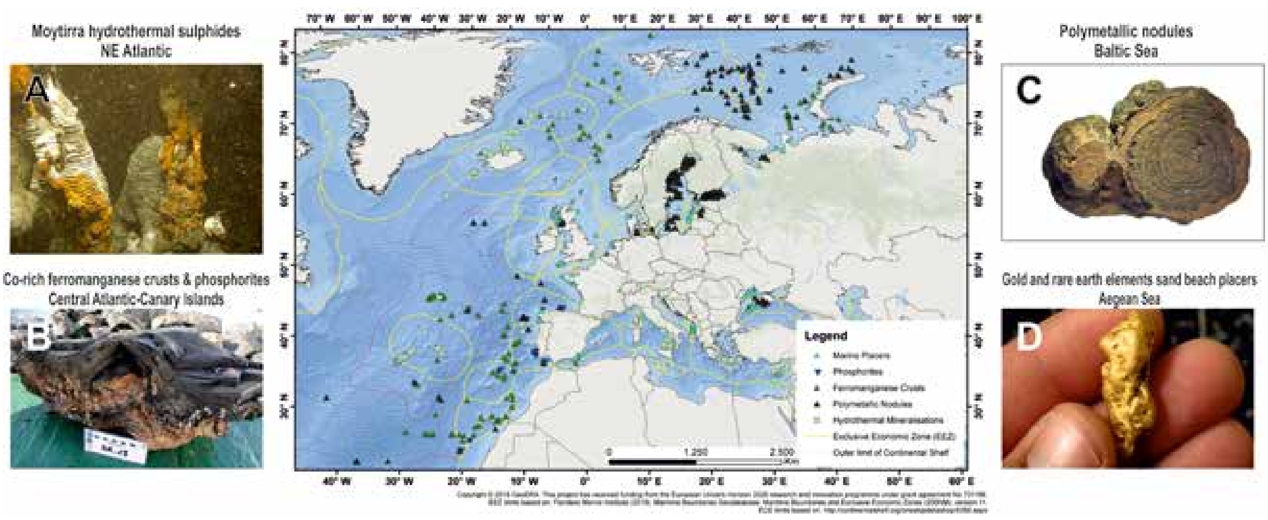


Figure 3: MINDeSEA compilation map by March 2020 of seabed mineral occurrences in the pan-European seas. A) ROV image on the sulphide chimneys from the Moytirra hydrothermal field, 3000 m water depth, expedition EXPLOSEA 2; B) Ferromanganese crusts and phosphorites recovered in the Canary Island seamounts, 1000-2500 m water depth, expedition DRAGO 0511; C) Cross-section of polymetallic nodule cluster from the Baltic Sea, 60–200 m water depth; D) Gold nugget collected in sand beach placers enriched in heavy and resistant minerals from the Aegean Sea.

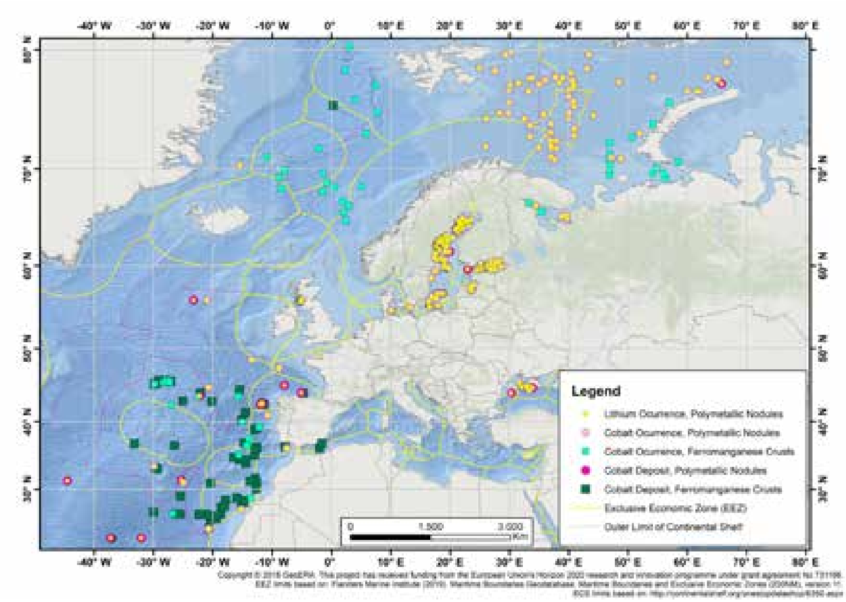


Figure 4: MINDeSEA pan-European map of energy-critical metals cobalt and lithium based on ferromanganese occurrences and deposits of nodules and crusts. Occurrences refer to Li_2O average content <660 g/t, potential resources <5,000 Mt, and Co average content <500 g/t. No up-to-date information is given about resource potential.

targets for metals exploration and environmental studies (***Figure 3C***). Finally, placer deposits of chemically resistant, physically durable minerals have been discovered in shallow-water settings (<50 m water depth on estuaries, deltas, beaches) linked to the weathering of onshore rocks and ore deposits from the Variscan Belt in UK, France, Portugal and Spain; the Eastern Mediterranean (Albania, Greece and Cyprus), the Black Sea (Ukraine, Romania, Bulgaria), the Arctic Ocean (Russia, Norway, Denmark) and the Baltic Sea (Poland, Latvia). Accumulations of heavy minerals include monazite, ilmenite, rutile, zircon, garnet, gold, diamonds, cassiterite and magnetite (***Figure 3D***).

In December 2018 MINDeSEA produced the first pan-European compilation map of "energy-critical elements" based on ferromanganese deposits (González *et al.*, 2018). The map reports occurrences and deposits for cobalt and lithium and can be downloaded at ***https://geoera.eu/projects/mindesea2/***. This map and other MINDeSEA products were included in the 2019 EU Blue Economy Report (European Commission, 2019a) and will be updated with new data in the upcoming 2020 Report (***Figure 4***).

For further information, see the GeoERA-MINDeSEA website (***https://geoera.eu/projects/mindesea2/***), a dedicated website (https://geoeramindesea.wixsite.com/mindesea), or social media (***https://twitter.com/MINDeSEA***, ***https://www.facebook.com/mindesea.mindesea.9***).

Acknowledgements

This work has been supported by the European Union's Horizon 2020 research and innovation programme, GeoERA (Grant Agreement Nº 731166, project GeoE.171.001). We thank Pedro Madureira, Antje Wittenberg and editors for comments that helped improve this paper.

References

European Commission (2012). Blue Growth. 2012. European Commission. COM (2012) 494 final.

European Commission (2017). 2017 list of Critical Raw Materials for the EU. Brussels, 13.9.2017. COM (2017) 490 final.

European Commission (2019a). The EU Blue Economy Report. 2019. Publications Office of the European Union. Luxembourg. DOI: 10.2771/437478.

European Commission (2019b). The European Green Deal. Brussels, 11.12.2019 COM (2019) 640 final.

Gessel, S.F. van; Hinsby, K., Stanley, G., Tulstrup, J., Schavemaker, Y., Piessens, P., Bogaard, P. (2018). Geological Services towards a Sustainable Use and Management of the Subsurface: A Geoethical Imperative. *Annals of Geophysics* 60. 8 pages. DOI: 10.4401/ag-7500.

González, F.J., Blasco, I., Blanco, L., Marino, E., Somoza, L., Medialdea, T., Ferreira, P., Magalhaes, V. (2018). First compilation map of "energy-critical elements" in pan-European seas: ferromanganese deposits. Map energy-critical elements, ***https://69ef338c-adbf-4a98-94a6-1e32d03179fa.filesusr.com/ugd/e60895_12f36311663d480cbb852fc40c9ec7f0.pdf***

Hein, J.R., Mizell, K., Koschinsky, A., Conrad, T.A. (2013). Deep-ocean mineral deposits as a source of critical metals for high- and green-technology applications: comparison with land-based resources. *Ore Geology Reviews* 51:1–14. DOI: 10.1016/j.oregeorev.2012.12.001.

ISA, International Seabed Authority. (2020). ***http://www.isa.org.jm***

Sovacool, B., Saleem, A., Morgan B., Radley, B., Nemery, B., Okatz, J., Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. *Science* 367:30-33. DOI: 10.1126/science.aaz6003.

United Nations (2020). ***https://sustainabledevelopment.un.org/sdgs***

News corner:
Compiled by Anita Stein, EFG Office

EFGeoMentoring

The European Federation of Geologists (EFG) invites you to participate in its new EFGeoMentoring scheme. This extension of our current early career mentoring programme offers mentoring and coaching services to mid-career and senior geoscience professionals.

Would you like to:

- broaden your professional network?
- improve technical knowledge in a particular field?
- improve your leadership/management skills?
- acquire practical tools and strategies for the transition from a junior role into roles with higher responsibilities?
- benefit from insider knowledge about work perspectives in another geosciences sector or in other countries and obtain practical advice and contacts?
- apply for the European Geologist title (***https://eurogeologists.eu/eurgeol-title/***) and ask your mentor to guide you through the application procedure?

As a complementary service we also aim at providing mentees with access to a database of professional coaches who may advise you on specific aspects such as career change, marketing and sales, financial management or personal development.

The EFGeoMentoring scheme is running on a continuous basis, matching mentees and mentors upon demand.

To participate, please check the conditions on our website and submit your application: ***https://eurogeologists.eu/efgeomentoring***

EFGeoBlog – EFG welcomes your contributions!

Our news blog informs readers about EFG activities and provides updates on the European projects which we are involved in. Under the category EFGeoBlog, we welcome guest posts from our National Associations, our Panels of Experts, and from external contributors who would like to present recent research or professional developments in the field of geosciences. Posts may include reports from geosciences events, information on publications and relevant EU policy developments. As one of EFG's main missions is to create public awareness of the importance of geoscience for society, we are particularly interested in best practice reports about geoscience outreach initiatives.

Find all information on how to contribute in our guidelines: ***https://eurogeologists.eu/introducing-efgeoblog-efg-welcomes-your-contributions/***

We look forward to receiving your contribution!

EFG Employment Survey 2020

In our annual 'EFG Employment Survey', we aim at taking a snapshot of the current labour market for geologists in Europe and beyond:

- Which industries are professional geologists working in?
- What is their current employment state and security?
- • Do their professional activities align with their training?
- • Are they exploiting job opportunities in other European countries?
- • What are the prospects for the future?

The information gathered by this survey is not only useful for EFG's work and to our national association members, but also for informing individual geologists at large through:

1. A clear overview of their work opportunities in Europe, helping them to orient their studies or career decisions;
2. Providing professional associations with input on which services to offer to their members, such as aid in finding jobs and supporting mentor programmes;
3. Furnishing evidence for professional associations in their pursuit of positive policy dialogue with public authorities and the shaping of effective training for geologists with education authorities.

To help us produce a comprehensive report about the evolution of our profession, we would appreciate if you could take our short survey. Answering the survey takes approximately 10 minutes. Thank you in advance for your time!

You can complete the survey via the following link: ***https://bit.ly/34yUDil***

The results of the 2019 survey are available online at the following link: ***https://arcg.is/0iT5f90***

Annual report 2019

The EFG Annual Report for 2019 introduces the Federation's main activities throughout the past year. It is structured around the six strategic action areas of the EFG Strategic Plan "Towards a sustainable future": Members, Network, Professional Expertise, Projects, Communication, and Panels of Experts. The 2019 edition of the EFG Annual Report also comes up with a new format which we hope you will like! You can access the report via the following link: ***https://bit.ly/3fijuMk***

EU projects

Horizon 2020 is the biggest EU research and innovation programme ever, with nearly €80 billion of funding available to secure Europe's global competitiveness in the period 2014–2020. EFG is currently involved in five active Horizon 2020 projects: INFACT, INTERMIN, ROBOMINERS, CROWDTHERMAL, REFLECT. In addition, EFG is also participating in two projects under the EIT RawMaterials initiative: ENGIE and PROSKILL. Below you will find descriptions of the topics and aims of these projects.

REFLECT

850626 - Redefining geothermal fluid properties at extreme conditions to optimize future geothermal energy extraction
START DATE: 1 January 2020
DURATION: 36 months
https://www.reflect-h2020.eu/

Objectives:

The efficiency of geothermal utilisation depends heavily upon the behaviour of the fluids that transfer heat between the geosphere and the engineered components of a power plant. Chemical or physical processes such as precipitation, corrosion, or degassing occur as pressure and temperature change, with serious consequences for power plant operations and project economics. Currently, there are no standard solutions for operators to deal with these challenges. The aim of REFLECT is to avoid the problems related to fluid chemistry rather than treat them. This requires accurate predictions and thus a thorough knowledge of the physical and chemical properties of the fluids throughout the geothermal loop. These properties are often only poorly defined, as in situ sampling and measurements at extreme conditions are hardly possible to date. As a consequence, large uncertainties prevail in current model predictions, which will be tackled in REFLECT by collecting new, high quality data in critical areas. The proposed approach includes advanced fluid sampling techniques, the measurement of fluid properties in in-situ conditions, and the exact determination of key parameters controlling precipitation and corrosion processes. The sampled fluids and measured fluid properties cover a large range of salinity and temperature, including those from enhanced and super-hot geothermal systems. The data obtained will be implemented in a European geothermal fluid atlas and in predictive models that both ultimately allow operational conditions and power plant layout to be adjusted to prevent unwanted reactions before they occur. That way, recommendations can be derived on how to best operate geothermal systems for sustainable and reliable electricity generation, advancing from an experience-based to a knowledge-based approach.

ENGIE

Encouraging Girls to Study Geosciences and Engineering
START DATE: 1 January 2020
DURATION: 36 months
https://www.engieproject.eu/

Objectives:

ENGIE aims to turn the interest of 13-to-18-year-old girls towards studying geosciences and related engineering disciplines. As career decisions are generally made in this period of life, the project aims to improve the gender balance in the fields of these disciplines. During the implementation of the three-year-long project an awareness-raising strategy will be developed and an international stakeholder collaboration network will be established for the realisation of a set of concrete actions. These actions include family science events, outdoor programmes, school science clubs, mine visits, mentoring programmes, international student conferences, competitions, publication opportunities, summer courses for science teachers and production of educational materials. The actions will be carried out in more than twenty countries throughout Europe.

PROSKILL

Development of a Skill Ecosystem in the Visegrád Four countries
START DATE: 1 January 2020
DURATION: 36 months
www.proskillproject.eu

Objectives:

The European Union puts emphasis on raising productivity as an important factor in maintaining economic growth. In order to improve productivity, it is vital to offer products and services with a high added value, and for that purpose highly qualified employees are required. Companies and professional organisations in the raw materials industries have stressed the need to improve the soft skills of students in order to meet the requirements of the labour market. The engineers of the future have to accept that engineering problems – as well as their solutions – are embedded in complex social, cultural, political, environmental and economic contexts. Engineers have to access, understand, evaluate, synthesise, and apply information and knowledge from engineering as well as from other fields of study. They have to find and achieve a synergy between technical and social systems. ProSkill has a double purpose. From the one side it adopts a 'skill ecosystem' concept, looking at what (hard and soft) skills are missing in the raw materials sector, which areas are affected by skill problems (shortages, mismatches and gaps) and what strategies can work. A high-skill ecosystem strategy supplemented with an action plan is developed. To ensure sustainability, the project focuses on lecturers in higher education ('train the trainer'). The main goal is to develop their knowledge about new and innovative educational techniques and to reshape outdated curricula. On the other side, a pilot project is launched involving the colleges for advanced studies in partner HEIs. Short-term and long-term programmes help to implement the strategy with the targeted development of selected soft skills.

INFACT

776487 – INFACT
Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT)
START DATE: 1 November 2017
DURATION: 36 MONTHS
www.infactproject.eu

Objectives:

Exploration discovery of raw material resources requires innovations that either change the geological targets of exploration, the physical places that are reached, or the manner in which they are explored. Despite its rich history of mining and residual mineral wealth, current conditions within the EU present a number of social, political, legislative, cost, technical and physical obstacles to raw material exploration: obstacles to be overcome by innovation, dialogue and reform.

The Innovative, Non-invasive and Fully Acceptable Exploration Technologies (INFACT) project unites stakeholders of Europe's future raw materials security in its consortium and activities. Via effective engagement of civil society, state, research and industry, the project focuses on each of these obstacles. It will co-develop improved systems and innovative technologies that are more acceptable to society and invigorate and equip the exploration industry, unlocking unrealised potential in new and mature areas.

The project is developing innovative geophysical and remote sensing technologies (less invasive than classical exploration methods) that promise to penetrate new depths, reach new sensitivities and resolve new parameters.

The project will also set the EU as a leader on the world stage by establishing permanent infrastructure to drive innovation in the next generation of exploration tools: tools that are cost-effective, designed for EU conditions and its raw materials strategy, and high-performing in terms of environmental impact, social acceptability, and technical performance.

INFACT is comprised of the following main components:

- Development and testing of innovative, non-invasive exploration technologies.
- Foundation of 3 test sites for exploration technology in the south, centre and north of Europe.
- Stakeholder engagement, education and policy reform.

These actions combine to reach each of the main areas in which the EU has the power to influence change in its raw materials security.

INTERMIN

776642 – INTERMIN
INTERNATIONAL NETWORK OF RAW MATERIALS TRAINING CENTRES
START DATE: 1 February 2018
DURATION: 36 months
http://interminproject.org

Objectives:

INTERMIN is intended to create a feasible, long-lasting international network of technical and vocational training centres for mineral raw materials professionals. Specific objectives:

- Develop common metrics and reference points for quality assurance and recognition of training;
- Develop a comprehensive competency model for employment across the primary and secondary raw materials sectors;
- Introduce an international qualification framework for technical and vocational training programmes;
- Create a conceptual framework for the development of joint educational training programmes based on present and future requirements by employers;
- Create and launch a joint international training programme by a merger of competences and scope of existing training programmes.

CROWDTHERMAL

857830 – CROWDTHERMAL
Community-based development schemes for geothermal energy
START DATE: 1 September 2019
DURATION: 36 months
http://crowdthermalproject.eu

Objectives:

CROWDTHERMAL aims to empower the European public to directly participate in the development of geothermal projects with the help of alternative financing schemes (crowdfunding) and social engagement tools. In order to reach this goal, the project will first increase the transparency of geothermal projects and technologies by creating one-to-one links between geothermal actors and the public so that a Social Licence to Operate (SLO) could be obtained. This will be done by assessing the nature of public concerns for the different types of geothermal technologies, considering deep and shallow geothermal installations separately, as well as various hybrid and emerging technology solutions. CROWDTHERMAL will create a social acceptance model for geothermal energy that will be used as baseline in subsequent actions for inspiring public support for geothermal energy. Parallel and synergetic with this, the project will work out details of alternative financing and risk mitigation options covering the different types of geothermal resources and various socio-geographical settings. The models will be developed and validated with the help of three case studies in Iceland, Hungary and Spain and with the help of a Trans-European survey conducted by EFG Third Parties. Based on this feedback, a developers' toolbox will be created with the aim of promoting new geothermal projects in Europe supported by new forms of financing and investment risk mitigation schemes that will be designed to work hand in hand with current engineering and microeconomic best practices and conventional financial instruments.

ROBOMINERS

820971 – ROBOMINERS
Resilient Bio-inspired Modular Robotic Miners
START DATE: 1 June 2019
DURATION: 48 months
http://robominers.eu

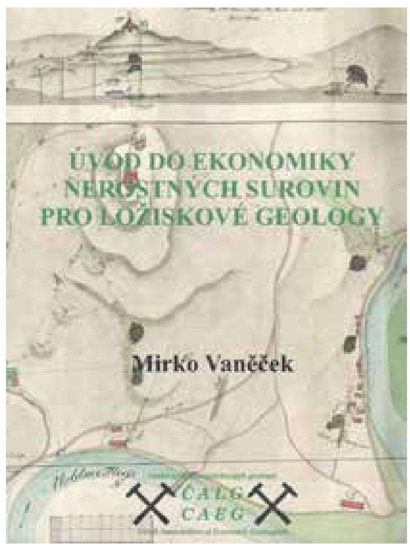
Objectives:

ROBOMINERS will develop a bio-inspired, modular and reconfigurable robot-miner for small and difficult-to-access deposits. The aim is to create a prototype robot that is capable of mining underground, underwater or above water, and can be delivered in modules to the deposit via a large diameter borehole. In the envisioned ROBOMINERS technology line, mining will take place underground, underwater in a flooded environment. A large diameter borehole is drilled from the surface to the mineral deposit. A modular mining machine is delivered in modules via the borehole. This will then self-assemble and begin its operation. Powered by a water hydraulic drivetrain and artificial muscles, the robot will have high power density and environmentally safe operation. Situational awareness and sensing is provided by novel body sensors, including artificial whiskers, that will merge data in real-time with production sensors, optimising the rate of production and selection between different production methods. The produced high-grade mineral slurry is pumped to the surface, where it will be processed. The waste slurry could then be returned to the mine where to backfill mined-out areas.

ROBOMINERS will deliver proof of concept (TRL-4) of the feasibility of this technology line that can enable the EU have access to mineral raw materials from otherwise inaccessible or uneconomical domestic sources. This proof of concept will be delivered in the format of a new amphibious robot Miner Prototype that will be designed and constructed as a result of merging technologies from advanced robotics, mechatronics and mining engineering. Laboratory experiments will confirm the Miner's key functions, such as modularity, configurability, selective mining ability and resilience under a range of operating scenarios. The Prototype Miner will then be used to study and advance future research challenges concerning scalability, swarming behaviour and operation in harsh environments.

Book review by Jiří Jiránek

Úvod do ekonomiky nerostných surovin pro ložiskové geology (Introduction to the Economy of Mineral Resources for Economic Geologists)



by Mirko Vaněček
Published by: Czech Association of Economic Geologists (CAEG), Prague, 150 pp, 2018
ISBN: 978-961-6498-46-3

The Czech technical literature has been in need of a book dealing with the economics of mineral resources that considers the changed economic conditions of the society after 1989. Another problem of Czech economic geologists has been the system of estimation of the quality of resources and the calculation of reserves, as the methods in use did not correspond to current standards as defined by CRIRSCO and PERC. This gap has been filled by this book by Mirko Vaněček, published in 2018 by CAEG.

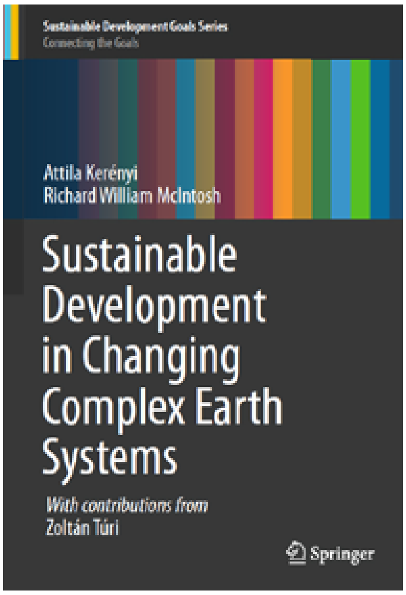
In 11 chapters (150 pages), the book provides a complete explication of terms, classification of resources and their reserves, methods of their valuation, and, finally, ways for public announcement of the results. The text is accompanied by 56 pictures and 56 tables. The book is completed by an index of subjects.

Presently, an edition of the book is in preparation for the Republic of Georgia, where the 90-year-old author is still acting as an external assessor.

Book review by Eniko K. Magyari

Sustainable Development in Changing Complex Earth Systems

by Attila Kerényi and Richard William McIntosh
Published by: Springer Nature, France, 292 pp, 2020
ISBN: 978-3-030-21644-3



In today's world of overspecialised publications, works with a holistic approach are rare. Fortunately, the book *Sustainable Development in Changing Complex Earth Systems*, published as a volume of the Sustainable Development Goals series of Springer Nature, takes this approach.

The authors of this volume review the most important processes in the geospheres from the Earth's core to the stratosphere, examining the interactions between the Earth's environment and human society, human activities and their consequences in the systems of Earth, as well as the consequences of changes in the development of human society. For better understanding of the latter, the structure and functioning of the global society today are analysed in detail. Via logical analysis the authors reach the problem of what humankind should do differently in order to live in a more environmentally friendly and peaceful society, i.e. a more sustainable society for the future. At the end of the book, the reader receives an answer to this question.

The volume presents a wide variety of issues in seven chapters.

The introduction (Chapter 1) presents the quality changes in the evolution of the Earth, including the emergence and development of the human society on our planet up to current days, when the Sustainable Development Goals of the United Nations were formulated.

Chapter 2 discusses the basics of systems thinking to give the reader a better understanding of the operation of global Earth systems and their vulnerability. The most important Earth models are presented, global climate and biosphere models, and then social models called "world models". The overall impact of social development on the natural environment and on humans as biological beings is also demonstrated.

Chapter 3 analyses the internal material flows of Earth and their effects on the society. Humankind can only accommodate to such effects (variations in the magnetic field of Earth, earthquakes, volcanism) to a certain extent and earth sciences have a major role in this accommodation.

In Chapter 4, we can study the effects of human activities transforming and modifying the natural environment. First, the authors discuss the consequences of activities in the outer boundary zone of the Earth's crust (mining, construction), and then describe the human influence on the pedosphere. The following three subsections look at changes in the hydrosphere, biosphere and atmosphere. Analyses point to the nature-degrading effects of human activities and the problems that make the sustainable development of society in doubt. In this extensive chapter, the authors often claim (and prove their claims) that human influences never remain within one geosphere, they inevitably spread to other geospheres, causing more and more problems for society.

In Chapters 5 and 6 the structure and functioning of the global society are examined in terms of what humankind should do to make our world more liveable than it is today. This includes an outline and critical analysis of the UN's Sustainable Development Goals. In addition, the authors express their views on necessary changes in the structure of the global society, the institutional system and people's attitudes in general that go beyond SDGs.

Finally, Chapter 7 outlines the essential conditions and tasks for realising a sustainable, humane and environmental friendly society.

The authors use consistent systems thinking for discussing global and local environmental and social problems and possibilities for solutions. This systems thinking is supported by giving knowledge in a clear and concise way. The book is illustrated by more than 120 figures and 12 boxes presenting interesting case studies.

The book is recommended as a basic textbook for undergraduate students in the geosciences, geography, and ecology, hopefully transforming their views. It can also be useful for representatives of nature and environmental protection institutions, green organisations activists and all readers interested in sustainable development.

Submission of articles to European Geologist Journal

Notes for contributors

The Editorial Board of the European Geologist journal welcomes article proposals in line with the specific topic agreed on by the EFG Council. The call for articles is published twice a year in December and June along with the publication of the previous issue.
The European Geologist journal publishes feature articles covering all branches of geosciences. EGJ furthermore publishes book reviews, interviews carried out with geoscientists for the section 'Professional profiles' and news relevant to the geological profession. The articles are peer reviewed and also reviewed by a native English speaker.
All articles for publication in the journal should be submitted electronically to the EFG Office at ***info.efg@eurogeologists*** according to the following deadlines:

- Deadlines for submitting article proposals (title and content in a few sentences) to the EFG Office (***info.efg@eurogeologists.eu***) are respectively 15 July and 15 January. The proposals are then evaluated by the Editorial Board and notification is given shortly to successful contributors.
- Deadlines for receipt of full articles are 15 March and 15 September.

Formal requirements

Layout

- Title followed by the author(s) name(s), place of work and email address,
- Abstract in English, French and Spanish,
- Main text without figures,
- Acknowledgements (optional),
- References.

Abstract

- Translation of the abstracts to French and Spanish can be provided by EFG.
- The abstract should summarise the essential information provided by the article in not more than 120 words.
- It should be intelligible without reference to the article and should include information on scope and objectives of the work described, methodology, results obtained and conclusions.

Main text

- The main text should be no longer than 2500 words, provided in doc or docx format.
- Figures should be referred in the text in italic.
- Citation of references in the main text should be as follows: 'Vidas and Cooper (2009) calculated…' or 'Possible reservoirs include depleted oil and gas fields… (Holloway *et al.*, 2005)'. When reference is made to a work by three or more authors, the first name followed by '*et al.*' should be used.
- Please limit the use of footnotes and number them in the text via superscripts. Instead of using footnotes, it is preferable to suggest further reading.

Figure captions

- Figure captions should be sent in a separate doc or docx file.

References

- References should be listed alphabetically at the end of the manuscript and must be laid out in the following manner:
- Journal articles: Author surname, initial(s). Date of publication. Title of article. Journal name, Volume number. First page - last page.
- Books: Author surname, initial(s). Date of publication. Title. Place of publication.
- Measurements and units
- Measurements and units: Geoscientists use Système International (SI) units. If the measurement (for example, if it was taken in 1850) was not in SI, please convert it (in parentheses). If the industry standard is not SI, exceptions are permitted.

Illustrations

- Figures should be submitted as separate files in JPEG or TIFF format with at least 300dpi.
- Authors are invited to suggest optimum positions for figures and tables even though lay-out considerations may require some changes.

Correspondence

All correspondence regarding publication should be addressed to:
EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Note

All information published in the journal remains the responsibility of individual contributors. The Editorial Board is not liable for any views or opinions expressed by these authors.

Subscription

Subscription to the journal:

15 Euro per issue

Contact

EFG Office
Rue Jenner 13, B-1000 Brussels, Belgium.
E-mail: ***info.efg@eurogeologists.eu***

Advertisements

EFG broadly disseminates geology-related information among geologists, geoscientific organisations and the private sector which is an important employer for our professional members, but also to the general public.

Our different communication tools are the:

- EFG website, ***www.eurogeologists.eu***
- GeoNews, a monthly newsletter with information relevant to the geosciences community.
- European Geologist, EFG's biannual journal. Since 2010, the European Geologist journal is published online and distributed electronically. Some copies are printed for our members associations and the EFG Office which distributes them to the EU Institutions and companies.

By means of these tools, EFG reaches approximately 50,000 European geologists as well as the international geology community.

With a view to improving the collaboration with companies, EFG proposes different advertisement options. For the individual prices of these different advertisement options please refer to the table.

Prices for advertisements

EGJ	**One Insertion**	**Two Insertions**
Full page (colour)	820 Euro	1320 Euro
Half page (colour)	420 Euro	670 Euro
Quarter page (colour)	220 Euro	350 Euro
Full page (black and white)	420 Euro	670 Euro
Half page (black and white)	220 Euro	350 Euro
Quarter page (black and white)	120 Euro	200 Euro
Business card size	90 Euro	150 Euro
Preferential location	25% plus	
Price for special pages:		
Outside back cover (colour)	1200 Euro	1900 Euro
Second page (colour)	1000 Euro	1600 Euro
Second last page (colour)	1000 Euro	1600 Euro

Geonews	**Annual Price**
Ad and regular newsfeed	1500 Euro
EFG Homepage	
Ad and regular newsfeed	1500 Euro
University ad	
Ad for training opportunities in the job area of the homepage	500 Euro
Annual package	
Business card size ad in EGJ, GeoNews and homepage.	3000 Euro