FRAME
FORECASTING AND ASSESSING EUROPE'S STRATEGIC RAW MATERIALS NEEDS

Newsletter
OCTOBER 2020

www.frame.lneg.pt

Issue 7, October 2020

FRAME, innovation in Mineral Exploration Science outreach

Antje Wittenberg (BGR), Daniel P. S. de Oliveira (LNEG), Eric Gloaguen (BRGM), Guillaume Bertrand (BRGM), Håvard Gautneb (NGU), Helge Reginiussen (SGU), Henrike Sievers (BGR), Lídia Quental (LNEG), Maria João Ferreira (LNEG), Martiya Sadeghi (SGU), Sophie Decrée (GSB), Tuomo Törmänen (GTK)

The pandemic situation gripping all of us has not curtailed any of the scientific outreach activities of Project FRAME. Quite the opposite, FRAME has had excellent exposure to the innovation in Mineral Exploration Science goals it set out at the beginning of the project.

FRAME was active in a variety of scientific fora this year, namely GeoUtrecht2020 and EAGE's "Mineral Exploration Symposium: Mineral Exploration in Climate-Neutral Economy."

GeoUtrecht 2020 (21-26th of August) had more than 620 participants from 54 countries with a dedicated session to GeoERA, namely: Raw Materials and their societal relevance for Europe. FRAME, in partnership with its sister deep sea project, MINDeSEA, presented a total of 6 talks.

GeoUtrecht 2020
24–26 August 2020 | Utrecht | The Netherlands

Below are the titles and authorship of the talks:

- de Oliveira, DPS, Gonzalez, FJ, Wittenberg, A, 2020. FRAME and MINDeSEA: Where land meets sea in the research, prediction and prospectivity of metallic mineral critical raw materials. GeoUtrecht2020 Abstracts, Submission 118.
- Sadeghi, M, Bertrand, G, Decrée, S, de Oliveira, DPS, 2020. Prospectivity mapping of phosphor in Europe; a part of the GEOERA-FRAME project. GeoUtrecht2020 Abstracts, Submission 125.
- Wittenberg, A, de Oliveira, DPS, Jørgensen, LF, Gonzalez, FJ, Sievers, H, Quental, L, Pereira, A, Heldal, T, Whitehead, D, 2020. Raw materials - you can't do well without them. GeoUtrecht2020 Abstracts, Submission 140.
- Sievers, H, Rambousek, P, Serra, M, Wittenberg, A, Oliveira, D, 2020. Raw Material Potential from Historic Mine Sites. GeoUtrecht2020 Abstracts, Submission 151.
- Horváth, Z, de Oliveira, D, Aasly, KA, Simoni, M, Jørgensen, LF, Whitehead, D, Wittenberg, A, Kral, U, Griffiths, C, Tulsidas, H, Solar, S, 2020. UN Framework Classification - a tool for Sustainable Resource Management. GeoUtrecht2020 Abstracts, Submission 240.
- de Oliveira, DPS, Ferreira, MJ, Sadeghi, M, Arvanitidis, N, Bertrand, G, Decrée, S, Gautneb, H, Gloaguen, E, Törmännen, Reginiussen, H, Sievers, H, Quental, L, Wittenberg, A, 2020. FRAME's (Forecasting and Assessing Europe's Strategic Raw Materials Needs) innovative research in mineral raw materials on the eve of the EU's "Green Deal". GeoUtrecht2020 Abstracts, Submission 119.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

GeoERA
RAW MATERIALS

The Mineral Exploration Symposium (17-18 September 2020) brought together the key innovators of the most advanced technologies and methods for mineral exploration in Europe, namely the representatives of European exploration companies (SMEs, industries) and professionals from academia and research institutes working on mineral exploration.

The event focused on the recent and innovative developments in integrated exploration solutions focused on finding new deposits, benefitting from multidisciplinary and integrated approaches of advanced mineralogical, geochemical, geophysical, remote sensing, multi-dimension modelling, automation and robotisation techniques. Special attention was given to the role that the EU is playing in sustainable supply of raw materials, through funding R&I projects that aim to develop breakthrough technologies for mineral exploration.

At this symposium, FRAME scientists presented three important talks and preliminary results, namely:

1. **Prospectivity mapping of critical raw material at the continental scale - State of the Art: a part of the FRAME project** (authors: Martiya Sadeghi, Guillaume Bertrand, Daniel P. S. de Oliveira, Nikolaos Arvanitidis, Sophie Decrée, Håvard Gautneb, Eric Gloaguen, Tuomo Törmänen, Helge Reginiussen, Henrike Sievers, Lídia Quental, Maria João Ferreira, Antje Wittenberg).

In this presentation the main focus was on the state of the art for the prospectivity mapping methodology and description of favourability mapping. The development on knowledge and data driven methods from past to recent years have been discussed.

Data-driven and knowledge-driven approaches have their advantages and limitations. Data-driven statistical approaches imply to model parameters calculated from training dataset (e.g. known mineralization), while knowledge-driven methods use expert knowledge on mineralization, model parameters and weights estimated by expert (s) but can be assisted by various statistical techniques at different steps of the process.

In the presentation, shortly described a “data-driven” mineral prospectivity method (Cell Based Association-CBA) which has been applied for some CRM in the FRAME (see Tourliere et al., 2015, and Bertrand et al., this conference, for more details). Some results on niobium-Tantalum mineralisation in Europe also presented that FRAME project also applied a “hybrid knowledge – data” fuzzy weights of evidence model for mineral potential mapping (Porwal et al., 2006).

Summarizing, there is not a “best” method to produce a favourability/prospectivity map, and each data and knowledge-driven method has its advantages and limitation, but the most important being the quality and quantity of input data which is critical to prospectivity mapping. At European scale, probably the best way is to start with data gathering on mineral deposits in a harmonized way, which is a main task for FRAME project (harmonized geological dataset that also includes Greenland with same resolution and accuracy). The favourability maps presented herein and derived from these datasets enable identifying permissive and prospective areas, at continental scale, that reflect the geological data and knowledge applied. In future steps, the highest mineral potential must be considered for additional data and knowledge gathering on mineral system, geochemical and geophysical information related to mineralization. This methodology represents different development stages, scales and progress of economic geology surveys which could be a tool to improve effectiveness and efficiency of future investments in exploration.

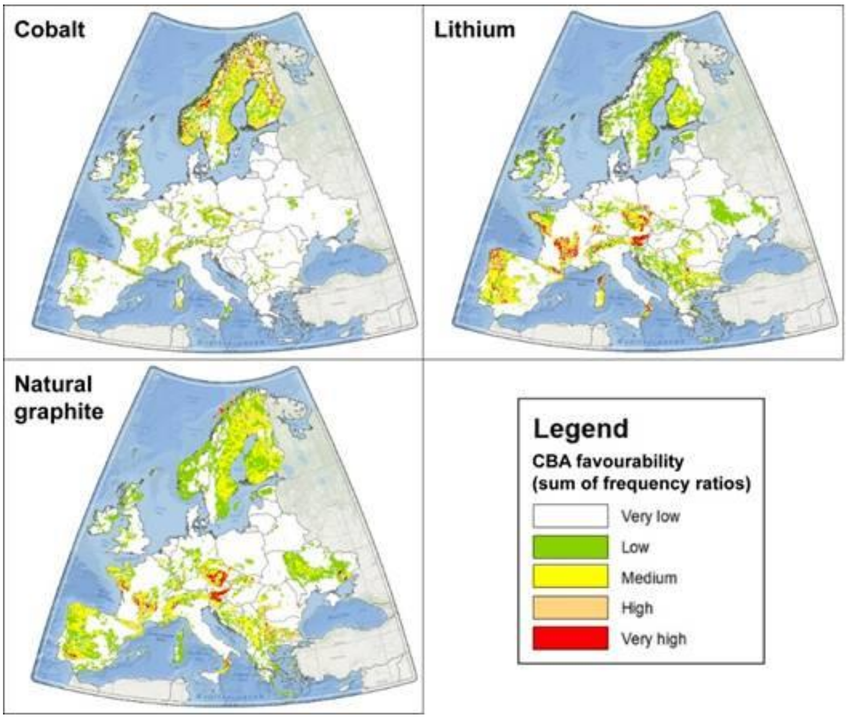
2. **Mineral Prospectivity Mapping for energy critical elements in Europe: The Cell Based Association approach** (authors: Guillaume Bertrand, Bruno Tourlière, Eric Gloaguen, Martiya Sadeghi, Håvard Gautneb, Tuomo Törmänen, Daniel de Oliveira).

Lithium, cobalt and natural graphite are essential for energy storage technologies. Li and Co are used in rechargeable batteries. Natural graphite (Gr) is used as refractory for steel production, but its consumption for batteries is growing significantly. Demand for these elements is expected to surge with the increasing electrification in the transport sector. Gr and Co are critical raw materials (CRM) for the European Union, while Li is above the supply risk threshold. As these elements are produced outside Europe, their supply for the European industry is potentially a threat. Moreover, primary resources should be exploited as a priority in Europe to reduce CO_2 emissions generated by the transport of raw materials. To address these issues, the FRAME project (www.frame.lneg.pt) has been designed to research CRM in Europe that are essential for “green” technologies. An objective of work package (WP) 3 in the FRAME project is to produce prospectivity maps of CRM based on GIS exploration tools at continental scale. The purpose of Mineral Prospectivity Mapping (MPM) is to identify a priori areas where the probability to discover new deposits is the highest (Sadeghi et al., this symposium). Ultimately, their objective is to reduce delay and increase accuracy of exploration campaigns and therefore improve their cost/benefit ratio.

In this contribution, we present mineral prospectivity maps of Europe for primary Li, Co and Gr, calculated with the CBA (“Cell Based Association”) approach (Tourlière et al., 2015) that is an alternative to GIS supported prospectivity methods. It has been developed by BRGM to better manage uncertainties related to cartographic data. The base principle of CBA is to overpass the one to one point-feature relationship that can be the source of significant errors in prospectivity mapping (e.g., uncertainties in point location and polygon contours, possibly inappropriate generalization of a favourability to a whole polygon, etc.) To do so, instead of considering unique point-feature links, the CBA will consider the environment of the points (e.g., not only the lithology polygon that contains a deposit, but also all others lithologies in its vicinity). This is done by superimposing a regular grid on the area of study and identifying the association of lithologies in each of its cells. In parallel, lithological associations are also defined around each known deposit. These associations are considered favourable. All cells of the grid are then ranked on their similarity with these favourable associations. Ranking of a cell is done by combining frequency ratios (FR, or frequency of a given lithology in all standard buffers versus frequency of the same lithology in all cells of the grid) of all lithologies it contains.

In this study, several techniques for combining FR were tested: sum of FR, product of FR, sum of filtered (i.e. > 1) FR and product of filtered (i.e. > 1) FR. In addition, a ranking by simply summing lithology frequencies in standards was tested. We performed statistical tests to measure the reliability of results from these different ranking approaches. The compilation of deposits for Li, Co and Gr has been provided by the WP 5 of FRAME (Gautneb et al., 2019). For each of the 3 deposit datasets, 100 CBA prospectivity maps were calculated with, for each of them, 50% of the dataset (randomly selected) used as training set and the remaining 50% used as controlling set. For each test prospectivity map, a ROC (Receiver Operating Characteristic) curve was calculated with the controlling set and its performance was evaluated by calculating the AUC (Area Under Curve) value. For each ranking technique, an average AUC value and standard deviation were calculated, that allowed to measure its performance per dataset. Results of these statistical tests show that the “product of FR” technique was always significantly underperforming and the “simple sum of frequency of lithologies in standards” technique was often slightly underperforming. The most performant technique was the “sum of all FR” for all 3 datasets. Based on these results, a prospectivity map was calculated for each complete dataset with the 1:1.5 million geological map of Europe (Billa et al., 2008), a regular grid of 10 by 10 km cells covering the whole Europe and the most performant ranking technique (“sum of FR”; see figure). The 10 by 10 km resolution is rather coarse, but it was a good compromise between computing constrains and exploration significance: 100 km2 cells are of the same order of surface than exploration permits.

The prospectivity map for Co highlights the high favourability of the Fennoscandian shield. The rich provinces in central Norway and along the Swedish border are associated with VMS deposits and those near the Finnish border are associated with the Karasjok greenstone belt. In Finland, the highest Co-grades occur in Outokumpu-type VMS deposits in E Finland, and Kuusamo-type Au-Cu-Co deposits in E Lapland. Komatiitic Ni deposits along komatiitic belts in E Finland and NW Lapland appear highly and very highly favourable, respectively. For the Li prospectivity map, most of the favourable areas are located along the W European segment of the Variscan belt. However, highly prospective areas are also along the Alpine belt, and in Corsica and Calabria. As genetic processes of hard rock Li mineralization involve partial melting (Gourcerol et al., 2019), a future development of this map would be to include cartographic indicator of either high pressure or geodynamic context. On the Gr prospectivity map, the province of the Lofoten-Vesterålen Islands is clearly highlighted. Note that the highly favourable graphite province of Austria is of a different type (amorphous Gr) than other areas (flake Gr).



CBA prospectivity maps for cobalt, lithium and natural graphite in Europe.

These maps highlights, at continental scale, areas that are favourable for the discovery of new energy critical elements deposits in Europe. As such, they are valuable outputs of the FRAME project that can help assessing (and possibly safeguarding) highly prospective areas where mineral exploration should be focused in the coming years.

3. **Assessment of critical raw materials content in phosphate mineralisations: an objective of the FRAME project** (authors: Sophie Decrée, Maria João Batista, Daniel P.S. de Oliveira, Khaldoun Al-Bassam, Nolwenn Coint and Heikki Bauert).

The presentation focused on how the FRAME-WP4 project aims to identify new areas of interest for CRM (P, REE, F) exploration in Europe, through a mineralogical and geochemical characterization of a large selection of phosphate mineralisations in Europe. Phosphate deposits in Europe, whether they are of sedimentary or igneous origin, could indeed significantly contribute to secure access to many elements listed as critical by the EC. An overview of phosphate mineralisations, with special emphasis on their Critical Raw Materials (CRM) content is therefore needed to assess the potential of these deposits, which is very poorly known for most of them.

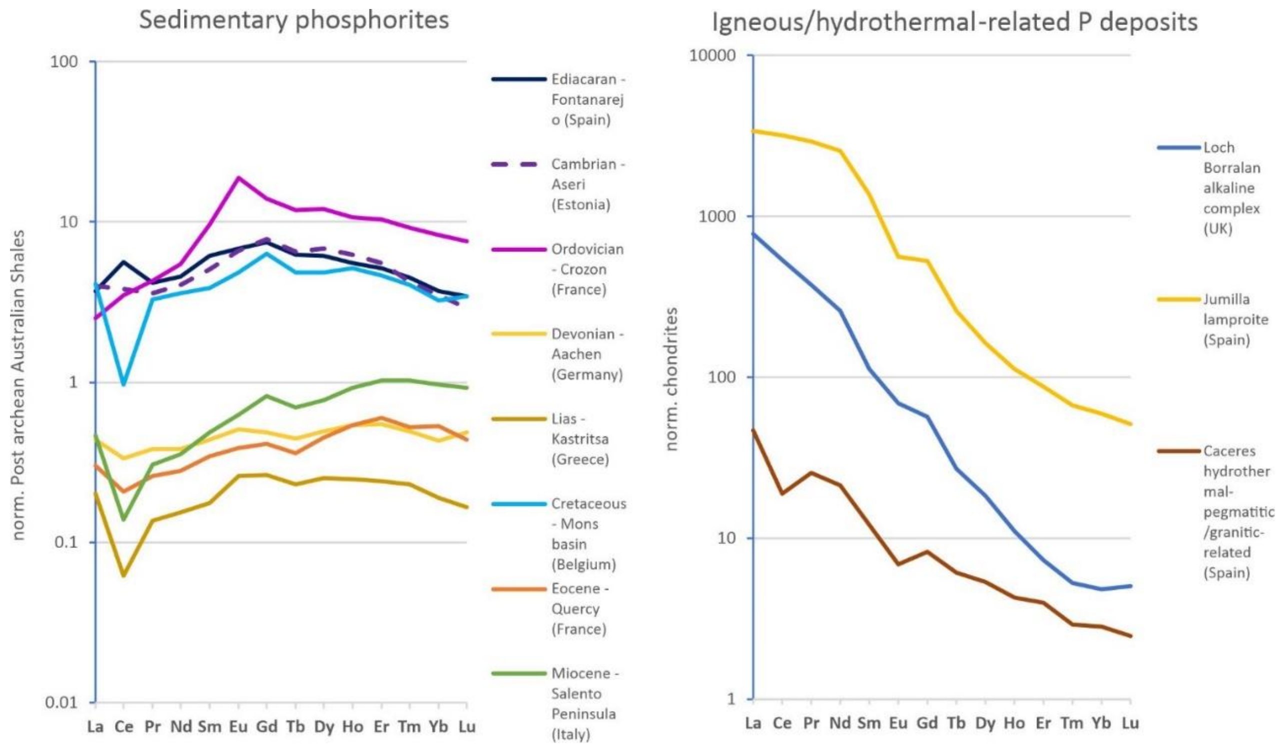
With this project, new mineralogical and geochemical data were acquired on a large selection of phosphate mineralisations in Europe. About 75 phosphate occurrences and deposits throughout Europe have been investigated at the Belgium Geological Survey and some other geological surveys of partner countries, using Scanning Electron Microscopy (SEM) coupled with energy-dispersive X-ray (EDX) analyses, Raman spectroscopy, X-ray diffraction and whole rock chemistry.

The most striking results issued from this study is that REE content is by large higher in igneous-related phosphate rocks than in sedimentary phosphorites. Moreover, a difference in REE distribution can be seen in the examples (Fig. 1). Magmatic apatite is strongly enriched in LREE, whereas the sedimentary apatite contains more M/HREE than some apatite of magmatic origin. This is interesting as M/HREE are much more valuable than LREE. Within the sedimentary deposits, which encloses phosphorite, oolitic iron, alluvial and eluvial placers, differences in terms of REE content are observed and can be correlated to the age of the mineralization.

The REE pattern of distribution in marine phosphorites show variation and some deviation from the REE pattern of open marine water which was related to variable redox conditions. Examples of the REE patterns are shown in Figure 1. Regarding their contents in REE, phosphorites dated from the Ediacaran, Cambrian and Ordovician are at the outset those with the greatest potential, with a total content of REE being usually above 500 ppm. Some of the Mid-Cretaceous phosphorites in the Bohemian Cretaceous Basin showed anomalous REE concentrations in the phosphate components exceeding 500 ppm.

Phosphorus and REE contents in igneous-related phosphate mineralisations vary significantly from one type to another (see figure below). Phosphate mineralization associated with lamproite in Spain is clearly enriched in P and REE, with contents reaching 19% P_2O_5 and 6800 ppm REE, the rocks from the Loch Borralan alkaline complex (the P_2O_5 content of which hardly reaches 2% in the samples studied) are also quite enriched in REE (288-1046 ppm). Finally, the hydrothermal P deposits related to granites/pegmatites in the Caceres-Logrosan zone in Spain are particularly poor in REE (7-61 ppm), though being enriched in P (25 – 41 % P_2O_5).

Besides, the potential in REE and other CRM also depends on the size (in terms of tonnes of reserves/resources) of the deposits, which must furthermore be (re-)assessed in many areas of interest. As a conclusion, one can say that the mineralogical and geochemical data acquired in the frame of the project help for a better understanding of the potential of European phosphates for CRM. The data gathered give clues about new areas of interest for CRM. Additional geochemical data – still to acquire – will help to better constrain these zones for future exploration.



REE patterns of some of the phosphate samples investigated. On the left: sedimentary phosphorites normalized to the Post Archean Australian Shale (Taylor and McLennan, 1985); on the right: igneous/hydrothermal-related P deposits normalized to chondrites (McDonough and Sun, 1995). Note the change of scale from one diagram to the other.

Research and innovation continue in FRAME.

Tungsten: Evaluating the prospectivity of the Eastern Alps

Julia Weilbold (GBA)

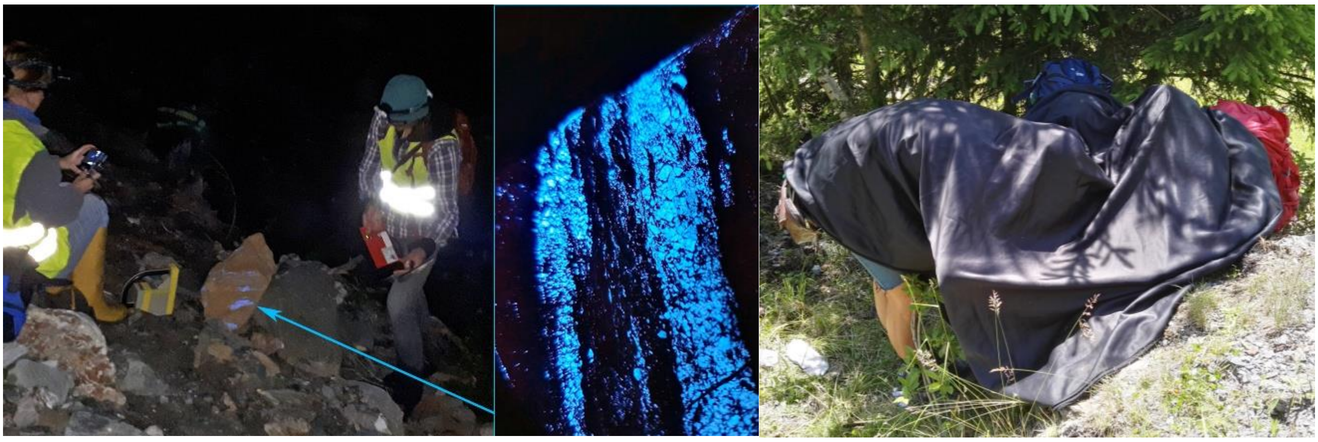
Geologists from the Geological Survey of Austria (GBA) and Montanuniversität Leoben are investigating the regional potential for Scheelite ($Ca[WO_4]$) mineralisation. This is done in close collaboration with “Wolfram Bergbau und Hütten AG” operator of the Felbertal scheelite mine near Mittersill.

The aim is to reevaluate known scheelite occurrence in the light of newly developed understanding of the geotectonic structure of the Eastern Alps in combination with novel analytical technologies. In particular, fingerprinting of scheelite mineralization types using LA-ICP-MS analysis will be tested.

During the field season of 2020 different types of scheelite mineralization were investigated and sampled:

- Stratabound carbonate-hosted:
  - Mühlbach/Neukirchen (W)
  - Tux Lanersbach (W + magnesite)
  - Mallnock (W + magnesite)
- Skarn-like (calc-silicate rocks)
  - Lienzer Schlossberg (Fe-Cu±W)
- Orogenic gold
  - Schellgaden (polymet. Au±W)

The characteristic fluorescence of scheelite under shortwave UV-light is very helpful to distinguish it from other minerals with similar properties. Hence, exploring mineralized outcrops and mountain rivers at night was a routine task. During one of these sessions, a scheelite-rich boulder (0.5 m diameter) of Fe-dolomite was recovered from a riverbed. This magnificent specimen will be exhibited in the street window of the GBA Foyer in Vienna using UV light installation for the winter months. Stratabound carbonate-hosted:



Field work in 2020 involved prospecting for scheelite using UV lamps during night time and "under cover".

Due to the Covid19 situation it was impossible to visit the Felbertal tungsten mine in 2020. The tungsten deposit Felbertal is located at the northern border of the Nationalpark Hohe Tauern and is producing scheelite concentrate for production of specialized steel products in Europe. This deposit formed as a result of magmatic-hydrothermal scheelite mineralization of Variscan age with a significant metamorphic overprint during the Alpine orogeny. In Felbertal, four generations of scheelite can be distinguished that occur in stockwork-like quartz veins and also as dissemination in the host rocks.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

The progress of work package 5

Håvard Gautneb (NGU), Eric Gloaguen (BRGM) and Tuomo Törmänen (GTK)

Data collection finished

The work package 5 have now ended its collection of data. Last country to be included was Greenland. Over the years the data for the Li, Co, and graphite occurrences in Europe and have been collected from a number of different sources and the presently about 60% of the data come from sources that are not direct partners in the project. (Fig. 1)

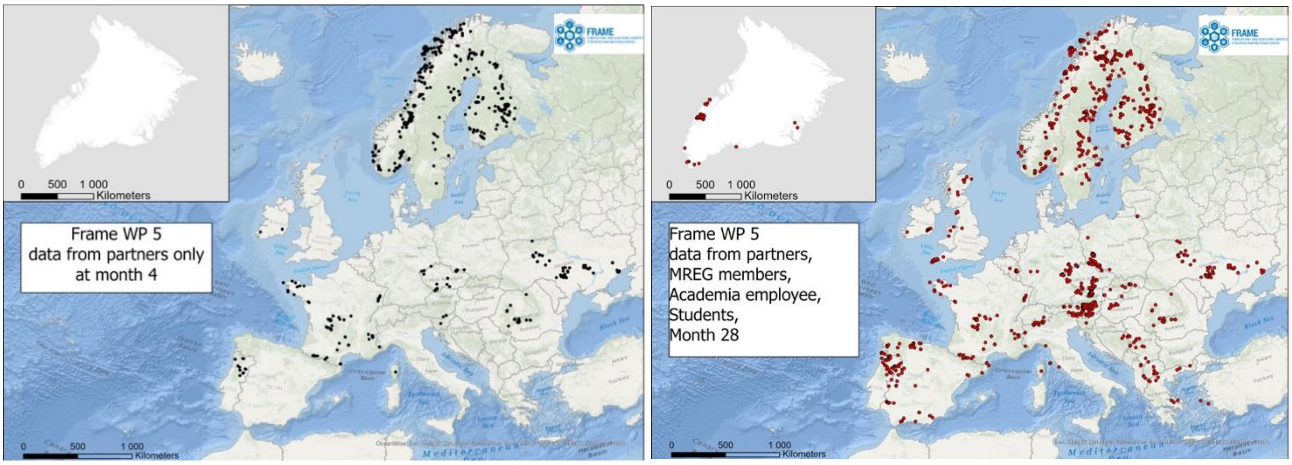


Fig. 1 Data at project start (M4) and at M28 of project showing the occurrences of Li, Co and graphite in Europe.

The most important group of non-partner contributors are the Mineral Resources Expert Group member institutions that are not partners of FRAME or GeoEra. The FRAME project is not alone in investigating the energy critical elements: several university researchers, post docs and Ph.D. students are also working on this and has enabled a mutual exchange of data.

Since WP5 started very early with compiling deposit data, a code list for the genetic type of mineralisations was decided on that it could easy be used for data deliverance particularly from non-partners or countries without a national database, but with a complexity specially designed for the geology of the energy critical elements. This code list is not compliant with anything developed by INSPIRE or Minerals4EU. This is presently an obstacle for a seamless integration of our data. How to solve this will be a major issue that must be solved before the project results can be displayed on web maps under EGDI. One must accept that a substantial amount of occurrence data will not be part of national databases and not be harvested directly to central databases. Discussions are ongoing on how to solve these in best and simplest way.

Our future work on the dataset will include only error corrections and optimization for our future maps and deliverables.

Change of base map

A map intended for posters or other type of paper printing, of the energy critical elements has been supplied the EU commission and used by them at several events (for instance two times at PDAC). The outline of the base map has been changed, and we now use a proposal for based maps made by WP3. Anyone that need to use these type of static maps should request updates from the WP leads (HG). Below is the is examples of the new map outline (Fig.2).

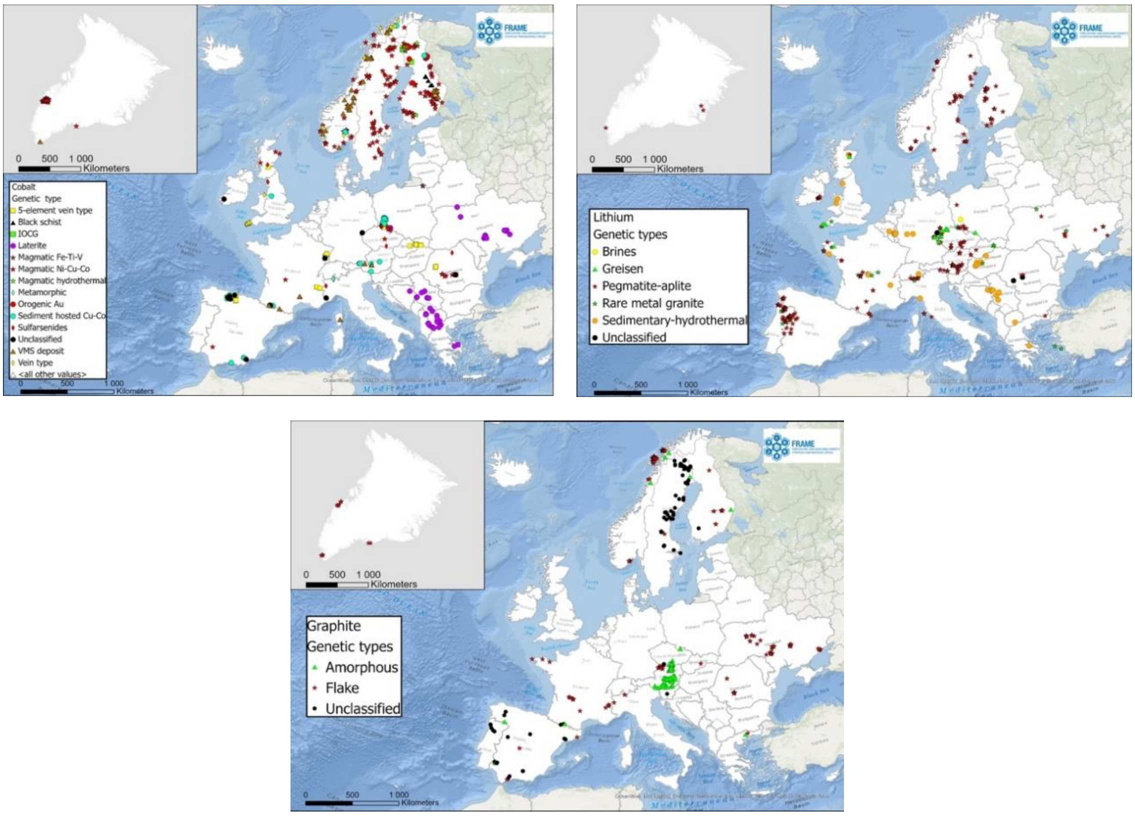


Fig. 2 The new base maps for wp3 showing with in this case the genetic types of mineralization.

Maps of the metallic zones of Li, Co and graphite have also been produced and delivered to WP8 as partial delivery from WP5 according to FRAME's data delivery plan. There is a large difference in the geological complexity that lies behind the definition of the metallic zones. Where Li, and Co are greatly more complex that graphite. On European scale however this complexity not apparent. Fig. 3 show our metallic zones for Li, and Co.

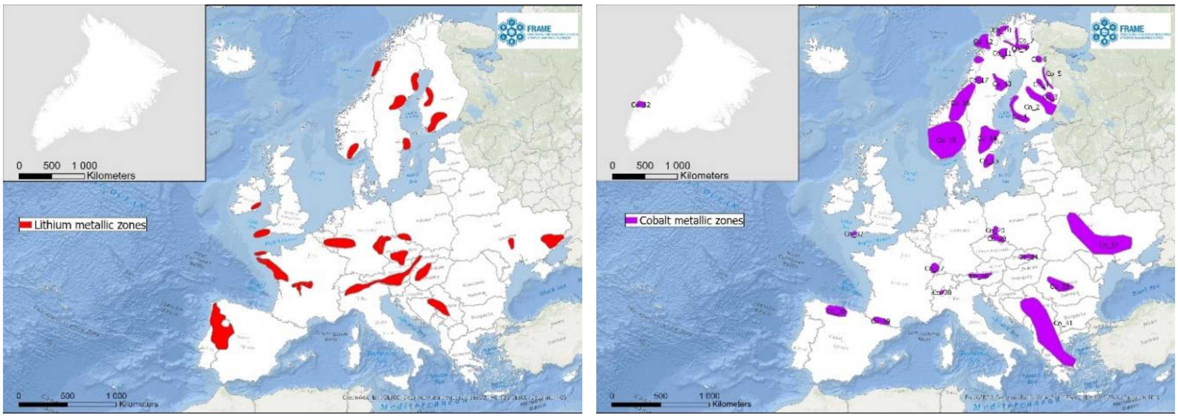


Fig. 3 The metallic zone of Li, and Cobalt.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

FRAME - Forecasting and Assessing Europe's Strategic Raw Materials Needs

Website: www.frame.lneg.pt | e-mail: frame@lneg.pt

Find us on Social Media

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

GeoERA RAW MATERIALS