NATIONAL EXPLORATION PROGRAMME

CRITICAL RAW MATERIALS IN HUNGARY

SARA Supervisory Authority for Regulatory Affairs

Content

1. Basic Information

1.1. Geological background related to primary raw material deposits

1.1.1. Transdanubian Central Range

The Transdanubian Central Range is composed mainly of Paleozoic-Mesozoic sedimentary rocks, with subordinate younger sediments and insignificant quantities of igneous formations.

During the Mesozoic, the area was repeatedly emergent land, where bauxites formed during tropical weathering were preserved in the karstified dolines of the carbonate surface. Prior to the political transition, intensive bauxite mining and processing took place in Hungary. Bauxite mining in Hungary ceased not because of the depletion of reserves, but because of the change in the economic environment at the time of the political transition and inadequate privatization.

In the same unit, not only bauxites but also sedimentary manganese deposits occur, which were previously mined (Eplény, Úrkút). Significant quantities of carbonate manganese ore remained in the abandoned mines.

In addition, several manganese-carbonate indications also occur in younger sediments in the eastern part of the country. In Bükkalja (around Demjén and Szomolya), manganese-carbonate clay occurs in the deeper part of the Oligocene Kiscell Clay. Detailed investigation of this has not yet been carried out.

1.1.2. Paleogene and Neogene magmatic areas

Paleogene magmatism can mainly be traced along the Balaton-Darnó Line. In the western half of the country, Paleogene magmatic formations are known mainly from deep boreholes. Their two more important surface outcrops are located in the Velence Hills and around Recsk, on the northern side of the Mátra Mountains. Several ore indications and closed smaller mines, mainly Pb-Zn and fluorite mines, are also known in the Velence Hills, but within the Paleogene magmatic area the Recsk ore complex has the greatest critical raw material potential. The Recsk ore complex is an exceptionally complete and preserved example of a porphyry-epithermal system, which, in addition to copper, contains significant quantities of other metal resources (Zn, Pb, Au, Mo), as well as concentrations of critical elements and other elements indispensable for modern technologies (e.g. Re, In, Bi, Te). Along the Darnó Line, other former closed ore mines and promising indications also occur (e.g. Rudabánya Fe-Cu-Zn barite).

In the Neogene volcanic area extending from the Pilis to the Tokaj Mountains, several historical mining districts are located (Börzsöny, Mátra, Tokaj Mountains). There are mines that ceased operation in the recent past (e.g. Gyöngyösoroszi, Recsk-Lahóca), and promising indications also occur in this region. It can be stated for each mine that it did not close because of depletion of reserves, but for economic reasons. The closure was also contributed to by the fact that, during the operation of the mines, the necessary geological investigations were not carried out and the surroundings of the mines were not sufficiently known. During the re-examination of the closed mines and known indications, we demonstrated the presence of numerous critical elements that had not previously been known. Based on this new knowledge, further research can be continued.

1.1.3. Placers associated with young sediments

A large part of Hungary is covered by young sediments, in which previous investigations identified promising placer mineral enrichments (Ti, Zr, REE). The most prospective areas are those where igneous and metamorphic rocks were eroded and where coastal and fluvial environments provided the possibility for placer formation.

1.1.4. Ore deposits associated with metamorphic rocks

Potential ore deposits may occur in metamorphic rocks. Based on our previous investigations within the Geological Survey of SARA, as well as descriptions of sporadic archived core samples, domestic areas that are prospective in terms of enrichments of critical raw materials (titanium, nickel, cobalt, precious metals), but are almost completely unknown and unexplored, can be identified in the shallow, largely metamorphic basement of Southern Transdanubia and in their erosion products in the nearby young sediments. The metamorphic basement outcrops can only be traced in patches at the surface. Nickel, cobalt and precious metal indications occur in certain rocks and drill core material derived from these areas.

1.2. Secondary raw materials containing CRMs

1.2.1. Red mud

As a residue of domestic bauxite mining and alumina production, approximately 50 Mt of red mud has accumulated. In the red mud, after the extraction of alumina, the residual elements such as iron, titanium, vanadium, zirconium and rare earth elements became relatively enriched, and approximately 10 wt.% aluminum also remained in it.

1.2.2. Manganese sludge

This relatively large-volume waste material, containing approximately 2.8 million tonnes of manganese sludge, may be prospective if its processing and the economic extraction of manganese can be solved. According to our measurements, the material of the waste dump contains approximately 15-21 wt.% manganese.

1.3. Available information on primary raw material deposits

Mainly paper-based reports, mine closure documentation, and geological, structural and production information and maps recorded during the operation of the mines are available. Some of the more important documents and maps are also available in digital form.

In addition, archived samples from several former mines were investigated using modern methods in order to determine their previously unexamined critical element potential. During these investigations, several promising results were obtained, indicating that some of the ores found in our closed mines also have significant critical raw material contents. These new analyses are important starting points for some of the projects formulated below and also significantly determine the direction of further research.

1.4. Available information on secondary raw materials

Paper-based reports, data from the national waste dump registry, and recent major- and trace-element measurements are available.

2. Objectives, vision

The supply-chain disruptions caused by COVID, the wartime energy crisis and the confrontation between the USA and China have shown that, for Hungary's economic development and social welfare to be stable in the coming decades, the restart and strengthening of the extraction of domestic critical and strategic raw materials is essential. This task and need fit within the policy framework that most strongly determines EU raw materials policy today, the EU Critical Raw Materials Act (EU-CRMA). This work can only be achieved through strong and professionally unquestionable geological, raw material exploration and mining competencies and through the implementation of conscious and effective mineral resource management.

The Draghi report analyzing the competitiveness deficiencies of the EU again emphasizes the importance of critical and strategic raw materials, as well as the role of conscious management of basic and raw materials within the Union that are important for the economy. The report highlights the lag of the EU and the Member States compared with the other economic power centers of the world.

Despite the country's size and geographical location, Hungary's mineral raw material potential offers numerous breakthrough opportunities for the national economy in the fields of supply security, development of domestic defense capabilities and support for reindustrialization.

This can be explained by several factors: on the one hand, there are mineral raw materials whose quantity is suitable to satisfy the needs of our national economy; on the other hand, as a result of technical development worldwide, mineral raw materials that represent serious economic value even in small quantities have become more valuable, and new exploration and mining technologies have made accessible resources that were previously inaccessible or not economically usable. In addition, demands have also emerged for new raw materials whose potential occurrences may be presumed, but which have not yet been explored in detail in Hungary.

On this basis, it can therefore be stated that, in the case of certain domestic critical mineral raw materials, foreign imports can be reduced, or, in an optimal case, domestic production may even be able to satisfy national economic needs (e.g. copper, bauxite, gallium), and it represents a breakthrough point from the perspective of reindustrialization (vehicle, battery, defense industry). All of this substantially re-evaluates the assessment of the country's raw material potential.

One of the most important elements of successful mineral resource management is systematic state raw material exploration and prospecting work. During this process, occurrences are identified and designated that, based on geological knowledge and changing economic conditions, must definitely be registered and possibly utilized, even though they have not yet been affected by exploration, or their reassessment has become justified. This requires a new approach to the evaluation of domestic raw material potential, during which it is especially important to determine which already known raw materials (and their occurrences) can, through development or additional exploration, be turned into industrial and agricultural raw materials with higher added value and wider applicability.

When planning the National Exploration Program, on the one hand, projects were identified that contribute to the country's safer raw material supply (e.g. the Recsk ore complex, bauxite), establish the basis for long-term critical mineral raw material supply and enable comprehensive information expansion.

On the other hand, we must also examine every opportunity that promises tangible economic development opportunities in the short term with relatively little input (e.g. placer exploration, water-dissolved CRMs, helium). On the one hand, strategic projects may even be built from some of these directions; on the other hand, there are raw material occurrences (primary or secondary) where, under appropriate frameworks and in the presence of economic viability, production can also be started. A brief overview of the proposed projects is given in Table 1.

It is a particularly significant step forward that, through the National Exploration Program, the entire geoscience profession can begin unified, aligned and planned mineral raw material exploration work. During this process, under the guidance and coordination of the Geological Survey of SARA, the mineral raw material exploration activities of individual university research groups and state-owned companies are carried out in a mutually reinforcing and concentrated manner, supplementing and supporting the research and exploration work of the Geological Survey. The National Mining Authority of SARA supports the work with mining supervisory records and archive documents, as well as expertise, and with the review of the necessary legal environment.

As a result of the development and capacity expansion necessary for the implementation of Regulation (EU) 2024/1252 of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations 168/2013/EU, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020 (hereinafter: CRMA), the fruits of previous years' systematic state raw material exploration-oriented organizing and exploration work will be utilized for the renewal of the domestic mining industry. It is particularly important that all this is realized as the unified result of the professional community behind the program, for which there has been no precedent in Hungary since the political transition.

3. Identification of target areas, expected results

Most of our former ore mines located within the territory of Hungary were closed as early as the 1980s, and no significant raw material exploration has taken place in the country in recent decades. The reason for the closures was mostly uneconomic production and/or depletion of the ore reserves known at the time (occurring in the absence of further exploration). In most cases, no new geological investigations were carried out in the surroundings of the mines (brownfields exploration), and the possible further extension or continuation of the ore bodies also remained unexplored. Several promising ore indications identified during previous investigations were also not explored in detail. The only exceptions that can be mentioned are the gold ore explorations carried out at Recsk Lahóca and around Mád and Füzérradvány in the Zemplén Mountains, which in some cases also identified significant geological resources. Academic research carried out at our universities with ore geology education also provides important information about these areas; however, those investigations were mainly directed at the genesis of the mineralization, and are therefore not suitable for resource estimation. It is important to note that the quantity and quality of information available to us on the somewhat known mineralizations vary significantly from area to area, which is also reflected in the description of the research tasks associated with the individual occurrences.

Several elements now defined as critical and/or strategic (e.g. lithium, rare earth elements) were not previously sought and were not mined, or were mined only to a small extent. We know relatively little about the domestic distribution of these raw materials. The exploration and investigation of occurrences previously explored only to a limited extent and only for certain raw material types or elements, also with respect to these critical raw material types and elements, has become important for assessing the true potential of a given area (e.g. Mátra, Börzsöny, Zemplén Mountains). Through the investigation of archived samples, we have already shown that ores left behind in some of our closed mines contain several utilizable critical raw materials for which no data were previously available. In contrast to our already somewhat known mineralized areas, there are also areas in the country about which we have no or very little information, but which, based on geological analogies and other indications, may potentially contain enrichment of one of the critical raw materials (greenfields exploration). The process of investigating these areas is summarized in Figure 1.

Work specifically aimed at the exploration of critical raw materials was carried out after 2010 as a state task and within the framework of a basic research project between 2012 and 2014 (CriticEl); however, a systematic, comprehensive, systems-based ore geological investigation resulting in the complete exploration of possible critical raw material deposits has not yet taken place in Hungary. In addition to the exploration of already known raw material occurrences, the Geological Survey of SARA carries out complex raw material exploration activities based on mapping, sampling, drill core investigations, mineralogical-petrographic, geochemical, structural geological and geophysical investigations. Using these results, the discovery of numerous new, previously unknown critical raw material occurrences can be expected.

At Hungary's leading universities (Eötvös Loránd University [hereinafter: ELTE], University of Szeged [hereinafter: SZTE], University of Miskolc [hereinafter: ME]), internationally recognized research groups operate that, through their professional background, basic research activities and training of the next generation, significantly support the implementation of comprehensive, systems-based research projects also followed in international practice. In addition to the data assets available at SARA, an indispensable condition for success is all the information held by state-owned companies operating in the country, with several decades of history and activities related to raw material exploration and mining (Nitrokémia Zrt., MECSEKÉRC Zrt., Rotaqua Zrt.). Based on the above, SARA would like to carry out the research work aimed at the broadest possible survey and exploration of Hungary's possible critical raw material deposits with the involvement of ELTE, SZTE, ME, Nitrokémia Zrt. and MECSEKÉRC Zrt. In addition to expanding the range of institutions related to raw material exploration, the implementation of the project requires laboratory and IT capacities of appropriate quality and quantity, as well as professional human capital.

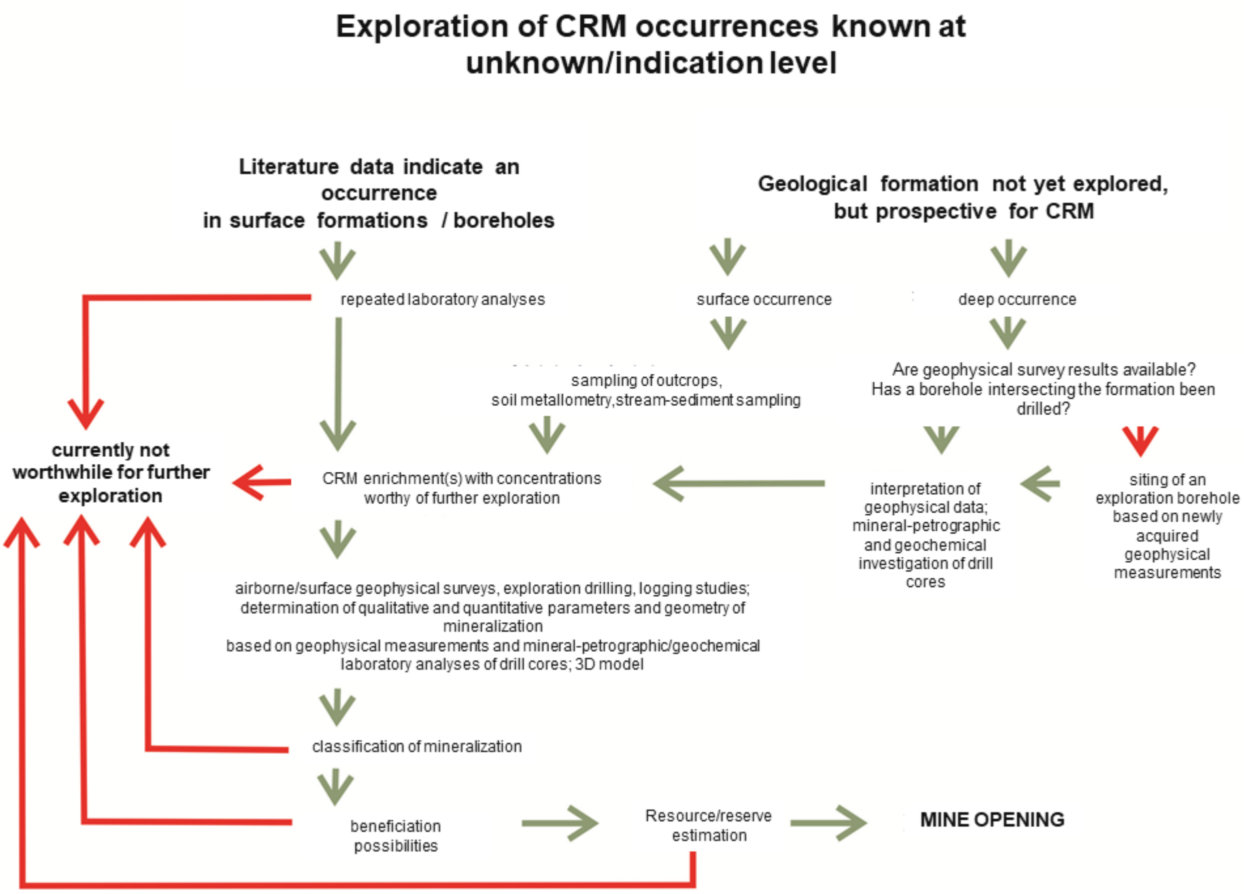

Figure 1. Simplified flowchart of the exploration of areas known/unknown at the indication level.

Based on our investigation results, as well as the professional activities carried out at universities and within the aforementioned state-owned companies, we compiled the proposed research program of domestic critical raw material occurrences included in the National Exploration Program. The Program primarily targets the exploration of primary mineral raw materials, and deals to a small extent with the investigation and exploration of secondary raw materials. The raw materials to be investigated include ores, industrial raw materials and fossil energy carriers, typically from the areas of the Transdanubian Central Range (mainly sedimentary mineral raw materials), the North Hungarian Mountains (mainly mineralizations related to volcanic activity), Southern Transdanubia and the Sopron Mountains.

Based on the country's geological characteristics, we see perspectives in the exploration of the following critical raw materials: antimony, arsenic, bauxite, barite, bismuth, cobalt, copper, gallium, germanium, helium, light and heavy rare earth elements, lithium, manganese, nickel, phosphorus, titanium. Among the listed elements, there are many that cannot be mined on their own, but can be separated and enriched as trace elements in another ore mineral. The 12-point National Exploration Program is presented in an order determined by considering the utilization potential, the level of exploration, the data assets available to us, and the time investment and new data demand required to achieve results (Table 1). The first 5 projects comprise geological exploration of areas affected by former mining (brownfields exploration), followed by research programs for areas considered prospective based on indications and geological analogies (greenfields exploration).

It is important to mention that the potential of individual raw materials is determined not only by the size of the ore body and the ore concentration present in it, but also to a significant extent by the quality of the beneficiation technology applicable to the extraction of the given raw material. In the case of some of the critical raw materials included in the Exploration Program, there is no beneficiation technology of adequate quality (e.g. manganese, Li clays, rare earth elements), therefore at least in the case of those raw materials for which we have known resources, it may be worthwhile to pay attention to carrying out industrial experiments of this type as well, since, if these are successful, the national economic significance of a given area/raw material can be significantly increased. In Hungary, beneficiation procedures are currently dealt with by the Institute of Raw Material Preparation and Environmental Technology operating at the Faculty of Earth and Environmental Sciences and Engineering of the University of Miskolc; in addition, it also has the laboratory background necessary for carrying out the experiments.

No.	Name of research project	Potential critical (and nationally significant) raw material
	Brownfields exploration projects:	
1	Exploration of the copper and other critical raw material potential of the Recsk ore complex	antimony, arsenic, bismuth, platinum-group metals, copper (precious metals, tellurium, rhenium)
2	Critical element potential of Hungarian bauxites and red mud	bauxite, gallium, titanium, REE
3	Critical raw material content of Hungarian manganese ores	manganese, phosphorus, REE
4	Critical raw material potential of the Rudabánya Mountains	barite, cobalt, nickel, copper, REE
5	Critical raw material potential of bismuth-rich mineralization related to intrusive activity	arsenic, bismuth, cobalt, manganese, copper (precious metals, indium, tin)
	Greenfields exploration projects:	
6	Exploration of rare earth element occurrences associated with phosphorites and phosphates	phosphorite, phosphates, REE
7	Exploration of placer-type critical raw materials in Hungary	titanium, REE (gold, zirconium)
8	Critical raw material potential of the pre-Mesozoic basement of Southern Transdanubia (titanium, cobalt, nickel, precious metals)	titanium, cobalt, nickel, (precious metals)
9	Reconnaissance exploration of lithium enrichments in Hungarian Neogene volcanic areas	antimony, lithium (precious metals)
10	Critical raw material potential of Hungarian zinc ores	gallium, germanium, manganese (silver, indium, cadmium, tin, copper)
	Recsk deep level	
	Gyöngyösoroszi	
	Other Mátra area	
	Nagybörzsöny	
	Pátka	
	Rudabánya	
11	Lithium potential associated with geothermal and hydrocarbon-related fluids	lithium
12	Hungary's helium potential	helium

Table 1. Order of the research projects and their most important known characteristics

As can be seen, the research areas and research projects overlap in several cases (investigation of zinc ores), and thus the proper interpretation and integration of the results obtained may contribute to a more thorough understanding of less explored areas.

In addition to the expected results characteristic of the individual projects, results will also be generated that are characteristic of all projects.

Within 1-5 years:

Direct results:

- Classification of archive data into a unified framework and according to the United Nations Framework Classification for Resources (UNFC). The use of UNFC is not only prescribed under the CRMA Regulation (Articles 7, 19, 21, 27), but also plays a role in preparing CRM occurrences and projects with mineral resources for investment.
- Creation and accessibility of integrated databases, establishment of a data room to satisfy the data needs of scientific work and thereby renewal and modernization of the domestic mineral resource registry.
- Expansion of the online map database with basic information on mineral deposits containing critical raw materials.
- Processing and integration of the results of new seismic measurements and geochemical measurements and drilling data into existing databases.
- Development of decision-support systems.
- Publications.
- More detailed genetic understanding of our already known or partly known raw material deposits and increasing the reliability of available resource information.
- Identification of new raw material deposits.
- Announcement of concession tender(s), appearance of investors in the domestic mining sector.
- Appearance of new technologies in mineral separation, beneficiation and processing.

Indirect results:

- Laboratory developments, increase of laboratory capacities.
- Review of the legal framework and permitting processes related to critical raw materials, with particular regard to secondary raw materials and the waste utilization phase.
- Strengthening of professional training in the geological-mining sector.
- Investigation of the accessibility of potential deposits.
- Development of closer cooperation between SARA, universities and the corporate sector.
- Science communication, public engagement, increasing appreciation of mining professional culture.

Within 5-10 years:

Direct results:

- Mine opening.
- In the case of successful results, continuation and territorial expansion of the initiated explorations.

- Announcement of concession tender(s).
- Understanding the genesis and resource information of newly identified raw material deposits.
- Publications.
- Cooperation with neighboring countries in the field of geological exploration and mining.
- Appearance of new mining entrepreneurs.
- Development and application of new technologies for the utilization of secondary raw materials and the extraction of trace elements.

Indirect results:

- Establishment of domestic geological-mining-beneficiation-processing research workshops and development of innovation in the aforementioned fields.
- Science communication, public engagement.
- Creation of new jobs.
- Increase in the proportion of those engaged in raw material exploration, strengthening of well-trained, experienced human resources belonging to the domestic geological-mining sector.

3.1. Target Areas, Presentation of Projects

3.1.1. Exploration of the Copper and Other Critical Raw Material Potential of the Recsk Ore Complex

From the perspective of the national economy, the ore reserves of Recsk are of strategic importance, since, in addition to copper, they also contain significant concentrations of other metal resources (Zn, Pb, Au, Mo), as well as critical and other elements indispensable for modern technologies (e.g. Re, In, Bi, Te).

The Recsk ore complex (Figure 2) is an exceptionally well-preserved example of a porphyry-epithermal system. The entire raw material reserves are related to five ore types formed in different zones of the same hydrothermal ore-forming system:

1. near-surface Cu-Au-Ag-As stockwork-breccia epithermal ore type (Lahóca-Lejtakna)
2. near-surface epithermal Au-Ag vein-breccia ore type (Veresvár-Veresagyagbérc)
3. deep-level Cu-Mo-Au porphyry ore type
4. deep-level Cu-Zn-Fe skarn ore type
5. deep-level metasomatic-vein Zn-Pb-Ag carbonate-replacement ore type

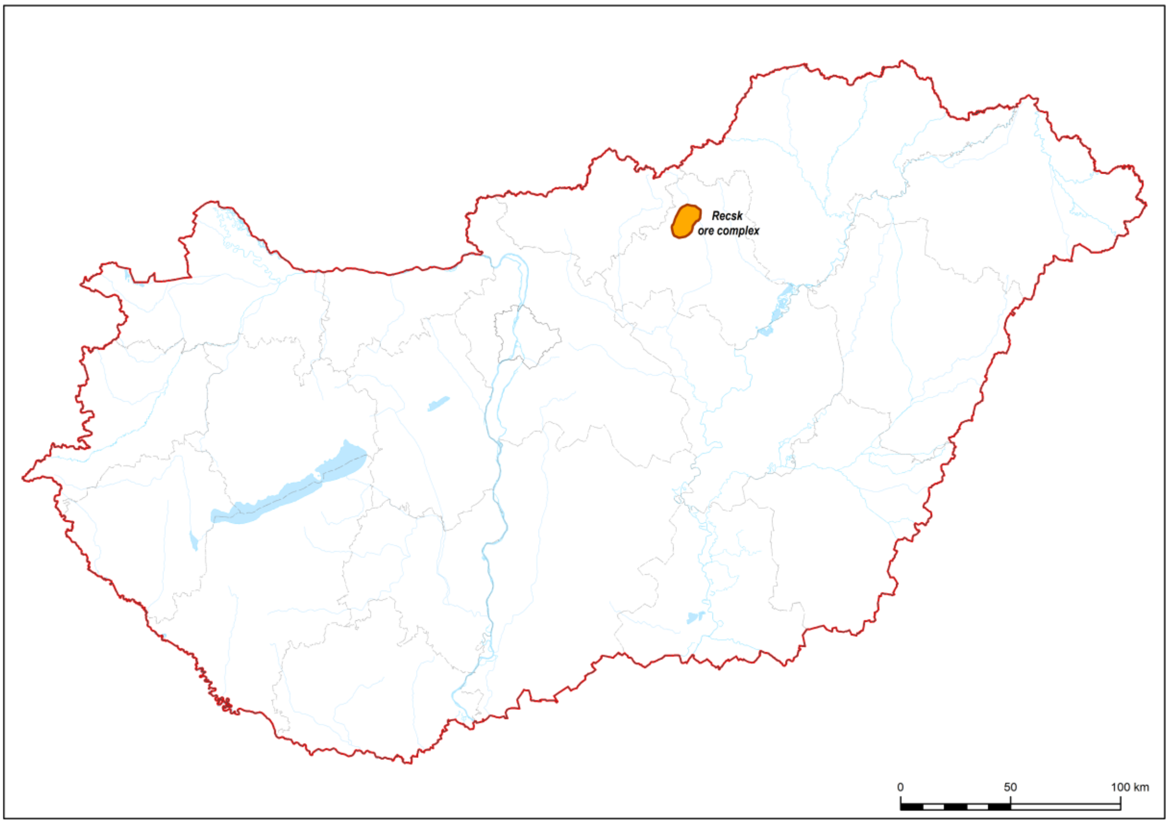

Figure 2. Location of the Recsk ore complex.

The distinction between the ore types is also important because their major- and trace-element concentrations, degree of exploration, possible mining and ore-processing characteristics differ from each other, and this must be taken into account in the evaluation of deposit models, resources, ore grades and the feasibility of possible extraction. The deep-level exploration at Recsk was interrupted and not completed. Due to the fall in the price of copper, exploration and maintenance of the exploration mine did not receive further state funding from 1999 onward. The raw material potential of the exploration is significant. The main target of the deep-level exploration was the porphyry mineralization. This delineated a significant quantity of ore resources, but the ore grade is still insufficient for economic mining. The skarn mineralization is richer, but due to its variability it requires more extensive exploration. Exploration data with varying density are available for approximately 10% of the potentially skarn-mineralized volume.

Following the closure of the exploration mine, meaningful utilization was hindered by exploration that had not been carried out according to the international standards introduced after the 1990s, the questionable quality of the analytical results, the outdated nature of the exploration documentation, and the strict economic conditions of the announced tenders. The most important deficiencies were highlighted, among others, by the report prepared in 2016-17 by KPMG, Golder Zrt. and MECSEKERC Zrt. under the supervision and countersignature of an international Competent Person.

The validated re-evaluation of the Recsk deep-level ore deposit and the genetically closely related surface and near-surface mineralizations (i.e. the Recsk ore complex) according to JORC or other relevant international standards, based on archived samples, as well as ensuring appropriate digital accessibility of the data, would significantly reduce this problem and could contribute to the assessment of the real value of the deposit and its marketing on a basis compliant with present-day requirements. In the longer term, reopening the mine would create the opportunity to continue underground exploration and to announce an exploration tender capable of successfully implementing this.

3.1.2. Critical Element Potential of Hungarian Bauxites and Red Mud

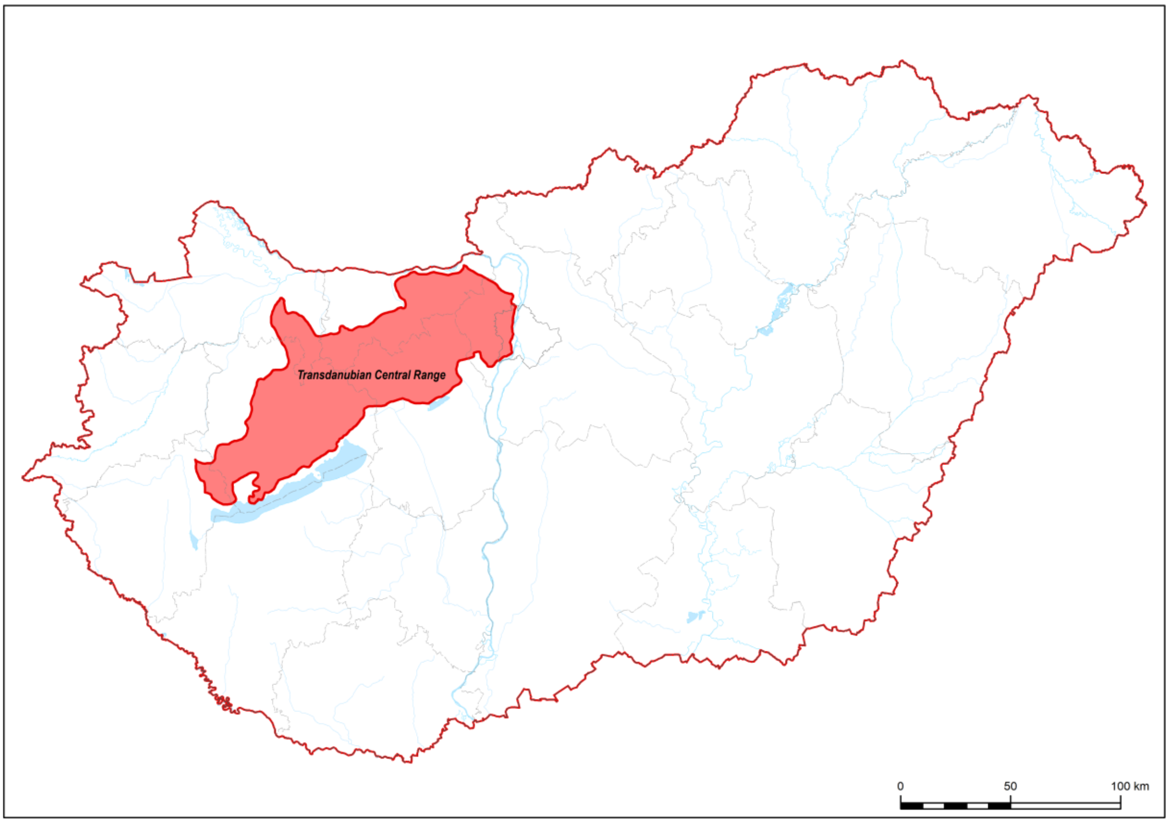

Figure 3. Most of the Hungarian bauxite deposits are located in the Transdanubian Central Range.

Most of the the Hungarian bauxite deposits are in the Transdanubian Central Range (Figure 3). During Hungarian bauxite mining, approximately 108 million tonnes of ore were extracted between 1926 and 2010, of which 28% originated from open-pit mines. Most of the bauxite is/was located below the karst water level. Prior to the political transition, extensive regional karst water level lowering was carried out in the Transdanubian Central Range to reduce the water recharge of the producing deposits for mining purposes. The operation enabling mining lasted until 1990. The intervention was then gradually terminated, which led to the decline of the national bauxite mining and the aluminum industry, and shortly thereafter - following the unfortunate red mud disaster of 2010 - to their almost complete liquidation. Large-scale bauxite production supplying raw material for the aluminum industry ceased completely in Hungary in 2013. Until 2018, the mine of EOSZEN Kft., based on the bauxite of the Bakonyoszlop-II deposit (and the sale of the associated coal resources), still exported small quantities of bauxite to pyrogenic alumina plants in Slovakia, but in 2020 this last private bauxite mine also closed. It is important to note that the cessation of bauxite mining in Hungary was not caused by depletion of reserves, but by changes in the economic environment and inadequate privatization.

The currently registered bauxite resources consist of approximately 124 Mt geological resources (79.8 million tonnes extractable resources), of which 34.6 Mt are located above the karst water level. In addition, there may also be unregistered prospective resources.

Bauxite was not utilized solely as aluminum ore. In addition to aluminum, gallium was also recovered, which is likewise a critical element and one of the indispensable components of today's high-tech electronics industry. In the Iharkút bauxites, analysis of 317 samples yielded Ga2O3 contents between 22 and 104 mg/kg (Szantner et al., 1986). Calculated as gallium, this corresponds to concentrations of 16-77 mg/kg Ga. If the average Ga value of 46.5 mg/kg is considered, this represents a gallium resource of 1231 tonnes in the case of complete extraction of the bauxites located above the karst water level. The bauxites also contain other critical raw materials (e.g. Ti, V, rare earth elements) in varying quantities. However, regarding both trace elements and REE concentrations, only old data from Hungarian bauxites are available (from the 1970s and 1980s). Verification analyses of similar samples using modern methods (predecessor institution of SARA: MFGI, CRITICEL 2014, and REEBAUX 2019) showed that the old trace-element analyses generally overestimated REE concentrations due to methodological reasons.

3.1.3. Critical Element Content of Hungarian Manganese Ores

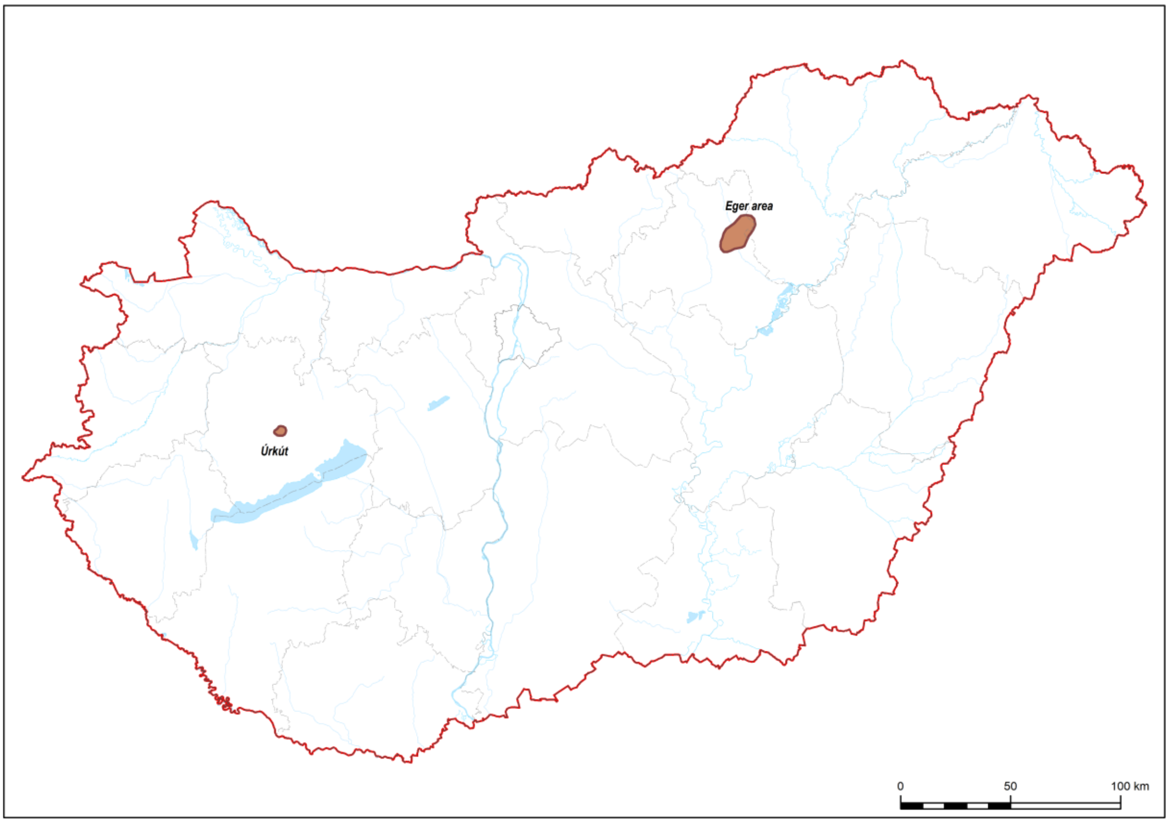

Figure 4. Location of Hungarian manganese ore occurrences.

Úrkút: Exploration of Mn ore and manganese sludge reservoir

The aim of the exploration is to carry out and optimize beneficiation experiments on the carbonate ore, and to identify manganese ore and any additional potentially utilizable critical elements associated with it (e.g. cobalt and nickel) (Figure 4). Most Hungarian manganese ore resources are in the Transdanubian Central Range, mainly in the Úrkút Basin and to a lesser extent in the Eplény Basin. The manganese ore of Úrkút and Eplény accumulated in a sedimentary environment during the Toarcian oceanic anoxic event. Since mining was carried out in both regions for several decades, the exact location of the manganese ore is known. In the case of the Úrkút deposit, data from nearly 1300 deep drillings are available, while in the case of the Eplény deposit, data from more than 230 deep drillings are available.

From a raw material perspective, the Úrkút deposit and its manganese sludge reservoir are the features with which potential can be associated. At the beginning of mining, oxide ore was extracted, and after its depletion mining shifted to carbonate manganese ore. Due to the grain size of the manganese carbonate (a few micrometers), beneficiation experiments were unsuccessful, and the average Mn content of the concentrate was 21% (University of Miskolc, 2016). Direct utilization of manganese carbonates was economically feasible only as an additive in the steel industry. However, metallic manganese can be produced from this type of manganese ore by electrolytic processing (e.g. Lu et al., 2016). This ore-processing technology is applied in numerous industrially advanced countries, and there is even a Hungarian patent specifically for the leaching procedure required for the electrolytic processing of Úrkút manganese ore. Hungarian and Czechoslovak industrial experiments carried out in the 1960s proved that metallic manganese could be economically produced from Úrkút ore by electrolytic processing. In the early 1970s, construction of a pilot plant with a capacity of 150 tonnes/year also began at Zagyvaróna, with the aim of later establishing a large-scale plant planned to produce 3000 tonnes/year, but due to lack of funding the pilot plant only reached 90% completion, and no further investment was subsequently made in this development.

The currently registered ore resource of Úrkút and Eplény exceeds 50 Mt (SARA).

Exploration of manganese ore around Eger

The clayey sequences of the Paleogene basins of northeastern Hungary (Kiscell Clay and Tard Clay) also contain manganese-carbonate intercalations. These were preliminarily explored around Eger in the 1950s (Pantó and Molnár, 1953). Based on analyses of selected samples, the Mn content of the clayey rocks was found to be between 5 and 15%. The mineralized zone can be traced approximately 20 km from Noszvaj to Eger-Demjén. The manganese-carbonate assemblage is approximately 400 m thick, within which more than 30 manganese beds with thicknesses between 0.1 and 2 m occur. The near-surface parts of the carbonate manganese ore contain higher manganese concentrations due to oxidation. These manganese ore occurrences form part of the Paratethyan Paleogene manganese ore belt extending from Kerch and Chiatura through southern Ukraine to Hungary and Slovakia (Kisovce and Svabovce manganese ores) (Molnár and Pantó, 1961). One of the conclusions of the investigations around Eger was that, similarly to the Úrkút ore, the very fine-grained manganese-carbonate ore occurring within the clayey sequence can only be recognized through chemical tests and analyses.

3.1.4. Critical Raw Material Potential of the Rudabánya Mountains

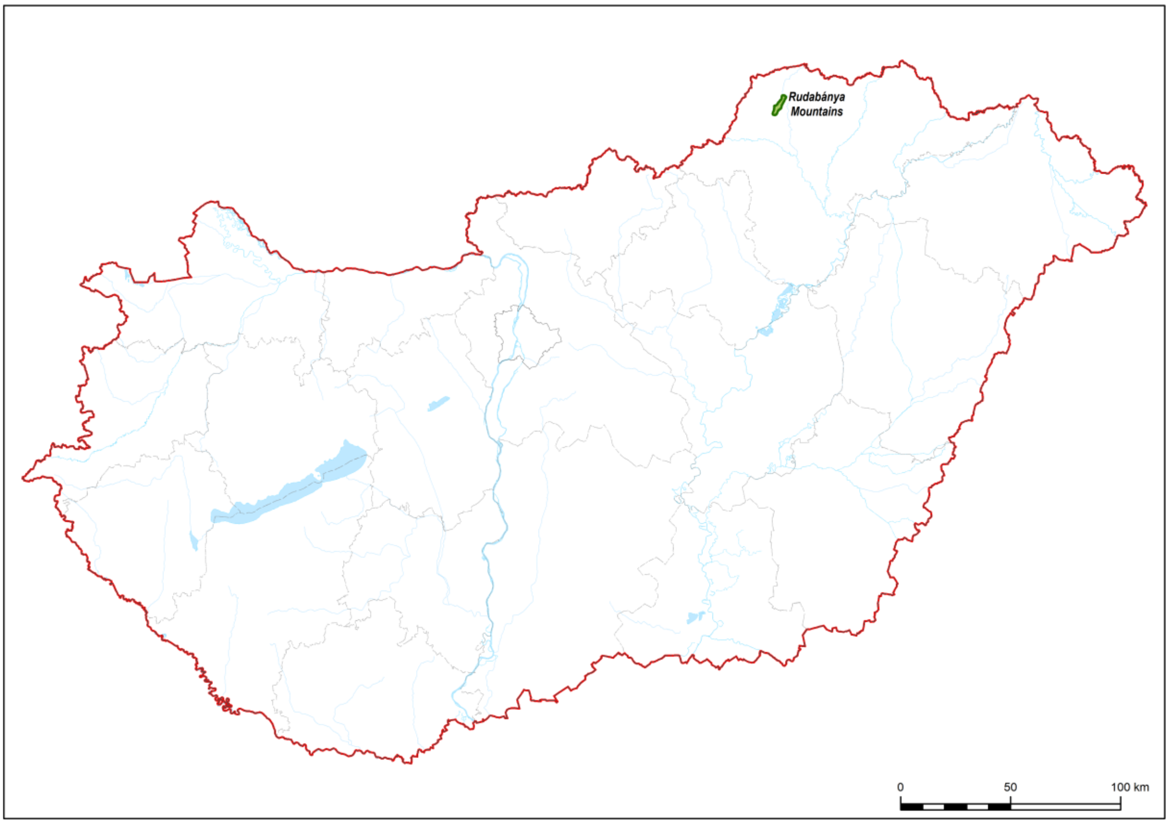

Figure 5. Location of the Rudabánya complex mineralization.

Rudabánya is one of the longest-mined regions in Hungary (Figure 5). Due to the surface outcrop of the raw material body and the copper ore minerals formed by its supergene transformation (azurite, malachite, native copper), it already attracted the interest of ancient peoples. Subsequently, from the Iron Age onward, the iron ore resources also became the subject of mining, and silver was later sought during the Middle Ages. Large-scale iron ore mining began in the 1880s and continued until the closure of the mine in 1985. During this period of more than 100 years, mainly high-quality limonite ore was extracted, but siderite and ankerite were also utilized. In addition, smaller quantities of galena, sulfide copper ore and barite were also produced.

According to data from the Hungarian Geological Survey (2003), at the time of the abandonment of iron ore mining at Rudabánya, the remaining unextracted lead mineralization amounted to 0.6 million tonnes with 1.4% Pb, 0.1% Cu and 105 g/t Ag, while in terms of copper ores, 1.6 million tonnes of ore resources with an average copper concentration of 0.6% were registered.

The open pit of Rudabánya contains complex mineralization, which has attracted the attention of many researchers. Based on the data available so far, the area contains prospective raw material resources that are worth refining through further exploration and, in the case of favorable values, utilizing. In addition to barite as a critical raw material and copper as a strategic raw material, the lead-zinc-silver ores and the remaining iron ore also deserve attention. Based on our current knowledge, this is Hungary's only prospective barite deposit. Using the new exploration results, a barite resource of 4.14 million tonnes has been identified, representing significant value, since barite is considered a critical raw material in the European Union. Thus, extraction of barite at Rudabánya could become an economic factor of European significance.

Within the framework of the activities of ROTAQUA Kft. and later RK Banyatarsasag Kft., further raw material exploration was carried out in the area between 2007 and 2015. ROTAQUA Kft. received exploration rights for “polymetallic ore, precious metal ore and iron ore mineral raw materials,” which were transferred in 2010 to RK Banyatarsasag Kft. RK Banyatarsasag Kft. expanded the transferred exploration rights to include “gravel, sand, clay, barite, limestone, dolomite, marl, gypsum, manganese ore, quartzite and coal (lignite).” From 2016 onward, ROTAQUA held exploration rights as a “new grant” in the “Rudabánya” exploration area, but exclusively with regard to “barite and manganese carbonate” mineral raw materials, within the framework of which it carried out drilling exploration activities. Since 2023, Goldminco Kft. has held an exploration permit for the Rudabánya MIN-1 area concerning non-metallic raw materials, including barite.

In a broader interpretation, several noteworthy indications are also known in the Rudabánya Mountains:

• Positive Pb and Zn anomalies can be detected in the zones between Rudabánya and Pelsőczardó (Ardovo), the exploration of which is discussed in more detail in the chapter dealing with the CRM content of Hungarian Zn ores.

• A mineralized area similar to the open pit, but smaller in extent, occurs within the administrative area of Martonyi.

• Copper-bearing clay shale occurs near Bódvalenke.

• Buried serpentinitized basic rocks (Ni, Co).

• Rare earth element, Y, U and P enrichment associated with F-apatite identified in the rhyolite intersected by the Szalonna-10 borehole, which is discussed in more detail in the chapter entitled “Exploration of rare earth element occurrences associated with phosphorites and phosphates.”

The surface and near-surface occurrence of the raw materials in the open pit and the other anomalies, the infrastructural development of the area and the ore enrichments identified so far provide a favorable outlook toward possible utilization.

3.1.5. Raw Material Potential of Bismuth-Rich Mineralization Related to Intrusive Activity

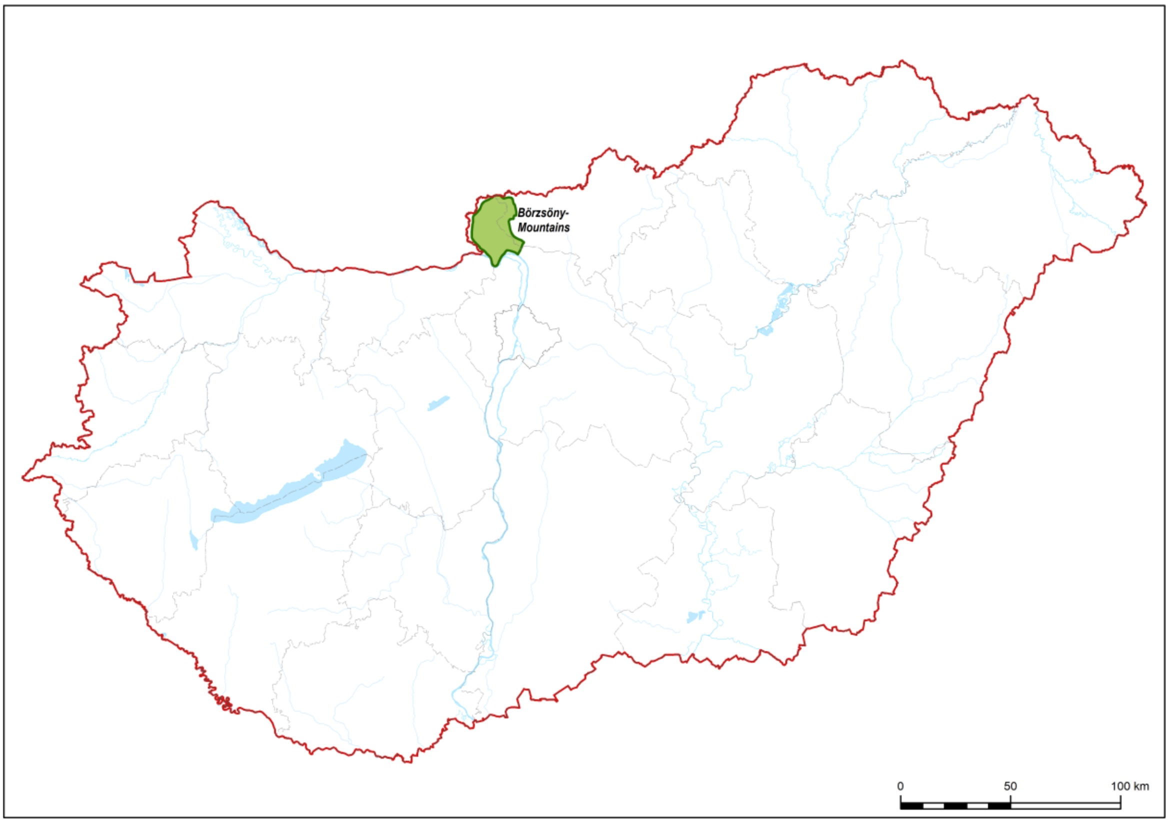

Figure 6. Location of the exploration target area.

Based on previous investigations carried out in the area, the mineralization of the Börzsöny Mountains (Figure 6) was considered to represent an epithermal-porphyry copper system. The best-known mineralization of the epithermal level of the system is Rózsabánya, from whose adits gold and silver were mined during the 15th-17th centuries. Although the near-surface enrichments of precious metals accessible with 17th-century technology were largely extracted, measurable enrichments of gold and silver are still present in the Rózsabánya area and in several mineralization zones of the Börzsöny Mountains. Between 1970 and 1980, volcanological, structural and ore geological exploration was carried out in the area, during which 11 mapping drills (50-300 m), 2 structural exploration drills (1000 m and 1200 m), and approximately 40 ore exploration drills were carried out. The locations of the drills were designated mainly based on geophysical measurements. Of the ore exploration drills approximately 30 were shallow (100-400 m), 7 medium-depth (400-750 m), and 3 deeper (1200 m). In addition, the redocumentation of the still accessible adits (19 adits totaling approximately 2800 meters) was also carried out. The mineralization intersected by the three deepest drills was identified at that time as porphyry copper mineralization, from approximately 800 m depth to the bottom of the drills. Based on the investigation results of the samples derived from the drill cores, this mineralization was considered low grade, although due to the extremely low number of drills, their insufficient depth and the uncertainty of the geophysical measurements, the horizontal and vertical extent of the mineralization could not be delineated. The 10-year exploration program focused fundamentally on copper from the perspective of ore occurrences; therefore, only copper, lead, zinc, gold and silver analyses were carried out on samples derived from the investigated area, and no substantial investigation of the critical and other trace-element content of the mineralization took place at that time. According to the results of the very first resource estimation carried out in 1960, 46 kt of extractable lead-zinc resources associated with the central mineralized area are registered (with average concentrations of 1.72% lead and 0.73% zinc), as well as 326 kt of extractable precious metal ore (according to the resource estimation prepared by Géza Szebényi in 1993, with average concentrations of 1.78 g/t gold and 44.75 g/t silver). The estimated resources cannot be regarded as reliable, because the analyses forming the basis of the calculations covered only a few elements and were carried out using outdated techniques compared with today's modern analytical possibilities, and moreover we know very little about the true extent of the mineralization.

Since the deposit model of epithermal-porphyry copper systems has undergone significant development in recent decades, the ore-genetic re-evaluation of the area and its further systems-based exploration could provide important data that are routinely applied in modern raw material exploration and are indispensable for assessing the true potential of the Börzsöny Mountains. Investigations aimed at determining the genesis of the mineralization and its exploitable metal content have been carried out for nearly 8 years within the Geological Survey of SARA, its predecessor institution, and the Faculty of Science of ELTE. During trace-element analysis of archive samples derived from the central area of the mineralization (from the Lower Rózsa adit, the Rózsa shaft connecting the Lower and Upper Rózsa adits, the Ludmilla adit, the Fagyosasszony adit, and the Altáró adit excavated beneath the adit system driven during earlier explorations), promising quantities of bismuth, arsenic and cobalt were measured in the ore material, and these elements may increase the value of the already known precious metal-lead-zinc-copper resources of the area. Arsenic and cobalt are associated with arsenopyrite, while bismuth occurs mainly in the form of native bismuth and bismuth sulfides, and more rarely as sulfosalts. In addition, according to our LA-ICP-MS investigations, valuable trace elements are also associated with sphalerite and chalcopyrite (cadmium, indium, tin and occasionally gallium). Enrichment of arsenic, cobalt and bismuth is also conceivable in the case of the other epithermal (near-surface) indications (Kuruc Creek, Kis-hideg Hill, Bányapuszta, Királyrét-Szokolya, Zálog Hill, Nagyirtáspuszta, Koppány).

3.1.6. Exploration of Rare Earth Element Occurrences Associated with Phosphorites and Phosphates

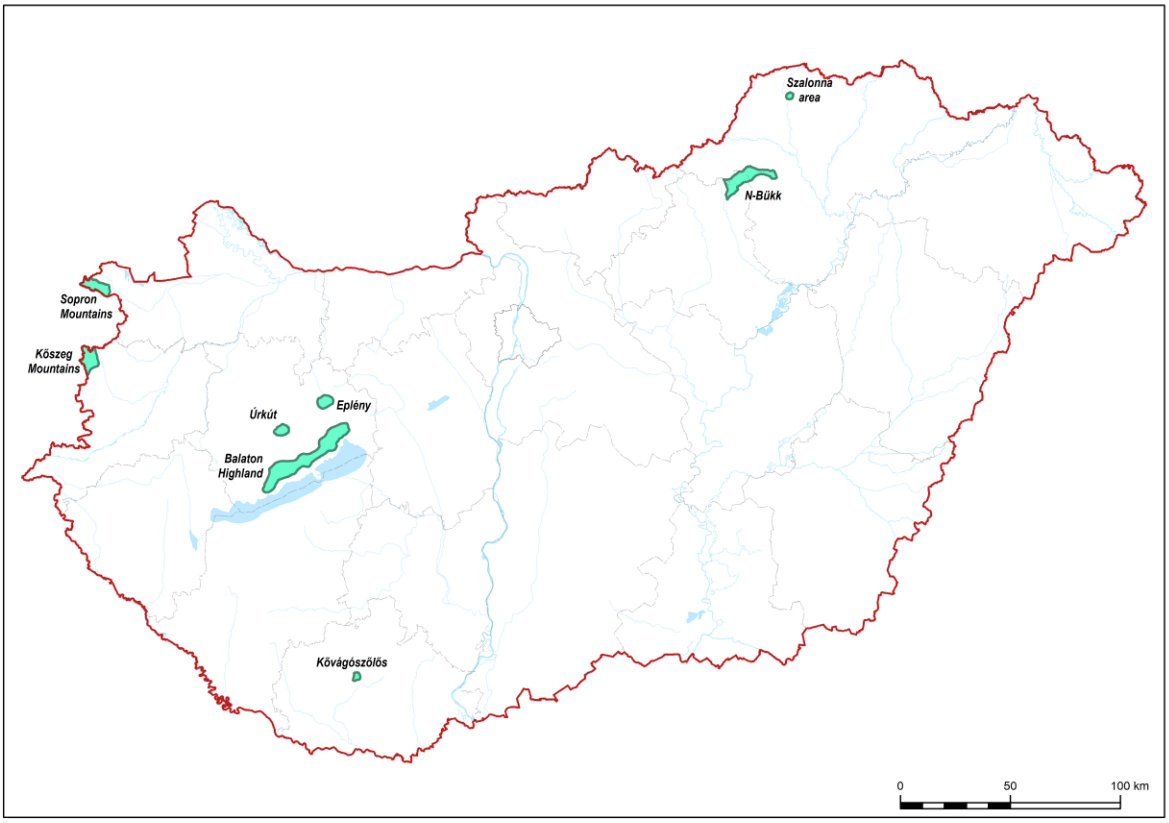

Figure 7. Potential phosphorite and rare earth element-bearing phosphate occurrences in Hungary.

The aim of the exploration is the modern reassessment and investigation of Hungarian phosphorite-phosphate occurrences and their associated rare earth element (REE) potential, as well as the designation of target areas for further detailed exploration aimed at economic utilization (Figure 7). Phosphorus-bearing minerals (primarily apatite, monazite and xenotime) typically occur as accessory minerals in numerous igneous, metamorphic and sedimentary rocks, and due to their crystal-chemical characteristics they may be enriched in REEs. However, the REE enrichment associated with accessory phosphate minerals in these rocks do not represent outstanding ore potential. The more significant Hungarian rare earth element enrichments (in addition to the placer occurrences discussed in a separate project material) were formed during metamorphic and epigenetic-hydrothermal processes overprinting various igneous and sedimentary rocks, as well as during the accumulation of sedimentary-carbonate rocks.

One particular example of Hungarian occurrences of metamorphic rocks with high phosphorus content is the REE-bearing quartzite identified in the Sopron Mountains during former U-Th exploration carried out by MÉV, which occurs as lens-shaped bodies locally reaching thicknesses of up to 1 m within kyanite mica schist. REE-rich phosphate minerals are concentrated in the quartzite. The total REE content of the REE-bearing quartzite lenses and layers varies irregularly, reaching several percent and locally exceeding 10% in certain samples: these represent the highest REE values identified in Hungary. Earlier investigations were able to identify the REE-enriched rock body over strike lengths of 250–300 m and dip lengths of 100–150 m. However, rock debris with high REE content occurs over a much larger area, raising the possibility that REE enrichment may also occur in formations other than the quartzite, or that the quartzite itself extends over a larger area. Smaller REE enrichments (on the order of 100 ppm) are also known from metamorphic rocks around Fertőrákos and metamorphic schists of the Kőszeg Mountains. Due to the exceptionally high REE content, we propose renewed exploration of the area, which could begin on the basis of reports and samples available at MECSEKÉRC Zrt.

The manganese ore deposits of Úrkút and Eplény also contain phosphorite intercalations, which themselves represent critical raw materials. Based on ICP-MS measurements carried out at MFGI, predecessor institution of SARA, the total rare earth element content of the phosphorites may reach 0.5 wt.%. The elevated REE contents indicate that, in the case of successful experiments aimed at the extraction of metallic manganese from the Úrkút and Eplény manganese ores and the subsequent implementation of industrial-scale processes, emphasis could also be placed on the recovery of rare earth elements.

Previous investigations identified epigenetic-hydrothermal REE indications with significant concentrations (total REE contents reaching up to 1000 ppm) in Paleozoic and Pannonian sedimentary formations of the Balaton Highland, as well as in weakly metamorphosed Paleozoic sedimentary formations in the northern Bükk Mountains. Similarly, in the Rudabánya Mountains near Szalonna, several drills intersected a 100 m thick rhyolite sequence, within which Szalonna-10 drill revealed anomalous REE, U, Y and P contents over an interval of several meters. Neutron activation analysis carried out at the Budapest University of Technology and Economics reactor determined La (83.0 g/t), Ce (215.0 g/t), Sm (39.0 g/t), Eu (0.93 g/t), Tb (9.4 g/t), Tm (5.5 g/t), Yb (33.0 g/t) and Lu (6.5 g/t), totaling 391.33 g/t. Concentrations of the remaining rare earth elements could not be determined by this method. In addition to the identified REE anomaly, the Y content (600 g/t, XRF determination) is also highly significant, and the U content (155 g/t, neutron activation analysis) is also notable. The objective of the exploration is therefore to determine the genesis, thickness, spatial distribution and possible economic significance of the REE, Y, P and U enrichment identified in the rhyolite intersected by the Szalonna-10 drill.

The REE content of these indications, mostly associated with phosphate minerals, require verification, especially because earlier analyses often determined element concentrations using spectrographic methods, resulting in a high degree of uncertainty in the data.

Hungarian bauxite deposits also contain total REE contents reaching approximately 1000 ppm, mainly associated with accessory phosphate minerals in the bauxite, but this is discussed in the project material dealing with the critical element potential of Hungarian bauxites.

Since phosphorus and phosphorite are themselves critical raw materials, the occurrences listed above are also prospective with respect to these commodities in addition to their rare earth element contents.

3.1.7. Exploration of Placer-Type Critical Raw Material Accumulations in Hungary

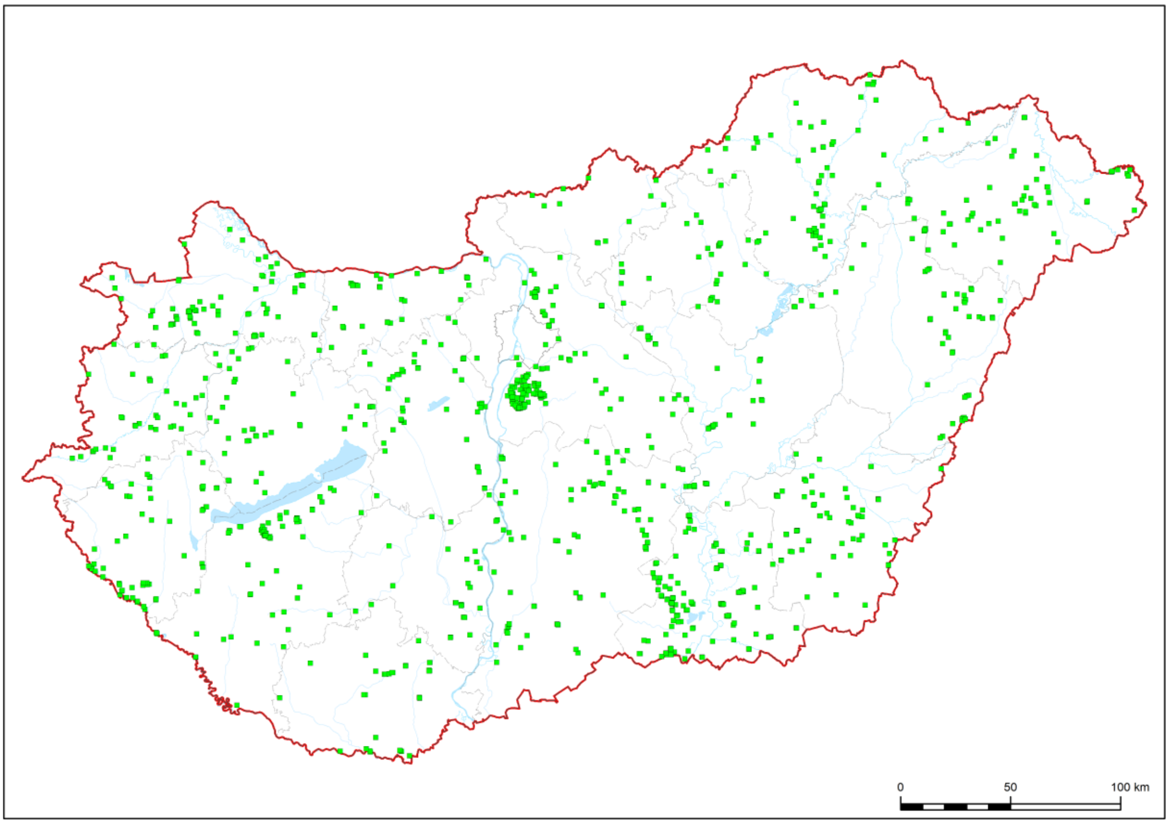

Figure 8. Distribution of the most important sand pits (possible hosts of placer accumulations) in Hungary.

In numerous countries around the world (e.g. Australia, India, Brazil, Indonesia), placer accumulations of rutile, zircon, ilmenite and monazite are exploited. The term "mineral sand" is a collective name for occurrences where, despite the relatively low quantity of heavy minerals, complex utilization allows the recovery of small amounts of high-value titanium, zirconium, rare earth elements and in some cases gold together with other mineral raw materials. Numerous rocks contain significant quantities of Ti-, Zr- and REE-bearing minerals, such as rutile, ilmenite, zircon, monazite, xenotime and zircon. Due to their high specific gravity and their chemical and physical resistance, these minerals survive weathering and erosion processes intact and may become concentrated into placers during transport and sorting. Such placer deposits may contain, in addition to rare earth minerals, other heavy minerals such as ilmenite or cassiterite. These placer deposits may form in various environments, such as coastlines or river deltas. By developing technologies for further beneficiation and separation, REE-enriched material may be produced. Mapping, sampling and analysis of Hungarian placer deposits, as well as the development of beneficiation technologies for REE- and titanium-anomalous materials, may contribute significantly to assessing the Hungarian REE and titanium potential. Since 2012, predecessor institutions of the Geological Survey of SARA (MÁFI, MBFH, ELGI, MBFSZ) have already conducted placer-related (secondary) critical raw material investigations in Hungary. Important aspects in the exploration of heavy mineral placers include the geological structure of the source area, the mode of accumulation (coastline, barrier reef), duration and extent of accumulation. Earlier investigations carried out by predecessor institutions, as well as literature data, have demonstrated that heavy minerals are mainly enriched in the ~30–80 µm grain-size fraction of different sands.

3.1.8. Critical Raw Material Potential of the Pre-Mesozoic Basement of Southern Transdanubia (Titanium, Cobalt, Nickel, Precious Metals)

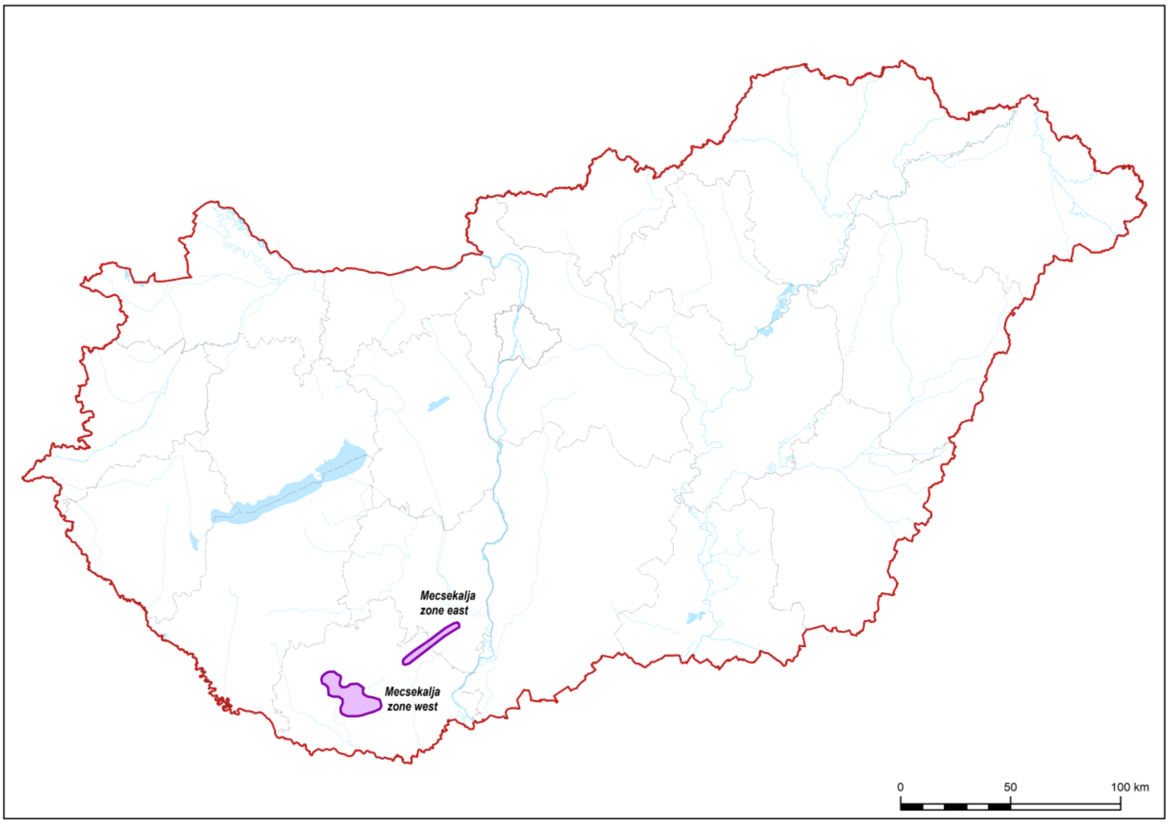

Figure 9. CRM exploration target areas in Southern Transdanubia.

Based on our investigations carried out so far within the Geological Survey of SARA, as well as descriptions of scattered archived drill core samples, prospective but almost completely unknown and unexplored areas can be identified in Hungary within the shallow-depth, predominantly metamorphic basement of Southern Transdanubia with respect to potential enrichments of critical raw materials (titanium, nickel, cobalt, precious metals) (Figure 9). Surface outcrops of the metamorphic basement occur only within the Mecsekalja tectonic zone in downtown Pécs and within an approximately 1.5 km wide belt between Pusztakisfalu and Zsibrik. Certain rocks and drill core materials derived from these areas show nickel, cobalt and precious metal indications. Nickel and cobalt form independent sulfide minerals (siegenite, gersdorffite, vaesite, millerite) associated with hydrothermally altered metabasites. Laboratory investigations of drill core samples from the Western Mecsek area also confirmed the presence of nickel, cobalt and precious metal indications beneath Neogene sediments at shallow depths (~80–100 m). Earlier investigations had already indicated nickel and cobalt anomalies in the Western Mecsek area based on studies of drill cores drilled in 1961 and 1962 to investigate magnetic anomalies near Helesfa and Gyód, but the analytical methods available at the time relied only on spectrographic analyses with uncertain accuracy. We carried out ICP-MS trace-element analyses on drill core samples from the Helesfa-1, Helesfa-2 and Gyód-2 drills (a total of 21 core samples from depths between 70 and 432.8 m). According to our ICP-MS investigations, the drill core samples contain an average of 0.2%

(2000 mg/kg) nickel, where the nickel is associated with disseminated sulfides (mainly pentlandite and millerite according to SEM-EDS), which is also confirmed by our aqua regia (AR) leaching analyses. The highest nickel concentration obtained from AR-insoluble silicates and oxides by LiBO2 fusion from all core samples was only 73 mg/kg. Cobalt-bearing sulfides accompanied by galena and sphalerite are also characteristic, reflecting hydrothermal alteration within the ultrabasic rocks. In certain drills located southwest of Szekszárd in the eastern part of the zone, sulfide-associated nickel, cobalt and precious metal anomalies are characteristic, together with locally high (>1%) titanium contents mainly associated with ilmenite. A highlighted area of the basement is the Mecsekalja tectonic zone, which according to our latest investigations can be integrated into the structural geological and ore deposit models characteristic of orogenic gold deposits. Furthermore, we have also confirmed the erosion of gold-bearing metamorphic rocks derived from the Mecsekalja zone and the occurrence of secondary (placer-type) gold accumulations in the Eastern Mecsek, which simultaneously raises the possibility of placer-type critical raw material exploration (Ti, Au) within younger sediments formed from erosion products of the metamorphic zone.

Within the geologically complex Southern Transdanubian zone, exploration of prospective critical raw materials (titanium, cobalt, nickel, precious metals) is planned in several focused target areas:

• within the Mecsekalja tectonic zone where the basement metamorphic formations occur at the surface or shallow depth, corresponding approximately to a 1.5 km wide and 30 km long belt between Pécsvárad and Szekszárd, as well as the immediate surroundings of Szentlőrinc and Pellérd;

• within the magnetic anomaly zones between Helesfa and Szekszárd, where the causative bodies may not only be Lower Cretaceous alkaline basalt bodies irrelevant from a CRM perspective, but also metamorphosed shallow-depth ultrabasic-basic formations representing further key exploration targets;

• within the magnetic anomaly areas of the Görcsöny Ridge;

• exploration of Permian microgranite-rhyolite bodies and their surroundings may also be justified if ongoing investigations of sampled hydrothermally altered and sulfide-bearing drill core samples (Szava-1 drill, south of Gyód) provide encouraging analytical results. Descriptions of additional dril cores intersecting Permian rhyolite and associated rocks (Vókány-2, Egerág-7, Diósviszló-3) also reported sulfide dissemination and nickel-cobalt indications;

• within the metamorphic basement of the Görcsöny Ridge, where the post-metamorphic propylitic overprint identified throughout the full depth of the Baksa-2 drill is systematically accompanied by polymetallic mineralization (Cu-Zn-Pb), which is characteristic even in the uppermost basement sections.

3.1.9. Reconnaissance Exploration of Lithium Enrichments in Hungarian Neogene Volcanic Areas

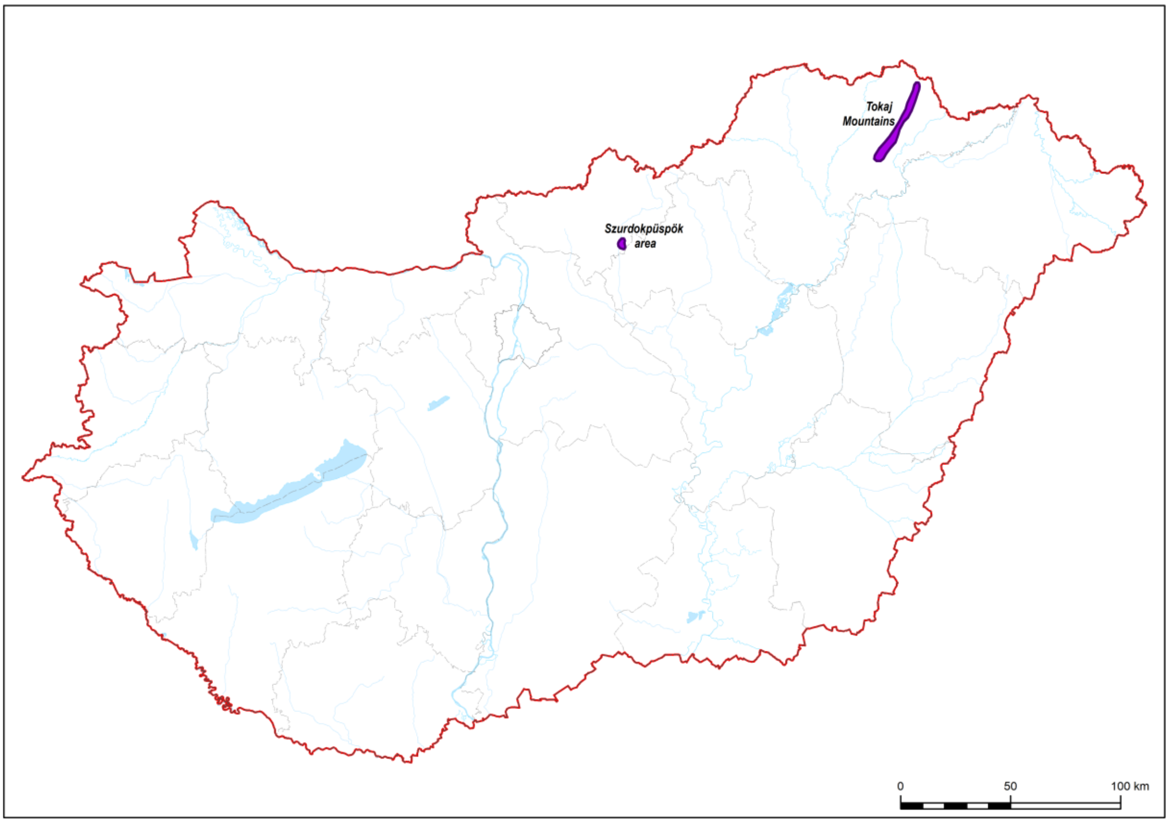

Figure 10. Location of potential lithium deposits in Hungary.

The primary raw material sources of lithium are related to pegmatites of granitic rocks and so-called greisen alteration zones, limnic-hydrothermal clay deposits of intermediate-acid volcanic areas, salt sediments (salars) of closed basins with arid climates in continental volcanic areas, and the deep-basin brines. Of these, in Hungary, apart from the dissolved Li content of deep-basin fluids, the limnic-hydrothermal facies of intermediate-acid volcanic rocks may have significant ore potential.

Based on the modern and unified volcanic-hydrothermal system model developed in recent decades for the Tokaj Mountains and the other Hungarian intermediate-acid volcanic units (Mátra, Börzsöny), it can be established that the surface zones of hydrothermal activity related to volcanism have been preserved in several areas. These zones are limnic basins formed in depressions of volcanic caldera structures and volcano-tectonic subsidences, typically fed by former hot springs of the Tokaj Mountains and the Mátra, in which significant clay deposits also formed. Lithium ore deposits located in similar geological environments are being discovered in an increasing number of places worldwide. For example, at Thacker Pass in the McDermitt Caldera (USA, Nevada), lithium concentrations of 1% were measured in illitic Miocene lacustrine sediments. The lithium enrichment there is also accompanied by fluorine. The lithium-boron mineralizations of the western Balkans, such as Jadar (Serbia) and Lopare (Bosnia), may also be mentioned. In the latter case, boron and magnesium are also among the recoverable elements.

During lithium exploration carried out over the past two years, certain hydrothermally altered rocks of the acid volcanic rocks of northeastern Hungary may represent prospective targets based on geological analogies. Based on our investigations to date, the most promising location is in the volcanic-sedimentary sequence near Erdőbénye, where the lithium concentration in the archived borehole Eb-165 clearly increases toward the bottom of the borehole. In the clayey veins located at the deepest point of the borehole (148.5-150 m), the lithium concentration reaches 542 mg/kg. Although lithium did not show a positive anomaly in near-surface samples, the clearly increasing lithium concentrations with depth make the area appear prospective. Lithium concentration showed positive correlation with magnesium concentration and smectite content. At the surface between Mád and Rátka, we measured lithium concentrations between 100 and 250 mg/kg at several locations, which stand out from the other samples, most of which contain lithium between 10 and 30 mg/kg. In certain samples, arsenic and antimony contents are also elevated (both critical elements), and gold (up to 1.1 mg/kg), cesium and rubidium also show significant positive anomalies. Antimony shows enrichment in several samples at concentrations of approximately 0.1-0.5 wt.%. If an increasing trend with depth can also be assumed here for lithium, then further exploration toward depth, the search for additional surface lithium anomalies, and metallometric mapping are certainly justified in this area.

In the Tokaj Mountains, we designated prospective areas partly based on data from previous works, partly based on the results mentioned above, and partly based on the comprehensive hydrothermal ore geological model for the mountain range. Based on these, we initially targeted the following areas (Figure 10):

In the Tokaj Mountains:

- clay deposits around Szegi;
- the limnic-hydrothermal facies of the area between Mád and Rátka;
- limnic bentonite-diatomite deposits of Erdőbénye;
- limnic facies of Füzérradvány overprinted by hydrothermal gold mineralization;
- bentonite deposit of Komlóska;
- potassic metasomatic zones around Telkibánya, Rudabányácska and Regéc;

In the Mátra:

- the area around Szurdokpüspöki.

3.1.10. **Critical Raw Material Potential of Hungarian Zinc Ores**

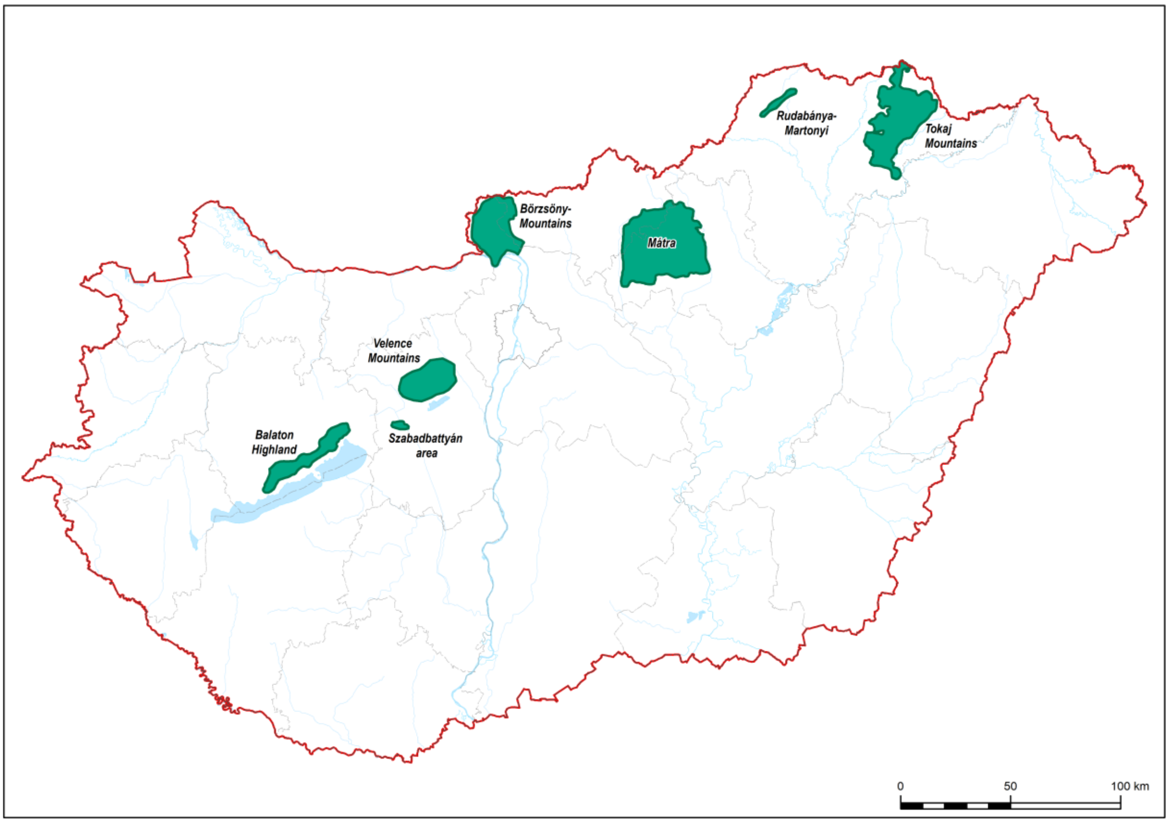

Figure 11. Areas of domestic zinc ore occurrences.

One of the most important ore minerals of zinc is sphalerite, which, in addition to zinc and sulfur, can incorporate numerous other elements into its structure (Ag, As, Bi, Cd, Co, Cu, Fe, Ga, Ge, In, Mn, Mo, Ni, Pb, Sb, Se, Sn, Tl, etc.). Of these, Ge, Cd, In and Tl should be highlighted, for which sphalerite is the primary raw material, as well as Ga, for which this mineral is a secondary raw material source. Sphalerite is a widely distributed mineral in the base-metal mineralizations known in Hungary (Figure 11). Recently, the sulfur-free carbonate ore of zinc, whose main mineral is smithsonite (ZnCO3, "zinc spar"), has also received more significant attention. Carbonate zinc ore is also characterized by the concentration of critical trace elements, primarily cobalt. It is therefore clear that zinc ore minerals have particularly favorable potential for the enrichment of critical metals. Since international scientific literature is already available on the formation conditions controlling trace-element incorporation (e.g. temperature-, redox- and pH-dependence, geotectonic setting), it is worthwhile to examine domestic deposits from this perspective.

The aim of the proposed research is the comprehensive investigation of domestic sphalerite and non-sulfide zinc ore deposits, the identification of possible CRM-bearing areas based on reconstruction of formation conditions, and the characterization of mineral-chemical and whole-rock chemical compositions in these areas. In addition, through the system-based investigation of different deposit types, new occurrences that have not yet been identified could also be recognized. A further objective is to investigate how and under what conditions and processes non-sulfide zinc ores that are more closely or more broadly related to sphalerite occurrences may inherit strategically important metal contents.

Based on mineralogical knowledge and geological analogies, elevated Ga and Ge contents may be expected in sphalerite from Zn-Pb occurrences along the Periadriatic-Balaton Line (e.g. Balaton Highland, Szabadbattyán, Velence Hills, Rudabánya). In the sphalerite-bearing ore of Pátka, we measured 100-180 mg/kg Ga in the ICP-MS laboratory of the Geological Survey of SARA. The occurrences of non-sulfide zinc ores between the Rudabánya-Martonyi ore district and Pelsőczardó (Ardovo) in Slovakia, also belonging to the zone of the Periadriatic-Balaton-Darnó Line, have significant spatial extent and therefore possess ore potential proposed for exploration. Critical element enrichments may also be expected in sphalerite associated with the polymetallic zones of epithermal systems in Hungarian Neogene volcanic areas (e.g. Neogene Mátra, Börzsöny, Tokaj Mountains), as well as in sphalerite occurring in the polymetallic skarn and carbonate-replacement polymetallic ores at Recsk. Sphalerite formed under higher-temperature and more oxidizing conditions may possibly contain In and Co (e.g. Recsk). Since researchers from ELTE and the Geological Survey have actively worked on this topic in recent decades, for certain areas we already have detailed mineral- and whole-rock chemical databases based on modern analytical methods (ICP-OES, ICP-MS, electron microprobe and LA-ICP-MS), on the basis of which further exploration can be recommended.

3.1.11. Lithium Potential Associated with Geothermal and Hydrocarbon-Related Brines

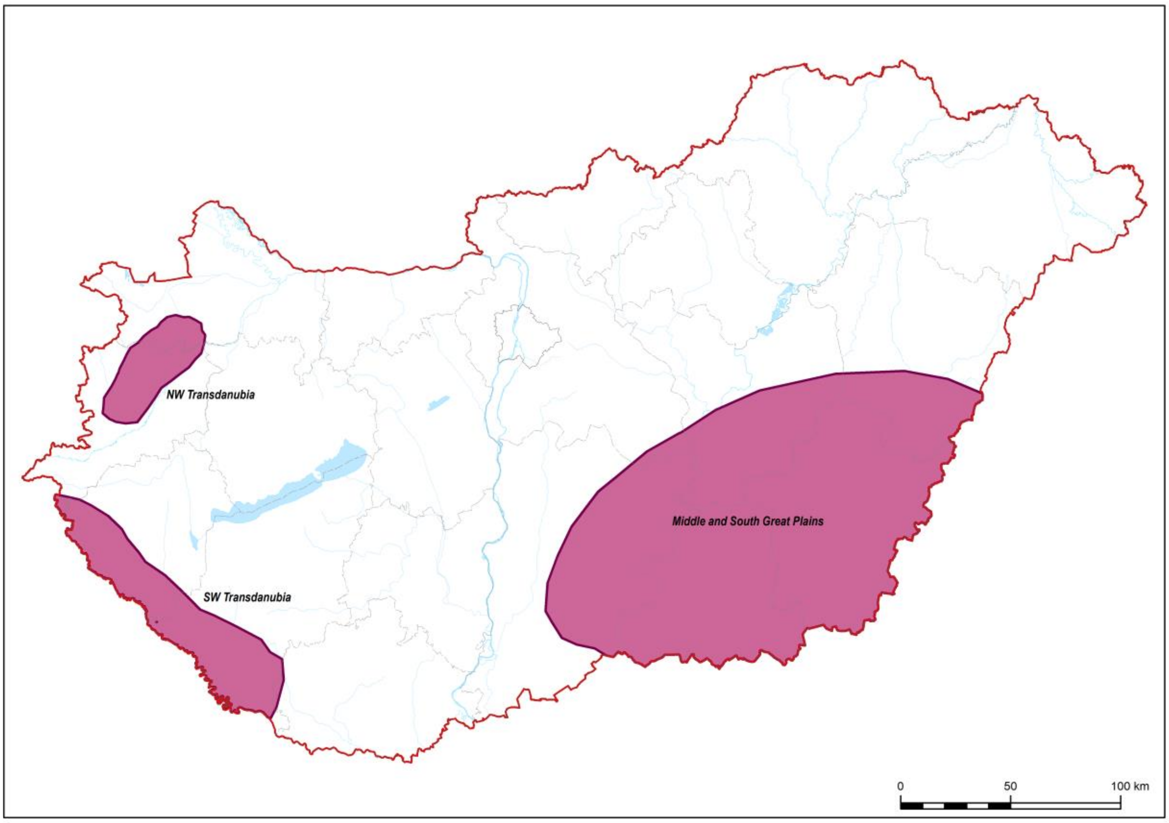

Figure 12. Location of potential domestic water-dissolved lithium occurrences.

Preliminary investigations related to geothermal and hydrocarbon-related brines have confirmed significant dissolved Li contents in certain occurrences. Lithium concentrations determined from water analyses of hydrocarbon-related brines show Li concentrations of 50,000-169,000 µg/l in the most prospective areas, typically in the southern and central Great Hungarian Plain region (Figure 12). Since 2023, SARA has begun re-examining these occurrences producing outstanding values using accredited sampling. Although the research program is still ongoing, preliminary results consistently show elevated concentration values. The highest values were found in the occurrences of the Battonya and

Pusztaföldvár highs. Detailed investigation of the area and completion of the national exploration program may bring us closer to a more accurate understanding of the domestic potential.

3.1.12. Hungary's Helium Potential

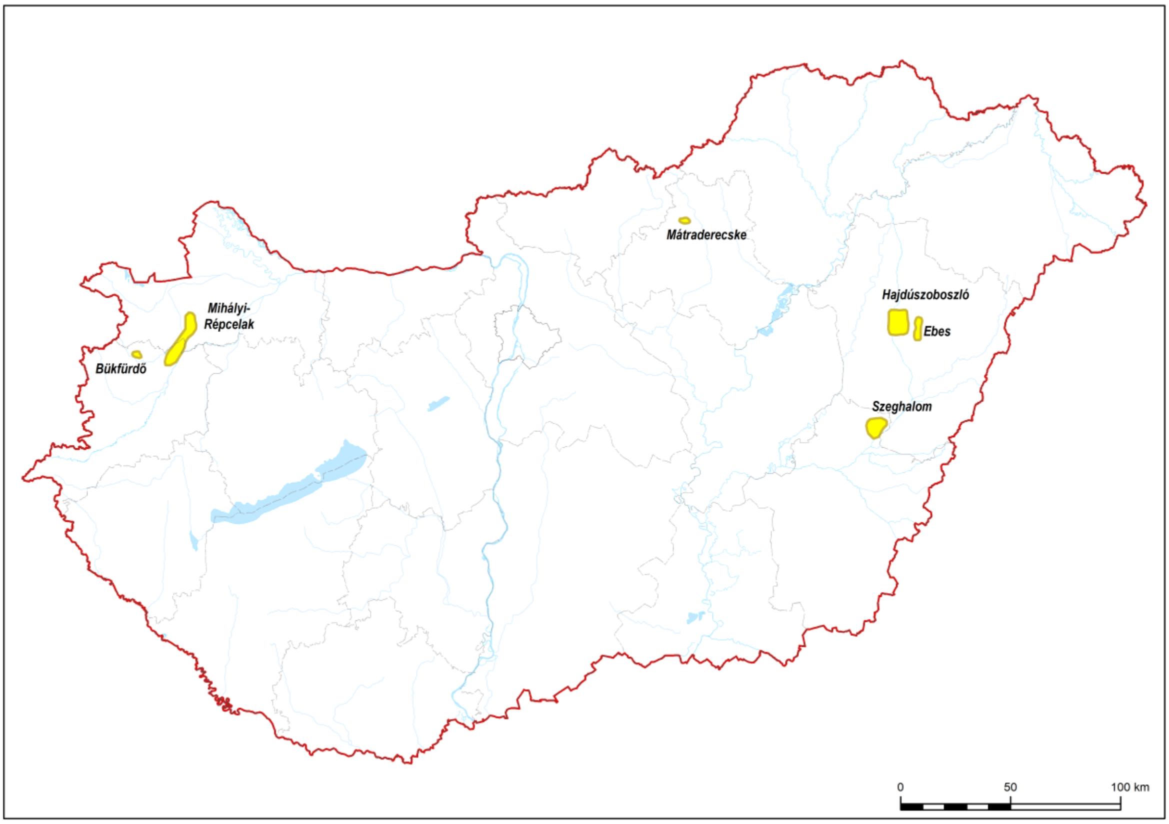

Figure 13. Potential domestic helium occurrences.

The investigation of He concentrations in domestic hydrocarbon and inert gas occurrences has been carried out since the 1990s, primarily for scientific purposes, in order to determine the origin and age of the gases. Occurrences with more significant concentrations are known from the areas of Hajdúszoboszló, Ebes (Ballentine et al., 1991) and Répcelak (Palcsu et al., 2014), and the concentration value of the Szeghalom field is also worth mentioning (Lollar et al., 1994) (Figure 13). Based on this small amount of data, significant He concentrations in Hungary are associated with hydrocarbon gas or mixtures of nitrogen and hydrocarbon gas, while the helium content of CO2 deposits is negligible. At the same time, the overview also shows that nationwide systematic investigations are lacking, and thus the true potential of hydrocarbon and other known "inert gas" occurrences is poorly known. It must be stated that possible He potential associated with geothermal utilization has not been investigated at all. The early, very limited number of results, however, may indicate even extremely significant potential.

A nationwide targeted investigation would enable a more accurate understanding of the domestic potential, as well as the selection of prospective areas, and possibly the development of separation technology optimized for domestic conditions could also begin. At the same time, it should be mentioned that the investigation of the gas content of domestic geothermal brines (or accompanying gases) may also yield significant results (e.g. Szelényi and Csajághy, 1941).

3.2. Expected Results of the Individual Projects

3.2.1. Exploration of the Copper and Other Critical Raw Material Potential of the Recsk Ore Complex

During the investigation of the Recsk mineral resources planned over the next 1-3 years, the level of geological knowledge can be increased by collecting and critically analyzing data, samples and information, validating the data, analyzing the collected control samples, reevaluating the geological model and recalculating the 2017 resource estimate. Based on these new results, the possibility of exploitation and retendering the ore occurrence can be considered again. By digitizing data and research results, organizing them into databases, and enabling 3D visualization of chemical analytical data, the data of the Recsk ore types and host rocks will be organized into a modern, transparent, searchable and verifiable system compliant with international reporting standards and the modern requirements of ore exploration. In addition to these data, refinement of the three-dimensional ore geological-genetic model and its support by the results of investigations carried out using modern mineralogical-petrographic and geochemical methods are also essential parts of internationally accepted reporting requirements. By reprocessing existing geophysical measurement data and carrying out new measurements, a more modern structural and geological model can be prepared, and the placement of new — validation-type — deep boreholes can be better substantiated. Publication of the ore geological and ore genetic models of the ore types in leading professional journals (e.g. Economic Geology) also increases investor confidence, since the quality of geological data and their interpretation is guaranteed by the strict publication rules applied in such professional journals.

By reanalyzing part of the old samples and statistically comparing them to the archive data, as well as by digitizing old laboratory reports, we aim to demonstrate the reliability and usability of the old data. This would promote the re-evaluation and exploitation of the ores of the Recsk ore complex of European significance. Determining the critical and strategic trace-element content of the minerals containing the main metals (Cu, Mo, Zn, Pb) supports a more substantiated economic evaluation of the ore types of the raw material deposit.

With the system of validated old and new data produced in compliance with international reporting systems, we may come closer to assessing the real potential of the Recsk ore deposit. Based on the research results, decisions related to further exploration of the deposit, reopening of the mine and expolitation will be much better founded. With the help of all this, by the end of the first 5 years at the latest, a level of knowledge can be achieved that enables concession tendering of the exploration rights of the area.

In the longer term (5-10 years), the results obtained by collecting new geochemical, geophysical and drilling data (complex mineralogical-petrographic, hydrochemical and rock-mechanical data) and integrating them with the old data will contribute to a better understanding of the ore deposits of the Recsk ore complex. This enables assessment of its true potential and more detailed analysis of the feasibility of mine opening.

3.2.2. Critical Element Potential of Hungarian Bauxites and Red Mud

On the basis of the collected and analyzed samples, we will obtain a realistic picture of the trace-element contents of Hungarian bauxites and abandoned red mud deposits in the first five years. We will be able to designate bauxites and red mud deposits richer in trace elements. More detailed exploration and sampling can then be continued at these locations. Based on the results, and in light of the changed economic environment since then, the possible extraction and utilization of the domestic bauxite resources remaining after mine closures can be reconsidered.

In a 5–10-year perspective, the aim may be to establish the basis for broader utilization of Hungarian bauxites, covering a wider range of elements. Within this framework, technology can be developed that is applicable not only to aluminum but also to the desired trace elements. (As mentioned above, a developed technology already exists for the complete processing of red mud. Considering the new results, there may be an opportunity to fine-tune this technology.)

3.2.3. Critical Raw Material Content of Hungarian Manganese Ores

Úrkút: Mn ore and manganese sludge reservoir exploration:

The location and quantity of the ore resources of the Úrkút manganese ore are well known. Manganese itself is a critical raw material, but the data on the associated critical element contents (Co, REE) require development. The well-documented sample collection can be used for this purpose.

In the case of the Úrkút manganese ore deposit, the main task is to carry out and optimize beneficiation experiments on the carbonate ore. In 2016, a condition set by the mine for the beneficiation experiments was that beneficiation should be possible using the existing technology available at the mine. These experiments were not successful. During the CriticEl project (2014), dissolution experiments were carried out on brown and green carbonate ore for the selective extraction of manganese, cobalt and REE. Manganese extraction in two stages reached 97-99%; in the case of Co it reached 70%, and total REE extraction reached 82-84%. The investigation did not proceed to selective metal separation experiments.

The objective that can be set within the present National Exploration Program is that ore beneficiation for manganese and additional critical elements should be economically feasible using dissolution and selective separation technology with the best available technology. In the first five-year period, we intend to progress from TRL 1-2 level (basic research, development of theoretical foundations and identification of technological concepts and applications) to TRL 5-6 level (experimental evidence under laboratory conditions and validation of the technology in an experimental environment).

In a 5-10 year perspective, if laboratory experiments are positive, the aim is for an investor to carry out large-scale (industrial) experiments for electrolytic metal extraction, which may be followed by the preparation of a resource calculation and feasibility study, and the submission of a strategic project.

Exploration of manganese ore around Eger

In the 1-5 year perspective, the aim is to collect literature data and carry out surface sampling and laboratory analyses. Further objectives are the delineation of manganese-bearing layers and possibly deposit(s), carrying out laboratory-scale electrolytic experiments, and evaluating the results. The results will be published continuously.

In a 5-10 year perspective, if the laboratory experiments are positive and ore bodies prospective for extraction have been identified during earlier exploration phases, the aim is to carry out large-scale (industrial) experiments for electrolytic metal extraction.

3.2.4. Critical Raw Material Potential of the Rudabánya Mountains

Part of the area of the Rudabánya open pit is close to the stage of establishing a mining plot. ROTAQUA Geological, Mining Research and Deep Drilling Ltd. applied to the Authority for the establishment of a mining plot entitled "underground (barite) mining activity in the 'Rudabánya (barite, manganese carbonate)' exploration area." By the end of the period, if the preliminary environmental assessment and the technical operating plan (MÜT) are successfully obtained, opening the mine is a realistic objective. In the event of successful mining plot establishment, within the mining plot the mining entrepreneur is expected to carry out validating and reconnaissance drilling exploration not only for barite, but also for other critical and strategic raw materials already identified at indication level in the area. In the event of a negative assessment of the application, the main task is to carry out detailed exploration for critical raw materials within the designated mining plot, and then to establish the mining plot based on the results. In parallel with this, validating and reconnaissance exploration of the wider surroundings of the mining plot must begin for strategic, critical and other raw materials.

Although, based on our current knowledge, the mineralized area is mainly restricted to the immediate surroundings of the open pit, since part of the mineralized zones is linked to a stratigraphic level, and the ore-bearing Triassic strata have significant spatial extent, and since the area has been affected by strong tectonic processes (shortening, strike-slip movements), it is worthwhile to allocate resources to exploration of the wider area as well within the Rudabánya-Aggtelek Mountains. The aim of the detailed exploration plan is to delineate the extractable ore resources, validate archive analytical data, and investigate prospective areas as well. Thus, the objective is to establish a mining plot for the already explored barite raw material, as well as to identify and understand the potential of other raw materials in the wider area and decide on detailed exploration. On the basis of the investigation of ore-bearing faults and the hydrothermal processes that created the primary mineralization, the range of targeted raw materials may be expanded. By digitizing archive materials, organizing the digital exploration material collected so far, and continuously incorporating new results, a 3D model can be built that can help expand and refine the resource data known so far.

3.2.5. Intrusive Activity-Related Bismuth-Rich Mineralization and Its Critical Raw Material Potential

By analyzing the Börzsöny samples, we can significantly increase the level of geological knowledge of the area, and through the use of a broader range of analytical methods we can better understand the processes responsible for the mineralization of the mountain range, as well as the spatial and temporal relationships between the ore bodies formed by these processes. This will help us define further prospective targets and estimate the potential of bismuth, arsenic, indium, copper, molybdenum, and precious metals. By applying modern, system-oriented ore deposit methodologies, we may also identify additional concealed or insufficiently explored parts of the epithermal copper-porphyry system.

Within the first five years, vectoring and modelling based on geochemical data will allow the designation of areas recommended for detailed exploration, where, provided sufficient funding is available, several exploration drill holes may be completed. In addition, based on previous geophysical investigations, it may also be possible to verify by drilling a formation located near Rózsabánya, on the southwestern slope of Rózsa Hill, which produces a geophysical anomaly stronger than that of the known mineralization around the Rózsa shaft. The exploration adit intersects the area in question, but the origin of the anomaly has not yet been identified. If this geophysical indication is indeed related to an ore body, then the presence of an ore body analogous to the mineralization around the Rózsa shaft may be confirmed by a drill hole with depth about 200 m. If the anomaly-causing formation is located below the adit, the required drilling depth increases (~500 m), and therefore the costs will be significantly higher.

Within a 5–10 year perspective, provided that sufficient quantity and quality geophysical and drilling exploration is carried out, it may become possible to delineate individual ore bodies, refine the quantity and quality of the registered ore resources, classify them according to international standards, and determine the reserve-scale quantities of previously uninvestigated critical raw materials. By integrating the resulting data into geological models, a more accurate understanding of the genesis and extent of the mineralization can be developed, enabling the identification of additional prospective areas. Only after this stage can the ore resources be properly delineated.

3.2.6. Exploration of Rare Earth Element Occurrences Related to Phosphorites and Phosphates

In the short term (1–5 years), the more accurate delineation of the already known occurrences, mineral-chemical and whole-rock geochemical analyses, as well as qualitative and quantitative determination of the ore material can be carried out. By integrating and evaluating the data within a unified database, the directions of further detailed exploration can be designated and deposit models can be developed for the processes responsible for the enrichments, thereby facilitating the identification of additional target areas. In the longer term (5–10 years), based on the preliminary investigation of the known occurrences, the REE mineralization of the designated exploration areas may become sufficiently understood to allow concession-based further mineral exploration.

Among the named occurrences, we first propose the delineation and investigation of the metamorphic rocks occurring in the Sopron Hills, considering that MECSEKÉRC Ltd. possesses a large amount of previous exploration data from the area, and based on the known REE concentrations and extent, this appears to be the most prospective occurrence. This may be followed by the investigation of phosphorites occurring within sedimentary sequences, where both phosphorite content and REE content must be examined (both are CRM). Phosphorite nodules associated with Mn mineralization are recommended to be investigated together with the Mn mineralization.

The implementation of the tasks listed in the “Research Tasks” chapter related to the rhyolite-associated rare earth element anomaly can be completed within a 1–5 year exploration period. As a result, it can be clearly determined whether the rare earth element, Y, P and U enrichment encountered in the rhyolite intersected by borehole Szalonna-10 is characteristic of the rhyolites of the Rudabánya Hills in general, or whether it is restricted to the specific rhyolite body intersected by the borehole. If the anomaly proves to be generally characteristic of the rhyolite, the mineralization will be characterized during this period, and its extent will be defined through surface geophysical methods and verification drilling. Based on the geological model constructed from the exploration data, a reconnaissance-stage resource estimate can be completed. In the case of favourable results, the area may subsequently be offered for concession, while further information related to possible exploitation will require additional years and can only be completed within a 5–10 year timeframe. The research results will be presented at conferences and published in scientific publications.

3.2.7. Exploration of Placer-Type Critical Raw Material Accumulations in Hungary

During the first five years, the sampling and assessment of domestic heavy mineral placer deposits and the evaluation of their titanium, rare earth element, and other exploitable raw material potential (gold, zirconium) content will be carried out. Depending on the sampling and analytical results, those areas and formations that are prospective with regard to the investigated mineral resources can be designated. Earlier institutions of the Geological Survey of SARA previously carried out placer-type heavy mineral investigations and exploration within Hungarian sand pits, based on which it can be concluded that the most prospective grain-size fraction lies between 30–80 µm. Besides ilmenite, rutile, zircon, monazite, and xenotime, scheelite and gold also occur at certain localities. Systematic, layer-by-layer sampling of sand pits, gravel terraces, and the laboratory investigation of the different fractions are required. Where genetically justified, sampling of older conglomerate and sandstone layers is also advisable. Field sampling is a highly time-consuming task because of the large number of outcrops and mining sites that must be visited; therefore, nationwide assessment within a five-year period is only possible through the expansion of professional staff and laboratory capacity, as well as the involvement of graduate students. It should also be emphasized that, in the case of positive results, the separation and beneficiation of heavy mineral-rich fractions requires significantly lower investment and simpler processing technologies compared to other ore types (e.g. sulfide and carbonate ores). Over a ten-year timeframe, a list of prospective formations and deposits, together with resource estimates and suitable beneficiation technologies, may become available, enabling the separation of heavy mineral fine fractions in the target areas. Our results will be published in peer-reviewed journals and annual reports.

3.2.8. Critical Raw Material Potential of the Pre-Mesozoic Basement of Southern Transdanubia (Titanium, Cobalt, Nickel, Precious Metals)

The Southern Transdanubian exploration areas are mainly related to Paleozoic metamorphic rocks (e.g. gneiss, amphibolite, serpentinite) and Permian rhyolitic basement rocks. In the five-year exploration of raw material potential, the prioritized factors are the depth of the basement below surface and the genetic type of CRM indications identified through measurements on surface outcrops and drill cores. These are determined by their fit to different ore deposit models. Further exploration of prospective areas and indications are initiated based on these models.

• Along the Variscan metamorphic belt of the Mecsekalja Shear Zone, cobalt-, nickel- and precious metal-bearing fluids migrated along deep faults and displacement surfaces, producing indications and potentially economic significant mineralization. The identification of the mineralized zones is our current task. Exploration of the shallow basement of the zone began with the sampling of surface outcrops and mineralogical-petrographic and geochemical investigation of the samples. These were complemented by surface geo-electrical and magnetic geophysical methods. At anomaly points, the locations of three shallow drill holes were successfully designated. Instrumental laboratory analyses of the drill cores (petrography, XRF, XRD, SEM-EDS, ICP-MS, LA-ICP-MS, Raman spectroscopy) and the evaluation of the results are expected in 2026. In the case of favourable results, additional drilling campaign, supported by magnetic, geo-electrical and seismic investigations is proposed. This may be implemented no earlier than 2026.

• CRM exploration of the ultramafic rocks of Southern Transdanubia began in 2024 with ICP-MS trace element investigations of drill cores from Gyód and Helesfa originating from different depths. Further investigations of Co- and Ni-sulfide-bearing rocks will continue in 2025 with surface magnetic geophysical surveys to refine the geometry of the bodies. In 2025–2026, determination of precious metal contents by fire assay and ICP-MS will be completed. Continued surface geophysical investigations are indispensable for identifying still undiscovered ultramafic bodies and can realistically be carried out within five years. At selected locations along the Görcsöny Ridge, additional drill holes may become necessary, potentially revealing further Ni, Co (Au, platinum-group element) indications based on geological models.

• In the case of the Permian rhyolites, only a mineralized section of the Szava-1 borehole has preserved as documentation material, which was sampled in 2025. Measurement of the CRM potential of the drill cores and evaluation of the results are expected by the end of 2025. In favourable cases, further exploration of the rhyolite bodies may continue using geophysical methods, and within the next five years, with sufficient resources, the designation and drilling of additional borehole targets may also become feasible.

The outlined exploration program requires intensive geophysical surveys, drilling campaigns, and large-scale laboratory analyses in all cases. In the Southern Transdanubian area, drill holes to depths of 500–

600 m are initially proposed at anomaly points, after which decisions regarding increasing or decreasing drilling depths and drill grid density must be made depending on the results. Field and laboratory investigations and drilling constitute a complex task requiring additional financial and human resources depending on the depth and number of drill holes. Results may be achieved within five years, provided that the required resources are allocated. Initial drill holes and evaluation of the results may be completed within this timeframe in all subareas, but only through the expansion of the professional staff, provision of sufficient financial support. and, Involvement of external laboratories (e.g. ALS, Actlabs) will be necessary for the large number of samples, and the accurate precious metal determination (accurate precious metal determination can only be obtained using fire assay method, which is not in the labroutine at the chemical lab of the Geological Survey).

More precise and detailed understanding and geometrical delineation of possible mineralization will require at least a ten-year timeframe and complex laboratory investigations based on an adequate number of drill holes. Based on our current data, the discovery of new mineral deposits is highly probable; however, expansion of the present research personnel and laboratory capacity is essential to achieve the required results.

3.2.9. Reconnaissance Exploration of Lithium Enrichment in Hungarian Neogene Volcanic Areas

During the first five years, the main tasks are to determine the priority ranking of prospective areas based on literature data and the hydrothermal ore deposit model developed for the Hungarian volcanic regions, and, following surface sampling and laboratory analyses, to identify those areas that warrant further exploration. We will refine the geological parameters responsible for lithium enrichment in the Tokaj Mountains and the Mátra. Based on these parameters, the delineation of prospective areas can be improved. The results will be published, thereby helping to attract the attention of potential investors. Within a 5–10 year timeframe, if significant positive lithium anomalies can be identified and project financing permits, deep drill holes and laboratory analyses of the drill cores could provide a more accurate understanding of the genesis and extent of the mineralization. This would contribute to subsequent ore body delineation and resource estimation, as well as the development of geological and ore deposit models

3.2.10. Critical Raw Material Potential of Hungarian Zinc Ores

1–5 years: Based on the literature and our previous investigations, fundamental fieldwork and material studies can be completed on the designated prospective exploration areas within this timeframe. These investigations will allow us to determine which geological environments, and which specific areas are the most suitable for detailed investigation of the CRM content of zinc ores. It is not necessary to establish a priority list among the named occurrences (Zn-Pb ores along the Periadriatic-Balaton Line and the domestic epithermal copper-porphyry systems), because the primary goal is to provide a comprehensive overview, on the basis of which areas for more detailed investigation can later be selected. However, it should be noted that several zinc-bearing areas are already known that enjoy priority due to their other ore contents and their current level of exploration. These include the "brownfield" exploration areas of Recsk, Rudabánya, and Börzsöny, and therefore investigation of the CRM content of their zinc ores should be carried out together. Based on the comprehensive overview, not only can areas for detailed exploration be designated, but a set of criteria may also be developed that could facilitate the identification of entirely new occurrences in addition to those already known. Within five years, the designated exploration areas may reach a level of geological knowledge sufficient for planning the timing of future concession tenders for mineral exploration. In the "brownfield" areas, and in conjunction with the investigation of their other CRM-bearing ores, a level of understanding may also be achieved within five years that allows the planning of investor utilization; thus, the given area may become suitable for concession-based further exploration. Furthermore, the research is expected to produce internationally significant scientific results, and therefore scientific publications are also anticipated, which may attract the attention of potential investors to Hungarian exploration opportunities. Within a 5–10-year timeframe, further investigations of the selected exploration areas may be planned through field surveys, geophysical profiling, drilling programs to verify prospectivity, and geochemical and mineral-chemical analyses of the resulting samples.

3.2.11. Lithium Potential Associated with Geothermal and Hydrocarbon-Related Brines

In the case of Li and other dissolved critical mineral raw materials, depending on the involvement of concession holders to cooperate, nationwide screening and interpretation of the data may be completed within approximately three years. Based on evaluation of the results, prospective areas suitable for further detailed exploration may be selected depending on the dissolved mineral raw materials. In addition to qualitative assessment, preliminary semi-quantitative potential estimates may also be carried out. In addition to determining the quantity of recoverable lithium, information regarding applicable extraction technologies is also available. Based on the results, the feasibility of establishing a new industrial sector may be assessed, and the development of the legal and financial framework necessary for exploiting the identified potential may begin, with the participation of the National Mining Authority of SARA. Potential state revenues from extraction may become predictable, and in certain cases there may also be an opportunity to develop a dedicated industrial strategy.

3.2.12. Hungary's Helium Potential

Within approximately three years, nationwide screening may be completed. Based on the analytical results, those occurrences may be selected whose exploitation can already be carried out under current conditions and for which commercially available technologies exist enabling economically viable helium extraction. Areas may also be designated where technology development is recommended. It is also necessary to develop the legal framework supporting extraction activities. The regulatory framework may also incorporate mandatory helium analysis and reporting obligations for hydrocarbon and gas production operators.

4. Description of Exploration Tasks

4.1. Tasks Related to the Exploration of Primary Mineral Deposits

4.1.1. Exploration of the Copper and Other Critical Raw Material Potential of the Recsk Ore Complex

- Collection, evaluation, digitization and database organization of archive data, materials, maps and samples. Compilation of information regarding which drill core samples and pulp samples are stored at Nitrokémia Zrt. and elsewhere. Collection and organization of archive documentation related to the samples and preparation of a digital database. Statistical evaluation and filtering of the data according to JORC (or other relevant international reporting standards), as well as examination of their reliability. This task also includes the digitization of paper-based reports, laboratory protocols and materials, as well as the georeferencing and digitization of maps. An important component of the task is the documentation of archive measurements and quality assurance protocols, and the attachment of available laboratory certificates to the measurements.

- Reinterpretation of old geophysical measurements using modern methods and integration of the reinterpreted data. This includes existing gravity data (Bouguer anomaly, filtered gravity maps, gravity edge maps, relative density (3D grid)), ground and airborne geomagnetic surveys, as well as airborne radiometric measurements (uranium, thorium and potassium base maps). Modern reprocessing of the available geophysical (gravity, magnetic, airborne geophysical) data using advanced software and information systems.
- Construction of geological and ore geological models based on archive data.
- Validation, correction, comparison and statistical evaluation of archive chemical analytical data. Re-analysis of samples for which statistically meaningful quantities of archive analytical results are available, comparison with old results, and statistical evaluation. This work phase also includes the determination of trace elements that were not analyzed in the archive samples. The development and application of analytical quality assurance protocols are also important (appropriate numbers of duplicate, blank and control analyses carried out in other laboratories, as well as attachment of protocols and laboratory certificates to the database).
- Determination of the occurrence of critical and technologically important accessory and trace elements within the mineral phases of the different ore types is also indispensable, since these data are essential for estimating the expected value of ore concentrates and assessing the differing economic utilization potential of the ore types.
- Three-dimensional modelling of ore geological and mining geological characteristics must be extended beyond elemental distributions to include lithological and alteration characteristics, through mineralogical and petrographic investigations of samples subjected to bulk geochemical and mineral phase-specific major and trace element analyses.
- In the internationally and investment-relevant renewed Recsk database, in addition to three-dimensional modelling based on mineralogical, petrographic, geochemical and ore quality parameters, it is necessary to refine and integrate into the deposit documentation the genetic model describing and interpreting the ore-forming processes of the Recsk complex. This is an internationally required and expected level of knowledge, for which the necessary complementary investigations have already begun within the research groups of ELTE and the University of Miskolc, and can be completed with relatively limited additional financial and intellectual investment. This modern conceptual model will also support both greenfield and brownfield further exploration of the ore complex.
- Execution of new surface geophysical surveys. In order to delineate the ore bodies, newly implemented surface geophysical measurements are also required, namely geo-electrical methods (ERT, IP, TEM, MT), test 2D reflection seismic surveys, and seismic tomography.
- In order to accurately identify the spatial position of the samples included in the investigation, the conditions of borehole deviation measurements for the relevant drill holes must also be clarified. Precise geometrical positioning requires the recovery and re-evaluation of old borehole deviation measurement protocols and their associated data. The condition of the RM series drill holes must be assessed, and new deviation measurements must be performed in accessible holes.
- For the purpose of data validation, in addition to the geophysical surveys, it would also be necessary to drill several surface boreholes to depths of up to 1500 m. The samples obtained

from these drill holes would not originate from the old boreholes, and based on these new and current data it would be possible to carry out comprehensive modern material investigations, prepare detailed geological base documentation, and accurately identify the precise spatial position of the boreholes.

The summary and sequence of the exploration tasks related to the Recsk ore complex are presented in Figure 14.

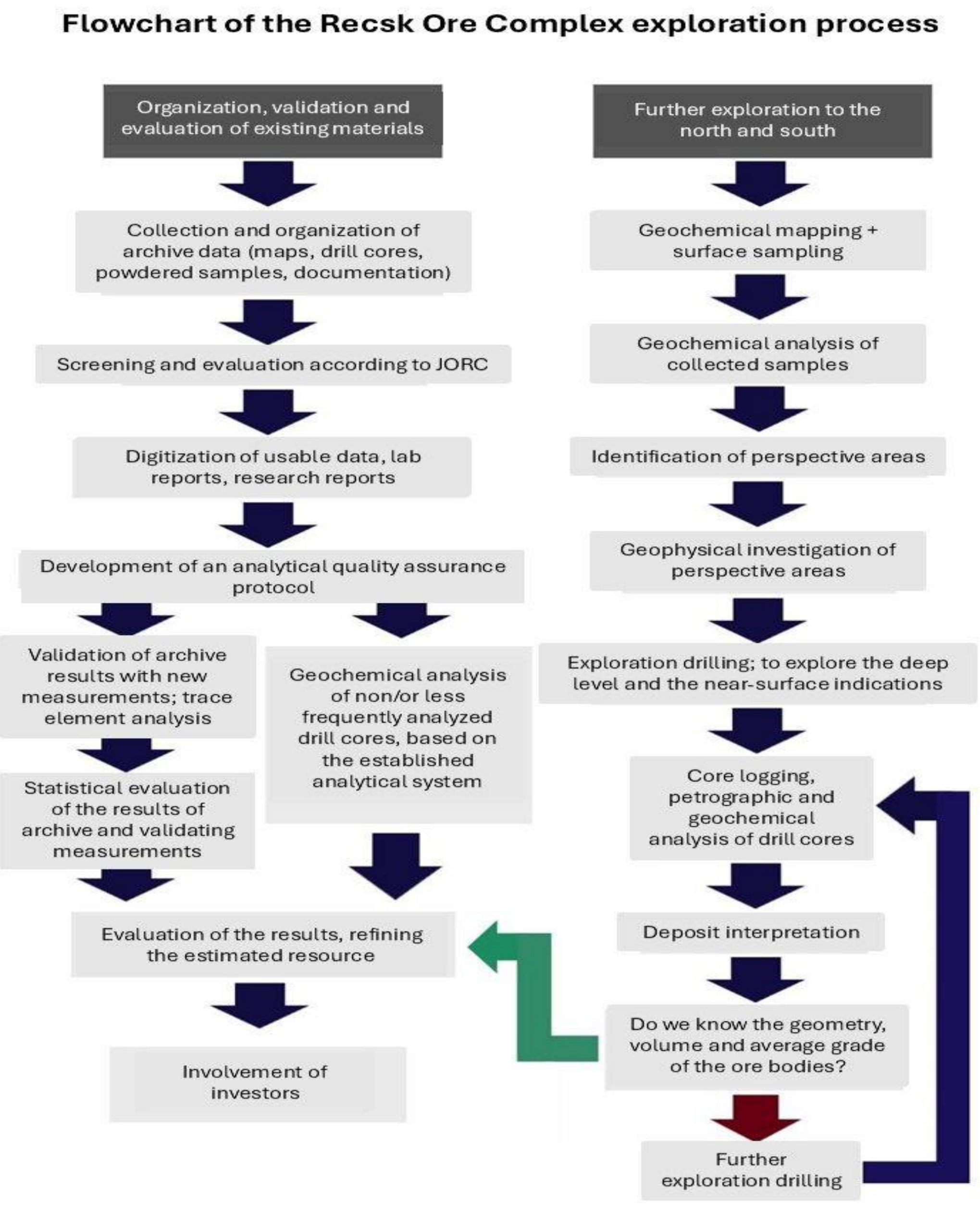

Figure 14. Simplified flowchart of exploration of the Recsk ore complex.

4.1.2. Critical Element Potential of Hungarian Bauxites and Red Mud

- Collection, evaluation and database storage of archive geological and geophysical data. Areas identified during previous exploration as possessing prospective resources are of outstanding importance for assessing further bauxite potential. Given the several decades of bauxite exploration and mining, the quantity of archive data is enormous.
- Construction of geological and bauxite geological models based on archive geological and geophysical data.
- Identification of new deposits based on the geological model.
- Collection and cataloguing of archive drill cores and museum/storage materials (e.g. Bakony Museum in Zirc, SARA core repositories, etc.) originating from known surface and above-karst-water-level bauxite bodies.
- Sampling of accessible surface bauxite bodies and archive drill core material.
- Analysis of samples using ICP-MS to determine the characteristic quantities of trace elements and rare earth elements and the mode of their occurrence (whether in discrete mineral phases or adsorbed onto submicroscopic Fe-Al phases of the bauxite).
- Identification and delineation of bauxite bodies showing significant trace element concentrations.
- Proposal regarding the range of exploitable trace elements.
- Evaluation of the trace element potential of the bauxite bodies investigated. (Based on measurements from known bodies, the trace element potential of each bauxite body will be evaluated separately, selecting deposits/deposit sections enriched in exploitable trace elements (e.g. Ce generally accumulates in the upper sections of deposits, whereas Nd accumulates near the lower footwall boundary).

The simplified exploration workflow for bauxite is shown in Figure 15.

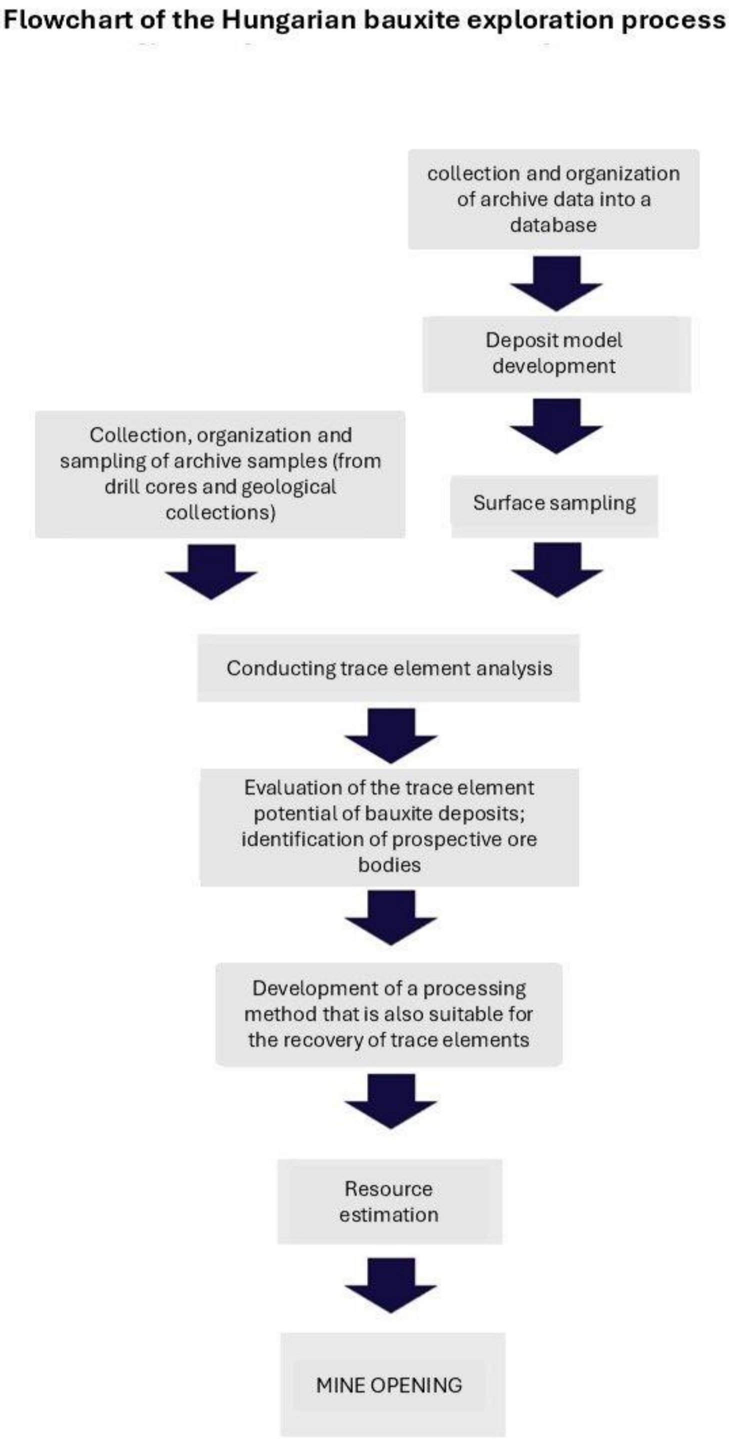

Figure 15. Simplified flowchart of Hungarian bauxite exploration.

4.1.3. Critical Element Content of Hungarian Manganese Ores

Úrkút: Mn Ore and Manganese Sludge Reservoir Exploration

- Validation of electrolytic ore processing experiments for the different carbonate ore types (brown, green, grey, black).
- Compilation of archive and recent geological and geophysical exploration results.
- Exploration of Manganese Ore Around Eger
- Compilation of archive exploration results and geological-geophysical data, and collection of still available drill core and other samples from previous exploration campaigns.
- Field identification of manganese-bearing formations using portable XRF measurements and systematic sampling.
- Detailed mineralogical and geochemical investigations of Mn-rich samples (XRD, SEM, XRF, ICP-MS), and determination of ore quality through analyses carried out in accredited laboratories.
- Reconnaissance drilling on the most prospective areas delineated by mapping, mineralogical and geochemical investigations.
- Execution of electrolytic ore processing experiments under laboratory conditions, and subsequently under industrial conditions using ore bodies identified as the most prospective during exploration.
- Resource estimation and preliminary economic evaluation.

The simplified exploration workflow for manganese ore is shown in Figure 16.

Flowchart of the Hungarian manganese exploration process

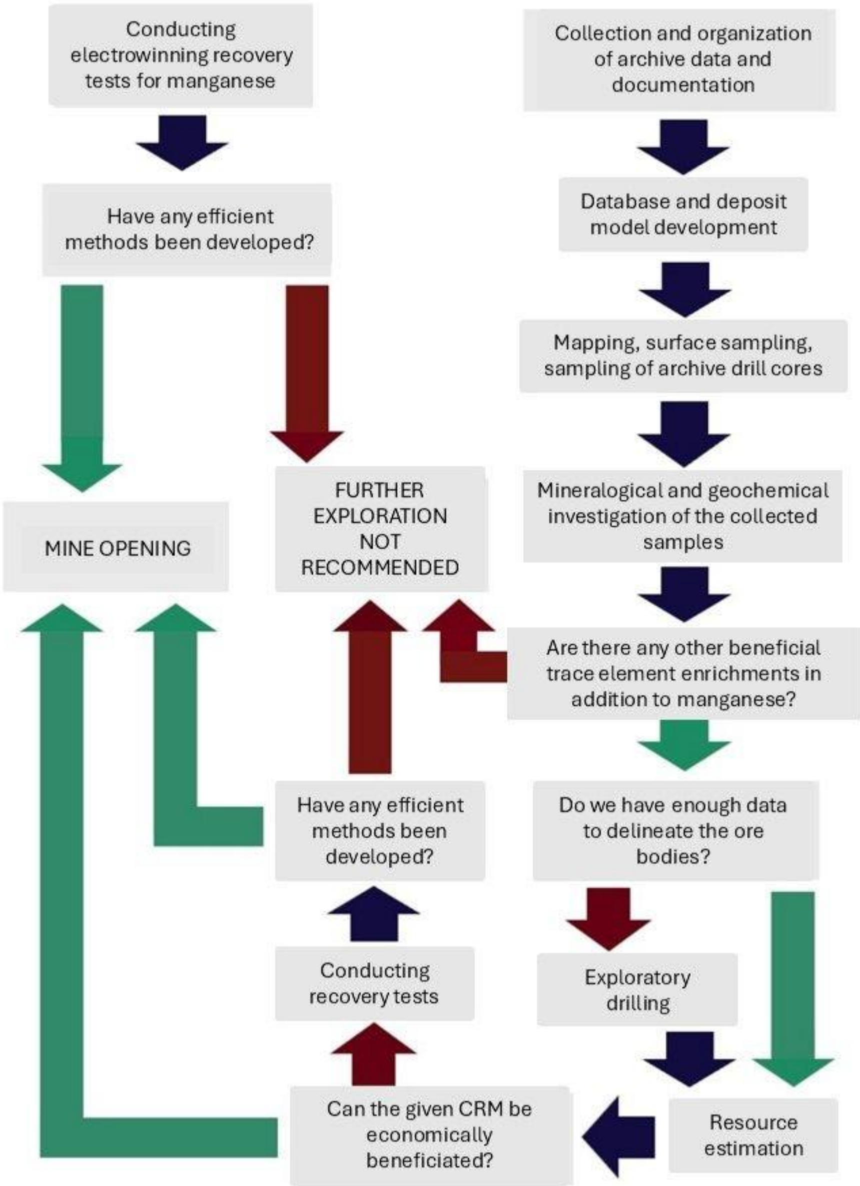

Figure 16. Simplified flowchart of manganese ore exploration.

4.1.4. Critical Raw Material Potential of the Rudabánya Hills

Exploration tasks related to the open pit and its surroundings:

- Compilation of currently available digital data and model construction.
- Digitization, organization and integration into the model of archive geological-geophysical, drilling and analytical materials and maps. Based on newly acquired data, model development must be continuous.
- Development of a detailed exploration concept based on the constructed model.
- Execution of trenching, surface and regionally extensive sampling campaigns (following Triassic stratigraphic horizons), and geochemical mapping using field portable XRF.
- Sampling of drill hole intervals characterized by base metal mineralization.
- Identification, delineation and drill sampling of waste dumps.
- Designation and execution of new exploration drill holes for deep investigation of raw materials, as well as for mapping the structural and stratigraphic controls of critical element anomalies identified in the wider surroundings of the open pit; documentation of drill cores.
- Analysis of samples originating from trenching, mapping, archive and new drill holes in accredited laboratories.
- Identification of mineralized fault zones.
- Delineation and evaluation of all raw material bodies considered relevant.
- In the case of favourable results, development of processing methods.

The simplified workflow of exploration in the Rudabánya area is shown in Figure 17

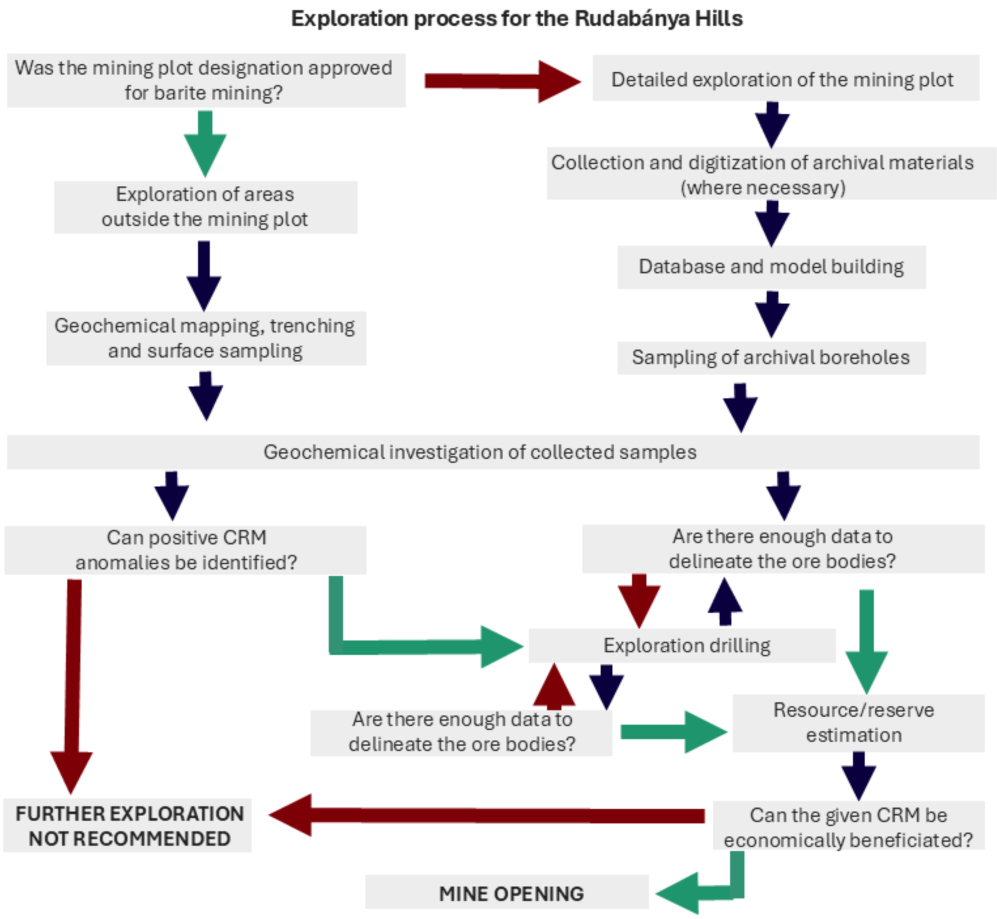

Figure 17. Simplified flowchart of exploration of the Rudabánya hills.

4.1.5. Raw Material Potential of Bismuth-Rich Mineralization Related to Intrusive Activity

In order to place the surface indications and the deep-level mineralization within the hydrothermal system, and to determine the prospectivity of the area, completion of the following tasks could represent progress:

- Collection of available archive data and samples, and construction of a database.
- Re-evaluation of archive materials from geophysical investigations and, if necessary, execution of new/additional measurements - if terrain conditions permit (e.g. seismic reflection surveys, tomography, transient electromagnetic measurements).
- Construction of an initial geological and ore geological model based on validated archive data.
- Designation of further prospective areas through surface mapping of hydrothermal alteration zonation and volcanic-hydrothermal facies, determination of their mineralogical-petrographic and geochemical characteristics, modelling of fluid-rock interaction, and definition of a system-based ore geological model.
- Petrographic and geochemical investigation of additional surface samples and archive samples from adits and drilled boreholes in accredited laboratories (XRD, ICP-OES, ICP-MS, LA-ICP-MS, SEM-EDS, fluid inclusion microthermometry, stable isotope investigations).
- Vectoring for mineral exploration purposes based on mineral chemistry, whole-rock geochemistry, fluid inclusion, indicator mineral and geophysical investigations.
- Integration of new geological, geophysical and geochemical information into the model.
- Drilling of exploration boreholes located on geophysical anomalies.

Depending on the completion of the above-mentioned tasks and their results, full-scale exploration of the area is not possible without further drilling exploration based on geophysical investigations. The exploration process is summarized in Figure 18.

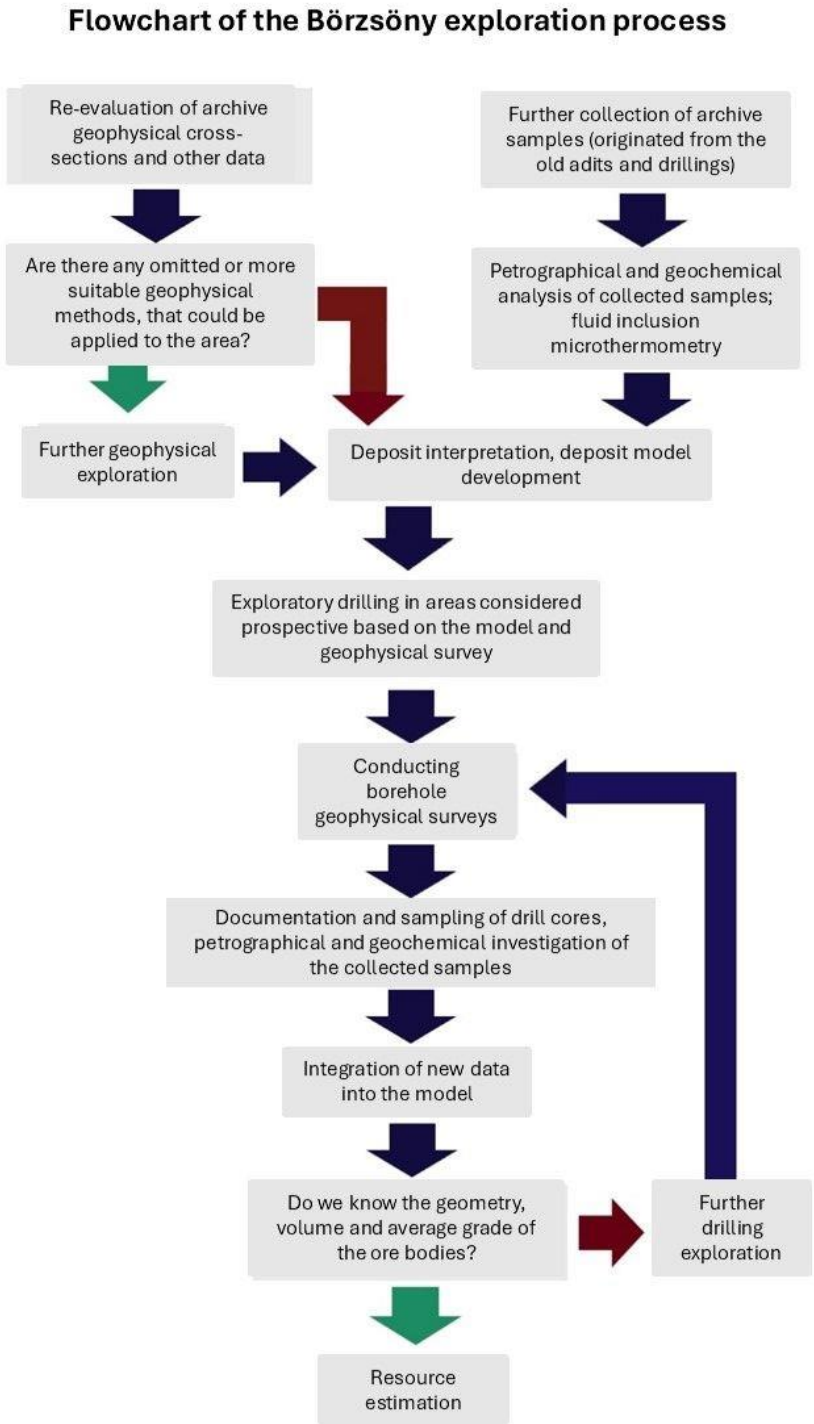

Figure 18. Simplified flowchart of exploration of bismuth-rich mineralization related to intrusive activity.

4.1.6. Exploration of Rare Earth Element Occurrences Associated with Phosphorites and Phosphates

- Creation of a unified digital database for Hungarian REE occurrences based on archive reports, geological-geophysical and geochemical data available at MECSEKÉRC Zrt. and SARA.
- Representative sampling of the most significant phosphate-mineral-bearing metamorphic rocks in western Hungary, the phosphoritic facies of Transdanubia and the Úrkút-Eplény manganese ore, as well as the material of borehole Szalonna-10, and modern REE analysis in accredited laboratories in order to verify earlier data. In parallel with this, verification measurements of boreholes and archive samples of other indications (e.g. northern Bükk), if they exist, as well as representative samples collectible in the field.
- Based on the results of the verification measurements, completion of field mapping and systematic sampling supported by portable XRF measurements in the areas considered prospective.
- Detailed laboratory investigation of the collected sample material (XRD, ICP-MS, ICP-OES, EPMA, LA-ICP-MS) in order to determine geochemical, lithological and mineralogical characteristics.
- Execution of surface geophysical investigations (VES) next to and around borehole Szalonna-10 and surface outcrops in order to understand the spatial distribution of the rhyolite.
- Integration of the results of geochemical, mineralogical and petrographic investigations into the digital database of Hungarian REE occurrences, and based on this, determination of the priority ranking of areas suitable for further exploration.
- Designation of the locations of reconnaissance exploration boreholes and execution of the drilling on the area(s) considered suitable for detailed exploration, based on detailed mapping and reconnaissance geophysical profiling.
- Geochemical-mineralogical-petrographic investigation of the core material from the reconnaissance boreholes. In the case of favorable results, if necessary, development of the drilling grid and drilling database to such an extent that a preliminary resource estimate can be carried out.
- Integration of the results of geochemical, mineralogical and petrographic investigations into the digital database of Hungarian REE occurrences.

The schematic exploration workflow of phosphorite and associated rare earth element occurrences is shown in Figure 19.

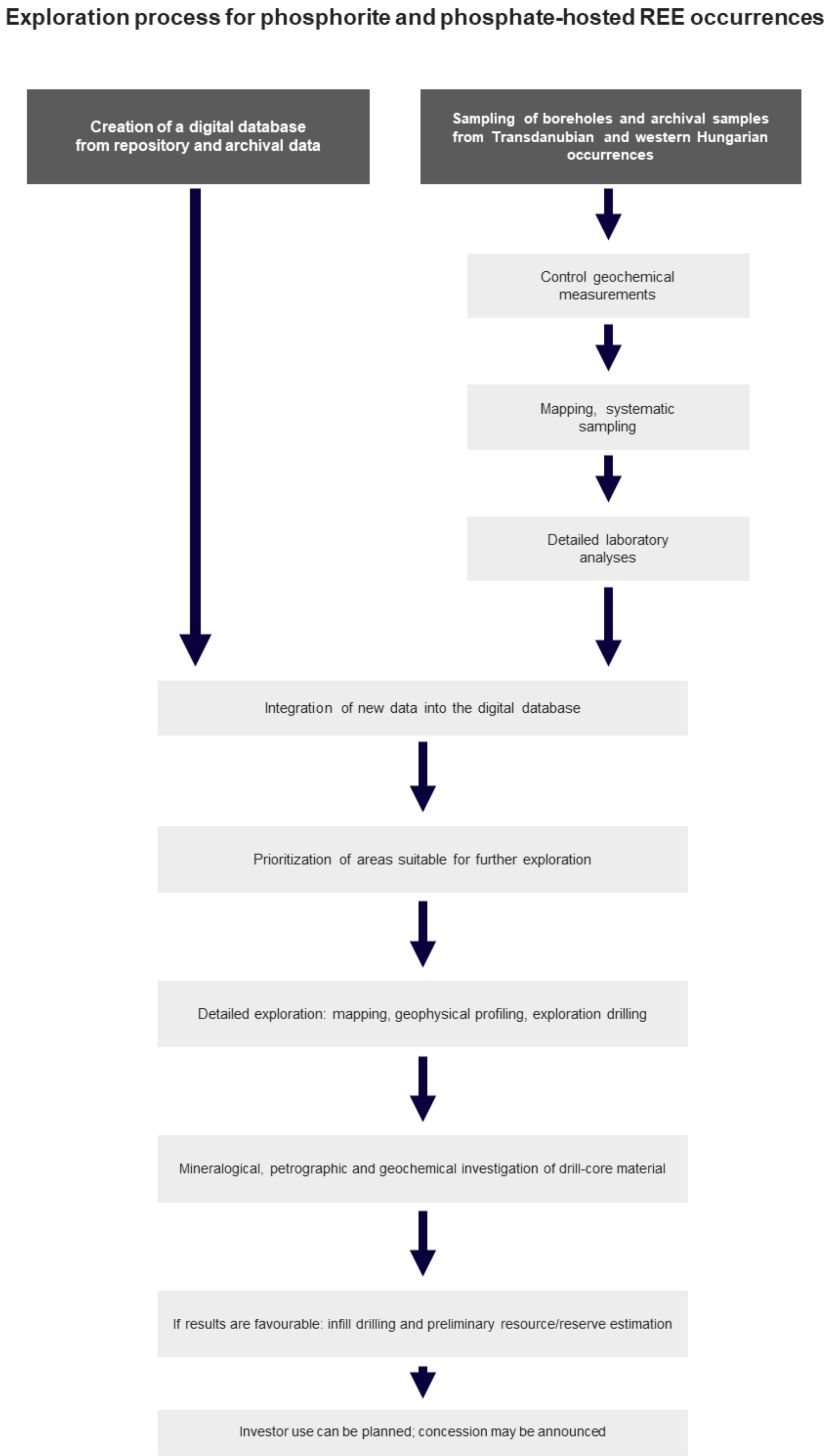

Figure 19. Simplified flowchart of exploration of phosphorites, phosphates and associated rare earth element occurrences.

4.1.7. Exploration of Placer-Type Critical Raw Materials in Hungary

The exploration tasks can be divided into several parts:

- Designation of prospective areas based on source areas, favorable depositional geological facies, and literature data.
- Sampling of recent-subrecent gravel terraces and point bars along the upper sections of Hungary's major watercourses (Danube, Drava, Mura), with separation of the fine fraction (<80 µm), LiBO2 fusion digestion, followed by ICP-OES, ICP-MS and XRD analyses.
- Layer-by-layer sampling of sand pits (Figure 8), supplemented by field XRF measurements, with separation of the fine fraction (<80 µm), LiBO2 fusion digestion, followed by ICP-OES, ICP-MS and XRD analyses. Based on our previous measurements, for example, such a prospective area may be the area of Pannonian sand occurrences derived from the erosion of the metamorphic rocks of the Mecsekalja Zone, the Permian rhyolite and the Mórágy Granite, where occurrences of ilmenite, rutile, anatase, titanite, monazite, xenotime and, in some cases, scheelite and native gold, as well as their fraction-based beneficiability, are expected.
- Paleo-placer exploration: investigation of older fluvial-coastal rocks considered prospective from a deposit geological perspective using optical rock microscopy, SEM-EDS, XRD, ICP-OES and ICP-MS measurements.

The exploration workflow of placer-type critical raw material accumulations is summarized in Figure 20.

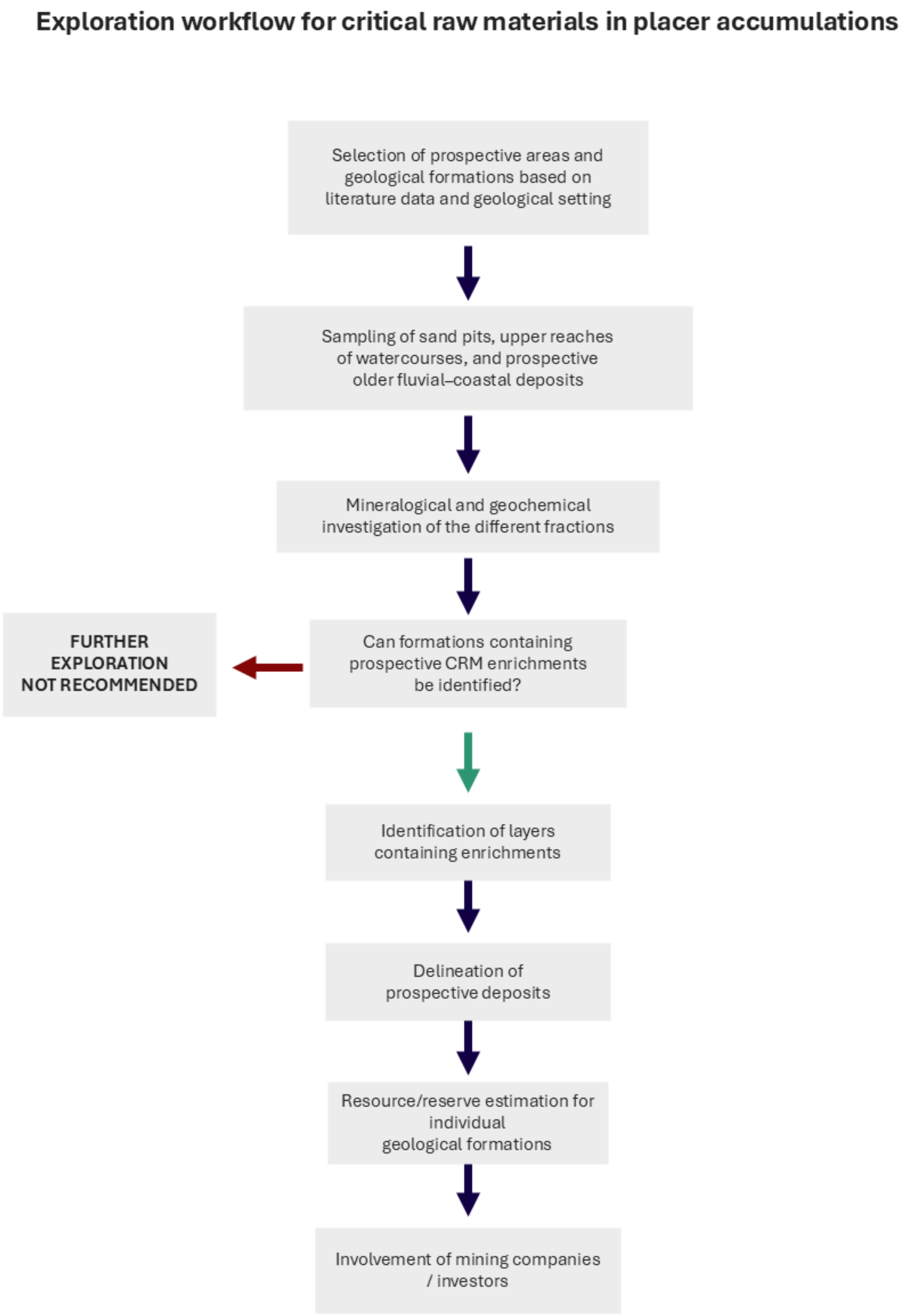

Figure 20. Simplified flowchart of exploration of placer-type critical raw material accumulations.

4.1.8. Critical Raw Material Potential of the Pre-Mesozoic Basement of Southern Transdanubia (Titanium, Cobalt, Nickel, Precious Metals)

Based on the favorable results obtained so far, we will continue further exploration of the area; however, the extent of rock outcrops traceable at the surface is extremely limited, and a significant part of the available archive drill core material has been destroyed. Therefore, further ore exploration can only continue through the establishment of drill holes, further geophysical investigations and complex laboratory investigations:

- Collection of geological data, boreholes and geophysical measurements concerning the area.
- Based on our analytical results from existing archive drill cores in the Ófalu-Zsibrik area, geochemical investigations of surface rocks and mapping of anomalies, as well as our geophysical measurements, we have designated several shallow drilling locations. In the case of favorable results, further drilling exploration of the area is justified.
- Across the entire exploration area, higher-resolution surface magnetic resurveying of previously mapped magnetic anomalies, parametrization of core samples and seismic tomography are required. From this perspective, the area of the Western Mecsek magnetic anomalies (Helesfa, Gyód) and the area southwest of Szekszárd are priority areas. By remapping and refining the magnetic anomalies and drilling ~500-700 m boreholes located on the anomalies, more precise delineation of the ultrabasic bodies known so far and discovery of new potential mineralizations would become possible.
- After establishing the boreholes, core scanning, borehole logging and complex laboratory investigation of drill cores are required (petrography, XRD, ICP-OES, ICP-MS, AAS, SEM-EDS, LA-ICP-MS trace element and stable isotope investigations, fluid inclusion microthermometry) in order to spatially and temporally distinguish rock alterations associated with mineralization, barren and mineralized vein systems, determine parageneses, and construct genetic and 3D geological-deposit models.
- Among the mineralized drill cores intersecting Permian rhyolite-microgranite, so far only part of the core material of borehole Szava-1 could be sampled; the other drill core material was probably destroyed. If our ongoing investigations provide favorable results, the investigation of the mineralization of Permian subvolcanic microgranite-rhyolite bodies and their surroundings can be incorporated into the exploration of critical raw materials, which can be supported by surface geophysical investigations and airborne gamma mapping; in the case of high-concentration metal enrichments, drilling exploration is recommended.
- Identification and spatial extension of the traces of propylitic overprinting and polymetallic mineralization confirmed in borehole Baksa-2 in additional boreholes intersecting the metamorphic basement of the Görcsöny Ridge.

From our results to date and the available data, it is clear that systematic, deposit-oriented exploration of the near-surface metamorphic basement of Southern Transdanubia is highly timely and is consistent with the current raw material policy of the EU: some occurrences are completely unknown, while for the potential mineral raw materials of other formations we have only sporadic data. Figure 21 outlines the exploration workflow for those areas where only very limited data are available, but which, based on geological-deposit models, are prospective for the occurrence of critical raw materials (CRM).

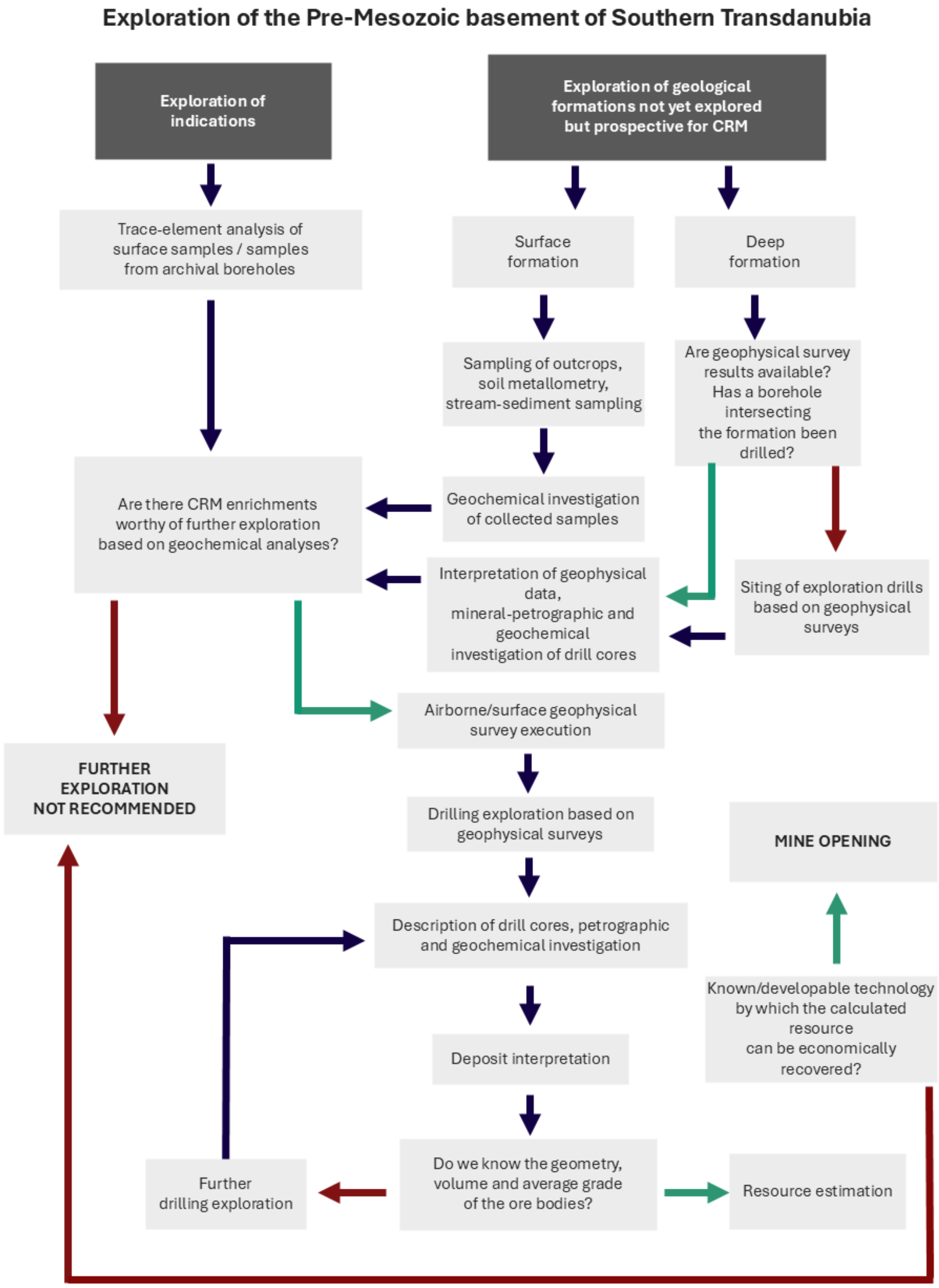

Figure 21. Exploration flowchart of the pre-Mesozoic basement of Southern Transdanubia in the case of unknown but deposit-geologically prospective areas and occurrences known at indication level.

4.1.9. Reconnaissance Exploration of Lithium Enrichments in Hungarian Neogene Volcanic Areas

- Search for and identification of prospective areas in the Tokaj Mountains and the Mátra, and collection of geological-geophysical data for the prospective areas.
- Field sampling from the surface, with particular regard to hydrothermally altered lacustrine volcanosedimentary layers and rocks affected by intense potassic metasomatism. Previous ore deposit studies and the results of airborne gamma mapping greatly assist in mapping the latter.
- Collection and detailed laboratory investigation of archive drill core material (XRD, ICP-OES, ICP-MS), with particular regard to areas showing positive surface lithium anomalies.
- Planning and execution of relatively shallow boreholes (maximum 200-300 m deep) in areas showing positive surface lithium anomalies. Documentation and detailed chemical analysis of the core material of the new boreholes.
- Based on our previous investigations, in areas prospective for lithium, we often observe significant positive anomalies also in As, Sb, Rb, Cs and Au. Among these, arsenic and antimony are critical elements. During sampling and laboratory investigations, it is worthwhile to pay attention to these elements as well.
- If project financing permits, in the longer term, planning and execution of shallow and deep boreholes in order to better understand surface indications identified by surface metallometric mapping and sampling, or depth indications identified through the investigation of archive boreholes.
- Surface and borehole geophysical measurements for delineating the anomalies.
- Laboratory investigations (XRD, ICP-OES, ICP-MS).

The workflow of lithium exploration in the intermediate-acid volcanic areas of Hungary (Tokaj Mountains, Mátra) is summarized in Figure 22.

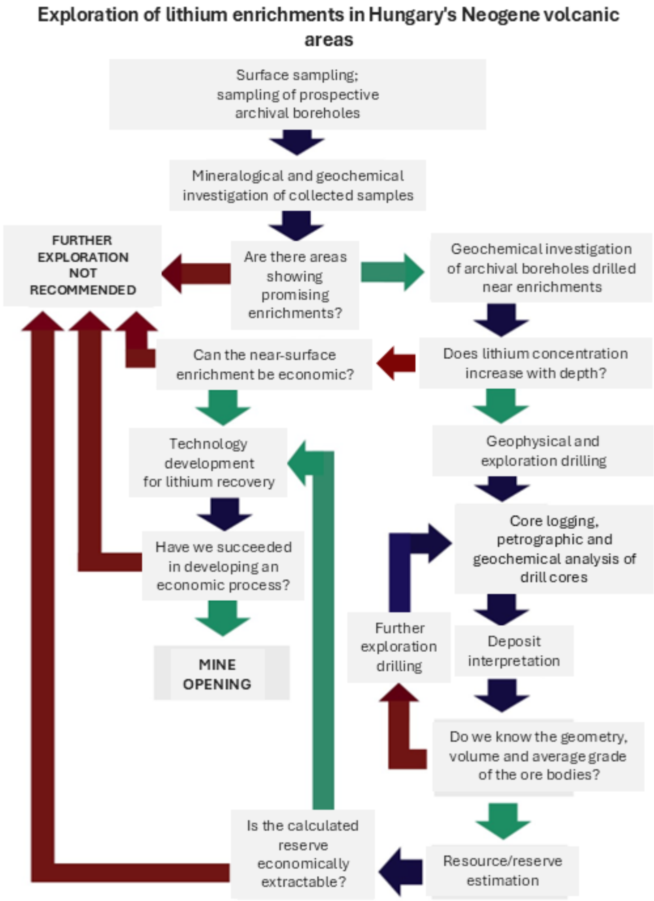

Figure 22. Simplified flowchart of exploration of potential lithium deposits.

4.1.10. Critical Raw Material Potential of Hungarian Zinc Ores

- Identification of prospective areas occurring in the vicinity of the Periadriatic-Balaton Line and related to domestic epithermal copper-porphyry systems, based on geological analogies and ore geological system models defined on the basis of preliminary own research results.
- Establishment of a criteria list for the different deposit types, as a result of which the search for possible new deposits beyond the already known occurrences also becomes possible.
- Collection of existing geological and geophysical data from the identified prospective areas, organization into a database and construction of preliminary geological-ore geological models.
- Field sampling and, where necessary, mapping in less studied but significantly prospective areas (e.g. the mineralized trend between Rudabánya and Pelsőczardó (Ardovo)). In the latter area, mapping and sampling using portable field XRF measurements may lead to results, because the fine-grained occurrence of low-iron sphalerite and non-sulfide zinc ore in the host carbonate rocks cannot be identified by simple field macroscopic observations.
- Search for archive collection materials (boreholes, museums).
- Modern material investigation of the collected samples, depending on the nature of the material: mineral chemistry, whole-rock geochemistry in accredited laboratories, fluid inclusion studies, and, if necessary, XRD, stable isotope geochemistry, etc.
- Reconstruction of formation conditions and linking these to the observed CRM content. Based on this, the most accurate possible delineation of the potential spatial extent and designation of covered but presumed potential exploration areas.
- Execution of further exploration, including drilling, in the areas thus designated.

The simplified exploration workflow of Hungarian zinc ores is shown in Figure 23.

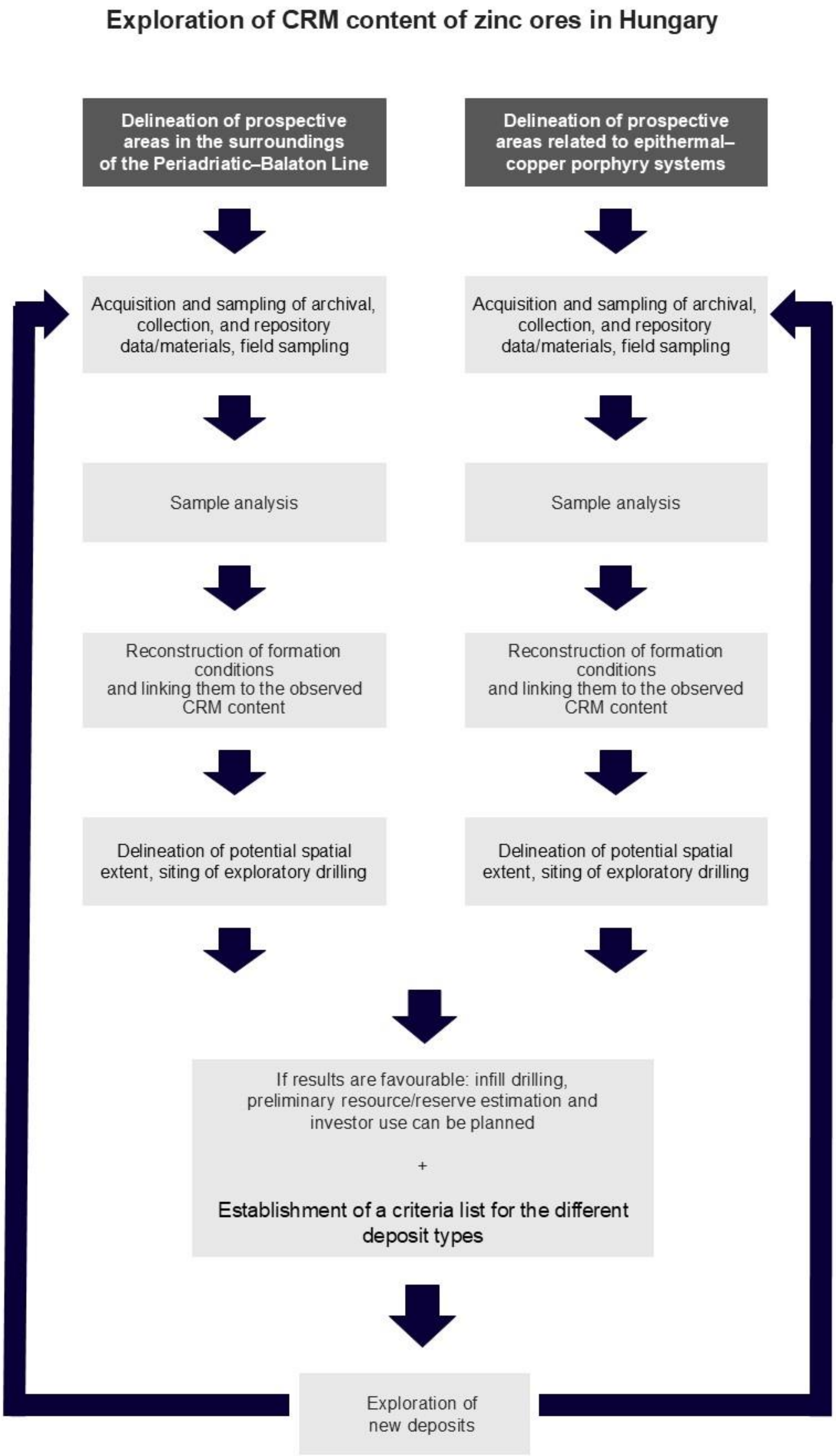

Figure 23. Simplified flowchart of CRM-focused exploration of Hungarian zinc ores.

4.1.11. Lithium Potential Associated with Geothermal and Hydrocarbon-Related Fluids

- It is advisable to further refine water-rock interaction models by considering different reaction and pressure conditions, while varying mineralogical composition and water composition.
- As a next step, among other tasks, we will investigate which operating hydrocarbon industrial mining sites or geothermal reservoirs should be sampled for previously identified high-lithium fluids or subsurface fluids expected to have potentially higher lithium contents.
- It is necessary to investigate along which structural elements the Li-richer fluids occur.
- It can be assumed that the source of the high Li concentration is alteration/weathering of the high-Li biotite of the Battonya Granite. From the perspective of Li concentration, it is worthwhile to systematically investigate the Li content of micas in other domestic surface and buried granite (+/- orthogneiss) areas as well. Based on international trends, in the long term the release of Li from biotite by in situ leaching technology may arise as a possibility.
- The systematic, parallel investigation of the produced water of the Szeged thermal system and the geochemical composition of the reservoir rock has shown that significant quantities of critical elements accumulate in the reservoir sediment in mobilizable form. The future applicability of rapidly developing in situ leaching technology makes it necessary to know not only the composition of the water, but also the depth-correct chemical and mineralogical composition of the drilling cuttings.

The simplified flowchart of extraction of water-dissolved lithium and other elements is shown in Figure 24.

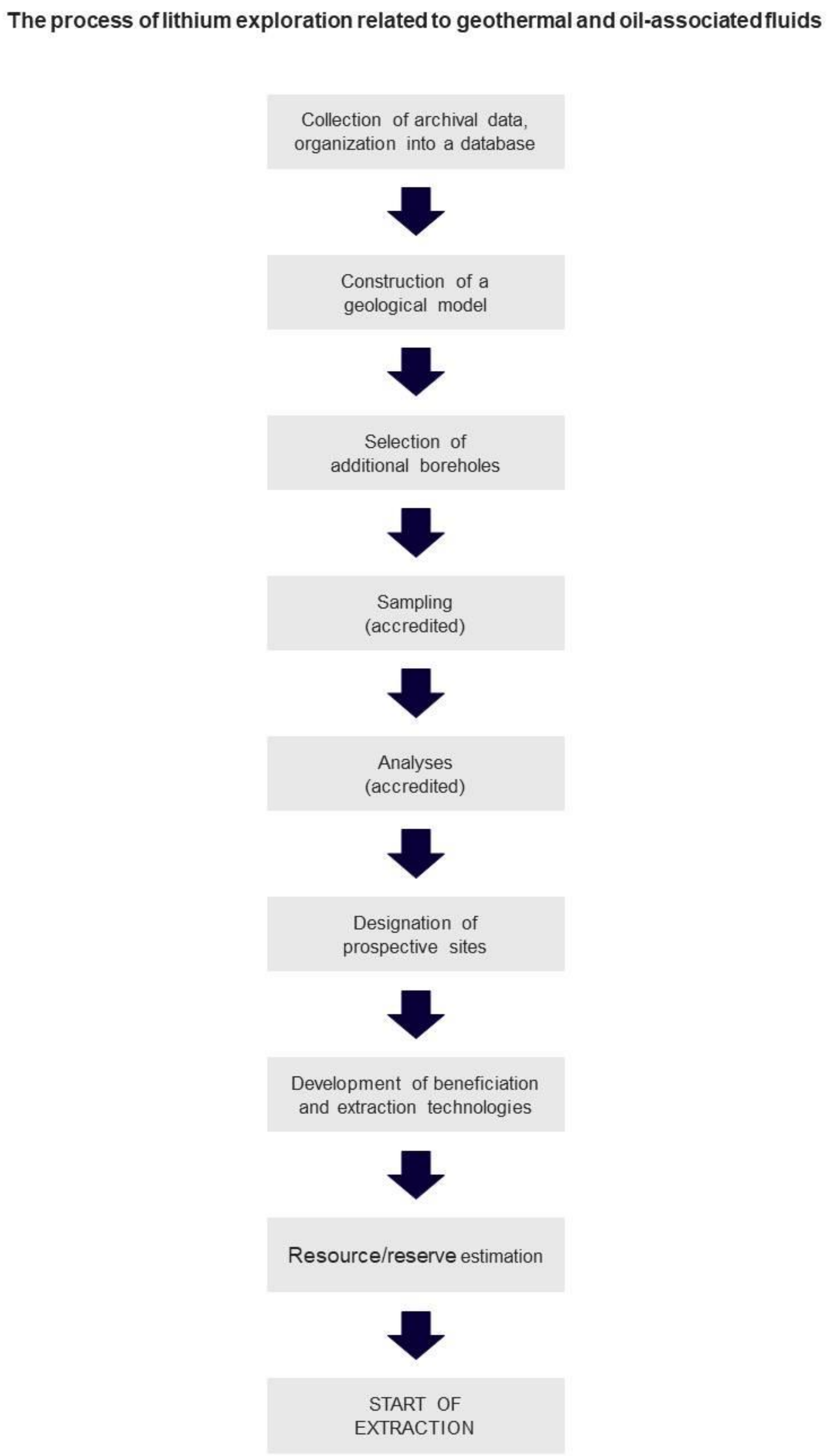

Figure 24. Simplified flowchart of extraction of water-dissolved lithium and other elements.

4.1.12. Hungary's Helium Potential

- The primary task is the critical review of currently available Hungarian archive data (e.g. Mihályi-Répcelak, Hajdúszoboszló, Szeghalom, Bükfürdő, Mátraderecske) and review of foreign scientific literature (e.g. Poland, Australia, USA, Canada, Africa, Germany), and their collection into a database.
- In parallel with all this, it is necessary to begin planning and implementation of a nationwide sampling campaign. In addition to operating wells producing primarily hydrocarbons and carbon dioxide, comprehensive investigation of currently non-producing gas wells with high inert gas content is also required.
- There may be significant potential in exploiting the helium content of geothermal fluids, and therefore their systematic measurement and assessment of their potential must be carried out.
- In addition, exploration of completely novel occurrence environments must also begin.

For the gas sampling tasks of the nationwide helium exploration project, procurement of gas sampling equipment and training in sampling with the assistance of an external expert are required. The simplified flowchart of helium exploration is shown in Figure 25.

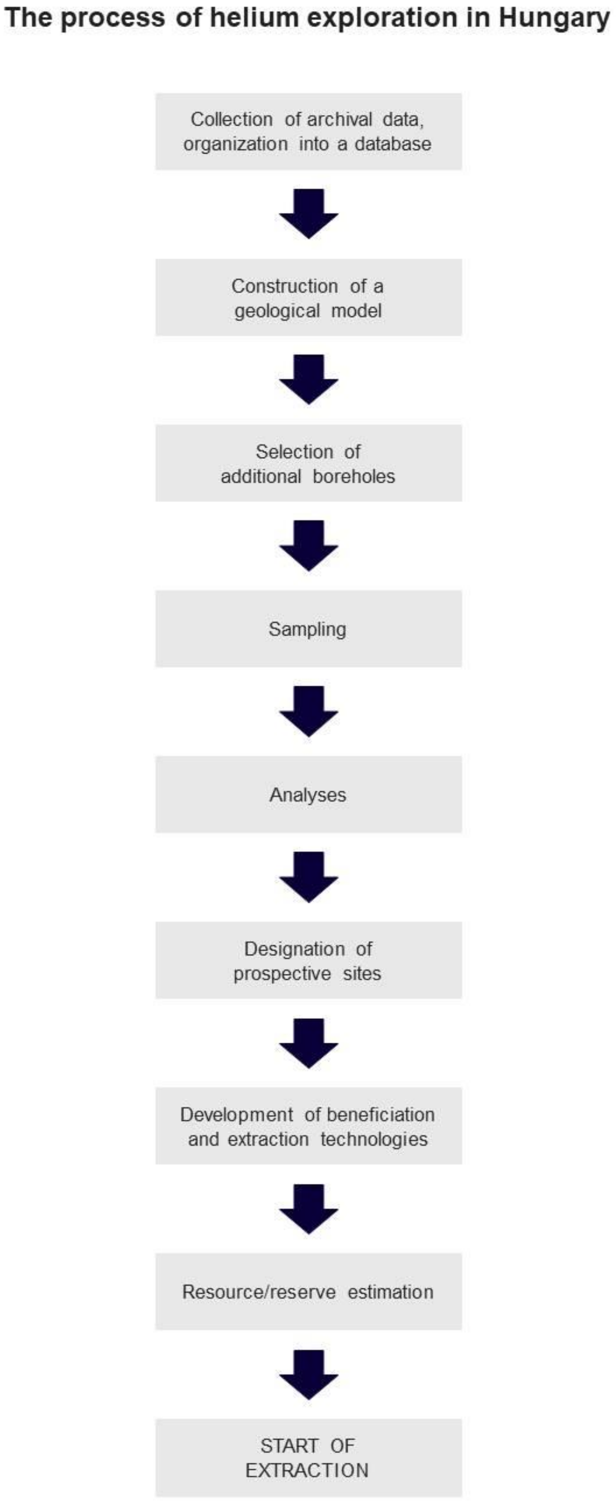

Figure 25. Simplified flowchart of helium exploration.

4.2. Research Processes Related to the Utilization of Secondary Raw Materials

4.2.1. Red Mud (Critical Element Potential of Hungarian Bauxites and Red Mud)

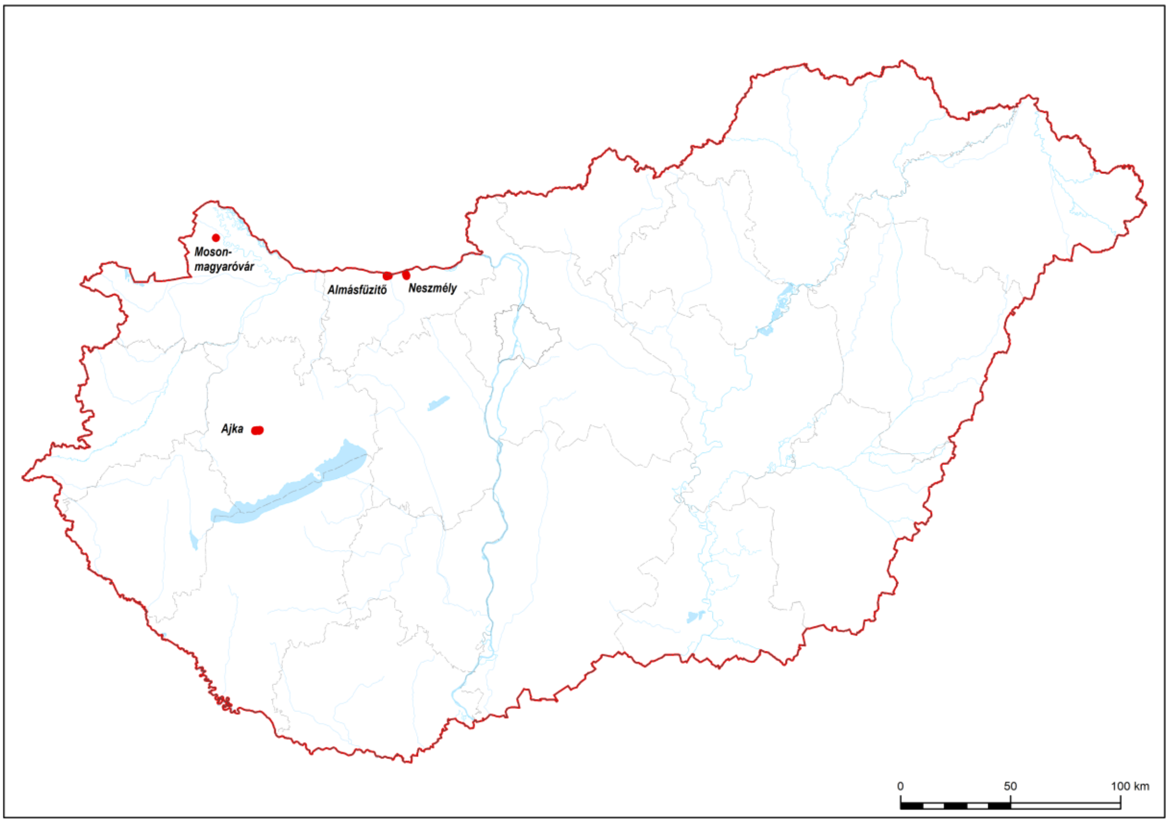

Figure 26. Red mud tailings deposits in Hungary.

In Hungary, red mud, the highly alkaline by-product of bauxite mining and alumina processing, is deposited in four large storage facilities (Ajka, Neszmély, Almásfüzítő, Mosonmagyaróvár; Figure 26), which contain approximately 50 million tonnes of material. Comprehensive chemical analyses of the red mud deposits were carried out at MFGI in 2012 as part of an extensive analytical campaign, providing a good basis for further evaluations and investigations. If, however, we want to obtain a realistic picture of their significance and true concentrations, new analyses based on systematic sampling would definitely be necessary. The utilization of bauxites and the red mud remaining after their processing could be reconsidered and re-evaluated on the basis of this new knowledge.

The enrichment of REE (+ Sc) in red mud follows a logic different from that of bauxites. Secondary phases not present in bauxite accumulate the critical elements (e.g. cancrinite), and their spatial distribution also shows a trend different from that of bauxite (gravitational differentiation). Therefore, systematic mineralogical, geochemical and spatial investigation of all red mud storage facilities is justified. Without this information, no resource estimate can be calculated. The following tasks can be identified in relation to the red mud tailings deposits:

In the short term (within 5 years), the aim of the research is the systematic investigation of the red mud tailings deposits and determination of the reserves of exploitable raw materials contained within them.

In the long term, the objective is the development of a new bauxite processing technology capable of utilizing the identified trace elements. (Possible reprocessing of red mud, for which, in addition to numerous foreign patents, a Hungarian technology developed at the former Metal Industry Research

Institute and at the Institute of Materials and Environmental Chemistry of the Hungarian Academy of Sciences also exists.)

4.2.2. Manganese Sludge (Critical Element Content of Hungarian Manganese Ores)

The estimated resource of manganese sludge is approximately 1.75 Mt, located in three storage facilities: Reservoir I (1926-1958) 400 kt; Reservoir II (1959-1970) 700 kt; Reservoir III (1971-1997) 650 kt. Available chemical data for the manganese and iron contents of the material in the manganese sludge storage facility are as follows (Szabó 2006):

- Mn: 10.9-13.7%
- Fe: 14.6-16.7%

Tasks related to the manganese sludge:

- Detailed mineralogical and geochemical investigation of the manganese sludge: critical element content, vertical and lateral heterogeneity (field sampling, XRD, SEM, XRF, ICP-MS).
- Execution of electrolytic ore processing experiments on the manganese sludge material.

5. Data Processing and Interpretation

5.1. Data Available from the Results of Previous Research

5.1.1. Exploration of the Copper and Other Critical Raw Material Potential of the Recsk Ore Complex

The documentation of earlier surface and underground exploration activities (from the 1950s onward) and the mine closure documentation are available in paper form. The most important reports and the analytical protocols for most underground drill holes are also available in digital form. The core samples and powder samples from previous surface and underground drill holes are available in the Recsk core sample repository managed by Nitrokémia Zrt.

The results of our investigations carried out in recent years are also available in digital form, together with major and trace element analyses of approximately 100-120 archive samples. Preliminary investigations regarding the critical and technologically important trace element contents of the individual mineral phases according to ore types have been carried out in recent years by the Geological Survey of SARA and ELTE. The database of these reconnaissance investigations, comprising data on the order of thousands, provides a solid basis for planning further investigations and based on the results, for determining the geochemical vectors required for further ore geological exploration.

Samples from the exploration of the deep-level mineralization are currently stored in sample repositories at Recsk. These are managed by Nitrokémia Zrt. In 2017, MECSEKÉRC Zrt. surveyed the samples from the deep-level underground drill holes and updated the inventory in digital form. During preparation of the KPMG study, in order to validate analytical values, 1497 samples were collected and prepared according to a Sampling Plan prepared with the participation and approval of the international expert (Competent Person). These samples are stored in a condition prepared for laboratory analysis. No analyses have been carried out on these samples to date.

Data and measurement results obtained within the framework of mine closure and land reclamation tasks belonging to the responsibility of MÉV and its legal successors, currently Nitrokémia Zrt., are available digitally, for example the water quality of open mine workings and shafts, and mineralogical/petrographic/geochemical data on the material of waste rock dumps created as a result of former mining activity. Most of the sampling and laboratory investigations were carried out at accredited institutions.

5.1.2. Critical Element Potential of Hungarian Bauxites and Red Mud

The major element composition of Hungarian bauxites is known, and many reliable archive measurements are available in the literature. Even these data show that the TiO2 concentration of Hungarian bauxites is relatively high (mostly between 1.7 and 3.4 wt.%). Ti is also a critical element. The concentration of certain trace elements, such as Ga, which was utilized together with aluminium, is also known at some deposits. Szantner et al. (1986) summarized analytical results from a large number of samples from the Iharkút bauxites, where, in addition to Ga, the also critical element V was measured together with nine other trace elements. However, our knowledge of the other bauxite deposits is rather incomplete, and reliable modern trace element measurements are rare.

In recent years (see SARA predecessor MFGI, CRTICEL 2014, REEBAUX 2019), ICP-MS trace element analyses have been carried out on numerous bauxites, red clay and red mud samples from various parts of the country. Among these analyses, several samples were found in which total rare earth element contents exceeding 0.5 wt.% were detected, generally alongside significant TiO2 concentrations (1-2.5 wt.%).

5.1.3. Critical Element Content of Hungarian Manganese Ores

Úrkút

Mn ore and manganese sludge storage exploration:

The Úrkút manganese ore mine was privately owned (Mangán Bányászati és Feldolgozó Kft., currently under liquidation). A digitized database was prepared between 2014 and 2016 for more than 23,000 samples in the core repository belonging to the mine (a precise inventory was prepared of the samples stored in the repository). The availability of the samples after mine closure depends on the permission of the owner.

The manganese sludge dumps originating from the mine are located on the mine owner’s property, and therefore their sampling depends on the owner’s permission.

Nearly 12,000 chemical analytical data produced by the mine were digitized (Bíró 2013).

Exploration of manganese ore around Eger

Exploration drilling was carried out in the investigated area (DJ-1 - DJ-11), of which the core material of one borehole, as well as sampled material from six further boreholes (rock samples, thin sections, polished section residues), can be found in the SARA sample repository at Rákóczibánya.

5.1.4. Critical Raw Material Potential of the Rudabánya Mountains

The former iron ore mine accumulated a vast number of documents on the exploration, mining and geology of the area. Most of these are probably available only on paper or photographic form.

At Rudabánya, Rotaqua Kft. has been conducting modern geological exploration since 2007 in order to understand the mineralization. As a result, they possess a detailed geochemical database, from the data of which ore geological models have also been constructed. Within the framework of the exploration, numerous old documents concerning the area were collected, 23 deep boreholes totaling 3030.3 m in length were drilled, a large number of sample analyses were carried out, and numerous scientific works and theses were produced in cooperation with the University of Miskolc and Eötvös Loránd University.

In June 2016, RK Bányatársaság Kft. prepared and submitted to the Mining Authority a Final Exploration Report concerning polymetallic ore, precious metal ore, iron ore, gravel, sand, clay, barite, limestone, dolomite, marl, gypsum, manganese ore, quartzite and coal (lignite), which was not evaluated due to legal reasons.

Further information is expected as a result of the exploration of Goldminco Kft., within the framework of which nine exploration boreholes of 200-350 m depth with core sampling, as well as geophysical measurements, are planned.

The Institute of Mineral Exploration Geosciences of the University of Miskolc, under the leadership of Professor Emeritus Dr. János Földessy, similarly possesses a large amount of exploration material, and researchers from the Department of Mineralogy of Eötvös Loránd University also cooperated in the exploration of the region. Therefore, the results of these two research groups are indispensable for understanding the utilizability of the area.

5.1.5. Critical Raw Material Potential of Bismuth-Rich Mineralization Related to Intrusive Activity

The basis for defining further exploration directions in the Börzsöny Mountains is provided by the results of geological and geophysical exploration carried out by MÁFI between 1970 and 1980 (geophysical anomaly maps, borehole descriptions, exploration reports, analytical protocols, fluid inclusion investigation results, recorded mineralogical observations, petrographic investigations, volcanological structure), the results of modern volcanological-geochemical and ore deposit studies published over the last approximately 25 years, and petrographic and trace element investigation results of ore material from archive samples originating from adits and deep boreholes. The documents are available digitally (scanned or in peer-reviewed scientific publications) and are also available in the SARA Data Repository. The material from the boreholes and adit samples is available in the SARA core repositories, in the collection managed by the SARA Collection Department, and in the collection of the Department of Mineralogy of the Faculty of Science of ELTE.

5.1.6. Exploration of Rare Earth Element Occurrences Associated with Phosphorites and Phosphates

Phosphorite as a potential raw material has not yet been explored for industrial purposes in Hungary. Quantitative REE analyses of phosphorite carried out with modern methods have only been used in scientific papers to resolve petrogenetic questions, and the measurements are not suitable for resource estimation. Since these scientific investigations are linked to ELTE, the samples, measurement databases and accumulated expertise are all available to us.

REE occurrences in the metamorphic rocks of the Sopron Mountains were identified during the uranium exploration programs of MÉV. The primary objective was exploration for U and Th, and recognition of the REE enrichments emerged as an accessory result. More detailed and systematic investigations focused on REE than the earlier work may increase the prospectivity of the area. Although the exploration material and the samples analyzed are partly available, new sample collection and analyses using standardized modern instruments, preferably in accredited laboratories, are required.

Many measurements on the Úrkút and Eplény manganese ores are available in the documentation of the closed mine, in other exploration materials, and in monographs.

Regarding the rare earth element, Y, U and P enrichment associated with rhyolite in the Rudabánya Mountains and the Bükk, only the analytical results described above are available. The analytical results were produced using reliable analytical methods that are still generally used today. No newer investigations have been carried out on this topic; however, the enrichments identified and the possible mineralization type that may potentially be demonstrated justify renewed exploration of the known anomalies.

5.1.7. Exploration of Placer-Type Critical Raw Materials in Hungary

- The basis of placer exploration is provided by the reports of multi-year investigation series carried out in the predecessor institutions of SARA, where, in addition to the results of sampling at different localities, the exploration methodology was also described.
- publications on the topic
- reports of operating gravel and sand pits
- SARA map server
- in the case of paleo-placer exploration, SARA core repositories (Rákóczibánya, Szolnok) and their databases.

5.1.8. Critical Raw Material Potential of the Pre-Mesozoic Basement of Southern Transdanubia (Titanium, Cobalt, Nickel, Precious Metals)

Our own investigations on the topic have been ongoing since 2019, based initially on the search for source rocks of recent-subrecent placer gold occurrences in the Eastern Mecsek. As a result, it was established that gold grains washed out from the rock material of Miocene fluvial clastic deposits are associated with metamorphic quartzite affected by ductile deformation and ductilely deformed granite and gneiss, which, based on our mineralogical-petrographic and geochemical research results, may have originated from the (Variscan) Mecsekalja metamorphic zone. This is confirmed by the fact that during the Miocene, fluvial transport routes ran from southeast to northwest, from the area of a former mountain range composed of metamorphic rocks and also metamorphosed granite (today reduced to the Geresd Hills) toward the Mecsek.

The discovery initiated deposit-oriented investigation of the tectonic zone by surface mapping and field XRF investigations, surface sampling, core drilling, microscopic and complex laboratory investigations (XRD, micro-XRD, ICP-OES major component analyses, ICP-MS trace element analyses, SEM-EDS investigations, Raman spectrometry, LA-ICP-MS trace element analyses), as well as U-Pb geochronological investigations to distinguish the relationship of mineralizations to orogenic cycles, in cooperation with the Department of Mineralogy of ELTE Faculty of Science. The areas of the anomalies were re-examined at 50 cm sampling intervals. Surface sampling is still ongoing, as are the sampling and laboratory investigations of available boreholes. Since 2022, we have been carrying out surface geoelectrical and magnetic geophysical investigations in the area, which we are continuing this year within the framework of the currently ongoing project. Based on the large number of measurement results obtained from surface samples and drill cores, as well as the deposit models, the current picture has emerged that the Mecsekalja shear zone, which was certainly active from the Permian to the Late Pleistocene, and the Variscan gneiss, amphibolite, quartz-sericite phyllite composing it, together with the meta-ultrabasic-basic rocks representing the sources of magnetic anomalies in and along the zone, are prospective formations for titanium, nickel, cobalt and precious metals.

Based on earlier drill core descriptions reporting sulfide-bearing rhyolites and their host rocks (Szava-1, Vókány-2, Egerág-7, Diósviszló-3), we also included the nearby subvolcanic, disseminated-vein sulfide-bearing Permian rhyolite bodies and their immediate surroundings in the exploration for critical raw materials.

In the deposit-oriented exploration of the shallow basement of Southern Transdanubia, in addition to our own measurement results, we can build on the following databases and sources:

- geomagnetic and other geophysical anomaly maps
- descriptions of archive boreholes
- reports
- publications
- public collection materials and databases
- databases of SARA core repositories (Szolnok, Rákóczibánya), samples from core boxes and documentation boxes
- core samples available in the MECSEKÉRC sample repository

5.1.9. Reconnaissance Exploration of Lithium Enrichments in Hungarian Neogene Volcanic Areas

Exploration of possible lithium occurrences has been carried out over the past two years. For this work, drill cores from archive boreholes drilled in the area and available in SARA core repositories were used, and this was supplemented by surface sampling. XRD, ICP-OES major and trace element analyses, and ICP-MS trace element analyses were carried out on the samples. Lithium was determined by ICP-OES. The results of the investigations are available in digital form. For the area of the Tokaj Mountains, a comprehensive ore geological model was developed based on ELTE research, which is suitable for refining the occurrences of limnic-hydrothermal formations hosting Li enrichments and for modelling the geological processes that formed them. According to preliminary investigations, this model can also be applied to other Hungarian Neogene volcanic units.

5.1.10. Critical Raw Material Potential of Hungarian Zinc Ores

In the broader surroundings of the proposed exploration areas, numerous investigations, including studies addressing mineral-chemical characteristics, have been carried out in recent decades. However, few of these were performed using modern methods and standardized instruments. Nevertheless, there are occurrences where researchers from ELTE and the (SARA) Geological Survey, as well as Nitrokémia Zrt., possess significant modern research databases. These include, for example - but not exclusively - various Zn-Pb occurrences along the Periadriatic-Balaton Line, Recsk, Börzsöny and Gyöngyösoroszi. We have worked on surface, collection and drill core samples from these areas, and in the course of our work we built a detailed mineral-chemical (EPMA, LA-ICP-MS) database. The modern research project on the non-sulfide zinc ore known across a very large area of the Aggtelek-Rudabánya Mountains is currently being prepared by ELTE researchers in cooperation with the University of Miskolc, for which the earlier results of ME researchers available in publications may serve as a basis.

5.1.11. Lithium Potential Associated with Geothermal and Hydrocarbon-Related Fluids

The samples selected for water analysis of the lithium content of hydrocarbon-industry fluids, primarily collected in the 1980s, confirmed the expected relatively higher lithium concentrations. In current practice, 0.01-0.2% Li occurs in 'mineable' brines. This may correspond to approximately 100-2000 mg/l lithium concentration. At the same time, it should be noted that this primarily applies to utilization of South American salars.

Based on the archive data (3920 water analyses), lithium concentrations above 10,000-20,000 mg/l occur in several places in the country, primarily in the southern and central Great Hungarian Plain, but also in southwestern Transdanubia and in the northwestern region. Our own re-analyses to date of available hydrocarbon-industry samples from the 1980s have supported lithium concentrations between 10,000 and 30,000 mg/l. These samples originate from Paleozoic or Mesozoic basement rocks and Miocene sediments.

Regarding water-dissolved Li, a nationwide screening campaign began in 2023 under the direction of SARA, which carried out accredited sampling and chemical analysis of certain oil-associated waters from the eastern and southern Great Hungarian Plain. In the coming years, the program will continue sampling in southwestern and western Hungary. The program involves the sampling and analysis of approximately 50 production wells. The wells were selected based on preliminary indications (high total dissolved solids content) and the geological environment sampled by the water.

Further information is expected from the completion of final reports for new geothermal facilities, because pursuant to the relevant legislation (SARA Decree 20/2022 (I. 31.)), the licensee is required to provide water compositions, including the concentrations of numerous critical trace elements, in the final exploration report. With the help of this, in addition to oil-associated waters, we expect the development of a nationwide data system on the composition of waters produced for geothermal purposes.

5.1.12. Hungary's Helium Potential

The history of helium exploration in Hungary should perhaps begin with the Székesfehérvár thermal water exploration by Szelényi and Csajághy (1941). In the gas inflowing from diorite intersected below 600 m by the drilled borehole, consisting of nitrogen and methane in a 2:1 ratio, 15,200 ppm helium was detected. The next systematic investigations were carried out in the Hajdúszoboszló (and Ebes) gas field. Here, in reservoirs located deeper than 1 km and consisting of thermogenic hydrocarbon gas and, to a lesser extent, biogenic methane, the average helium concentration may reach 1000 ppm (Ballentine et al., 1991). The helium content of the Szeghalom thermogenic gas reservoirs is also noteworthy, where according to Sherwood Lollar and co-authors (1994), it is 200-300 ppm. In contrast, the He content of the Kismarja CO_2 reservoir is only a few ppm.

During the most recent investigations, several reservoirs of the Répcelak field were examined. According to the studies of (Palcsu and co-authors, 2014), the helium content of the 'pure' CO_2 reservoirs is only a few ppm, whereas in the upper reservoirs containing a total of 10-20% thermogenic gas and nitrogen, helium reaches, and in many cases significantly exceeds, 1000 ppm.

Useful basic data for the National Exploration Program are provided by the registers maintained by the National Mining Authority of SARA (e.g. the mineral resource register and the register of mining areas), as well as by the archive and continuously expanding document and digital data holdings of the Hungarian State Geological, Geophysical and Mining Data Repository.

5.2. Data Generated During the Implementation of the Research Projects

Data are generated during several work processes of the research projects, and for easier management it is advisable to organize these into a database. In the initial phase of the research, these are mainly maps generated during field mapping, coordinates of sampling points, results measured by field XRF, and data relating to samples originating from other sources (archive collection or museum samples, samples taken from drill cores, samples taken from wells). During field investigations, surface geophysical measurement data are generated, and in connection with exploration of the Recsk ore complex, the results of deviation measurements in boreholes that are still accessible with instruments are also generated. In the case of areas that are already known in more detail and were also explored earlier, one of the first steps in database construction is the evaluation and validation of available archive documents (laboratory protocols, exploration reports, maps, sections), followed by digitization and organization of data of appropriate quality. In the case of exploration of the Recsk ore complex, the Rudabánya Hills and the Sopron Mountains, the status of data managed by external companies is uncertain (samples managed by Nitrokémia Zrt. and the database owned by MECSEKÉRC Kft.); agreements are required for their inclusion.

Following sample collection and their macroscopic and petrographic examination, the geochemical information obtainable from individual samples is acquired through various laboratory investigations. These may include mineralogical characterization tests (XRD, DTA-TG, IR spectroscopy), chemical characterization tests (AAS, ICP-OES, ICP-MS), mineral-chemical investigations (electron microprobe, SEM-EDX/WDX, LA-ICP-MS, Raman, stable isotope analysis), and thermometric investigations (fluid inclusion microthermometry). In order to ensure the long-term continuity of research and the comparability of data, we consider it important to establish a National Geoscience Laboratory on the laboratory base of SARA and the cooperating universities. Such an infrastructure could serve the analytical needs of domestic and regional scientific activity even after completion of the CRM research projects. If the number of samples exceeds the capacity of the laboratories of SARA, the universities and the participating partners (e.g. MECSEKÉRC Zrt.), and for the performance of control measurements, the involvement of an external accredited laboratory is required. Sample preparation depends on the type of investigation; therefore, several types of material may be generated from the same sample (e.g. polished section, powder, solution, mineral separate, etc.). Storage and organization of remaining samples after the investigations can be solved at SARA sites (e.g. core repositories, collection).

If justified by preliminary geophysical and geochemical investigations, the next phase of exploration is drilling, which is accompanied by borehole geophysical measurements, rock mechanical investigations and water sampling/water chemistry analyses. After proper documentation, halving and sampling of the recovered drill cores, the existing knowledge base and database can be expanded through further laboratory investigations. Storage of drill cores can be handled in the SARA core repositories.

5.3. Integration and Interpretation of Previous and New Data

Using the geochemical data obtained during the research, fluid-rock interaction models can be produced to determine the evolution of the ore-forming fluid. In addition, thermodynamic parameters can be estimated on the basis of geochemical information, and these can be used to define vectors needed for further exploration. Based on the 3D integration of geochemical and geological information, deposit-geological system models can be developed that support ore body delineation, resource estimation and the designation of further prospective areas. The interpretation of large amounts of data is also supported by the application of various geostatistical methods. For all this, appropriate software optimized for mineral exploration tasks must be applied (e.g. ioGAS).

In connection with exploration of the Recsk ore complex, the first computer-based modelling of the mineral resources of the Recsk Deep Level ore occurrence was carried out by MECSEKÉRC Zrt. in 2012 using Surpac software. For the same purpose, Golder Zrt. used Vulcan software in 2016. Naturally, geostatistical analyses were also carried out during these works. The 3D database of the ore bodies will be supplemented with new data, geostatistical analysis will be carried out, and based on the results of data validation, the mineral resources will be re-evaluated. The new trace element data will also be taken into account during the evaluation.

6. Database Structure, Content and Accessibility

The data generated during the research and intended for publication will be prepared in a format compliant with the rules of the EU spatial information infrastructure (INSPIRE), in order to ensure international comparability. The data intended for publication will be made available on the online interface of the European Geological Data Infrastructure (EGDI).

6.1. Data Models

The analytical data derived from the designated exploration areas, as well as related archive data, maps and reports, must be organized into a database system built according to a unified concept. Based on the nature of the stored information, the dataset can be classified into the following thematic groups:

- Areas holding mineral exploration and mining permits
- Mineral deposits and mineral resource data
- Geological-geophysical models
- Measurement projects and campaigns
- Analytical data
    - surface geological observations and geophysical measurements
    - borehole measurements
    - laboratory investigations
- Archive documents and exploration reports

The INSPIRE Directive, which is mandatory for European data providers, prescribes the use of data models based on international IT standards in relation to these thematic groups. (see https://inspire-mif.github.io/uml-models/approved/html/) The storage and sharing of mining register data are possible using the INSPIRE Annex III MineralResources data model. This contains the following classes relevant to the National Exploration Program:

- MineralOccurrence
- ExplorationActivity
- Resource, Reserve, UNFC Classification

These elements can be well used to describe occurrences delineated in the designated exploration areas and the associated resource estimates.

The INSPIRE Annex III Area Management Restriction and Regulation Zones data model is important for regulatory zones, in our case for areas holding exploration and mining permits. This corresponds to the mining plots and exploration areas recorded in the SARA BATER register.

In the case of geological data, the recommended standard is INSPIRE Annex II Geology/Geology. For more detailed description, GeoSciML 4.1 should be used.

Storage and sharing of geophysical measurements are carried out using the INSPIRE Annex II Geology/Geophysics data model. The usable classes are the following:

- GeophMeasurement
- GeophObjectSet
- GeophModel

These elements are suitable for sharing all surface and borehole geophysical measurements and processed data. The data types derived from GeophMeasurement and GeophModel implement the specific geophysical elements separated according to measurement geometry.

Measurements:

- point geometry - measurement stations, soundings
- line geometry - measurement lines (2D seismic survey, radar, direct-current profiling)
- polygon geometry - areal measurements (3D seismic survey, interferometry)

Models:

- line geometry - stratigraphic columns
- surface coverages - interpreted sections (2D seismic processing, resistivity sections)
- spatial coverages - 3D seismic volume

The results can be attached in industry-standard file formats (SEGY, LAS, etc.). Through the GeophObjectSet classes, the data model also supports the description of measurement and processing campaigns and research projects.

For sharing detailed analytical data, the INSPIRE Directive prescribes the use of the Observations and Measurements standard. This is a general framework suitable for documenting surface, subsurface and laboratory investigations alike. The starting point is the Spatial Sampling Feature, which consists of two main parts: geometry and any number of observations. Each observation contains the metadata describing the measurement and the result, which may be a quantity, data record, table or time series.

The simple data structure handles the diversity of investigations through digital dictionaries. The use of the RDF SKOS standard is recommended for implementing the dictionaries.

For describing borehole data, the INSPIRE Annex II Geology/Geology Borehole class can be used. For the same purpose, EGDI (European Geological Data Infrastructure) prescribes the use of the simplified BoreholeIndex developed in the EPOS project. This contains the master data of the borehole and links to associated analytical results grouped by topic (stratigraphy, geophysical measurement results, hydrogeology, groundwater level monitoring, etc.).

5.2. Databases

Due to our participation in the GeoERA and Geological Service for Europe (2022-2027) GSEU projects, the MIN4EU database is available to us for the storage of mineral raw material data. This system, jointly developed by the member services of the European Geological Surveys community (EuroGeoSurveys), covers the entire mining value chain and provides INSPIRE-compliant data storage. The system allows diverse and detailed record keeping.

In recent years, several efforts have been made to physically implement the conceptual data models related to INSPIRE. The fundamental objective of the ALFA database system was to implement this, and therefore it provides a good basis for constructing the IT system to be developed within the National Exploration Program. Regardless of whether this system is connected to external data provision interfaces, a unified geological information system based on international standards provides a reliable foundation for satisfying internal data use needs and implementing data asset management based on a unified concept.

Building this infrastructure cannot be achieved without an appropriately trained expert background familiar with geology, geoinformatics, database technologies and web service technologies.

6.2. Data Sharing

The basis of INSPIRE-compliant data provision is the use of standard web services. Access to data from databases built on conceptual data models must be ensured through services compliant with OGC (Open Geospatial Consortium) standards. In the case of High Value Datasets, such as the CRM data domain, machine searchability and readability in accordance with the F.A.I.R. principles (F: findable, A: accessible, I: interoperable, R: reusable) are especially important. The usual means of achieving this include WMS/WFS-based GIS services, OGC API Features, SensorThings API tools, and metadata catalogues based on the ISO 19115 standard (CSW - Catalogue Service for the Web). SARA's INSPIRE data provision is currently also carried out using such a metadata catalogue system. The SARA CSW server provides harvesting capability toward the National INSPIRE Geoportal and the EGDI metadata catalogue.

ISO 19115 metadata are intended to describe datasets and web services. They contain the most important keywords needed for searching datasets, textual descriptions, the method of data creation, data accessibility and access restrictions. They can be used as a database supporting the overview of archive and newly created maps and reports.

In the mineral raw materials domain, SARA's data provision toward EGDI (European Geological Data Infrastructure), with limited content for data protection reasons, is carried out from the MIN4EU database through a Deegree web server, which provides high-quality WFS service. The service is harvested monthly by the application connected to the EGDI central database. The same database can also be used to meet internal data storage and data provision needs with the content generated within the framework of the National Exploration Program.

7. Industrial, Academic and Social Linkages of the National Exploration Program

During preparation of the program, it was of key importance to develop a professionally coherent, agile exploration program based on a shared position. To this end, we established the CRM Roundtable, in which, besides the Geological Survey of SARA, all universities with geoscience education (Eötvös Loránd University, University of Miskolc, University of Szeged), the two most important geoscience civil organizations (Hungarian Geological Society, Association of Hungarian Geophysicists), the ministries concerned in connection with the CRMA (Ministry of Energy, Ministry for National Economy), state-owned mining companies (Nitrokémia Zrt. and MECSEKÉRC Zrt.), and staff members of the National Mining Authority of SARA participate - all those involved in critical mineral raw material exploration.

The Roundtable makes it possible to channel public administration, academic, social and industrial needs and experience into the exploration program, in order for the professional results intended by the program to achieve the greatest possible spill-over effect. Our aim is to establish lasting competences and achieve professional results capable of moving domestic mineral exploration in a permanently prosperous direction.

Community building is of key importance in the development of the elements of the exploration program and later in their implementation. The individual research topics and directions will be carried out through joint work; participants of the CRM Roundtable will continuously support the work of the

Geological Survey according to their competences and resources. Only through long-term joint work can the research topics become economically mature projects interpretable from a mining perspective.

Another important aspect already during planning was that information related to the projects should be offered to market actors structured within the unified geoscientific data system applied by the GSEU project, classified according to UNFC, and organized into a so-called CRM digital data room. This can significantly support and accelerate market investment decisions and make the dataset and completed work transparent. Beyond geoscientific professional challenges, the primary task of the exploration program is in fact to map mineral raw material resources for national economic purposes and, where possible, prepare their utilization as soon as possible. Therefore, during state exploration activities, attention must always be paid to the needs of market-oriented exploration aimed at preparing concrete utilization.

The purpose of creating the CRM digital data room is to provide an opportunity to access the collected CRM information organized into digital geological-geophysical data systems, by making available in one place the tools and information required for analyzing digitally accessible geological and geophysical data. Within this framework, we will also provide access to direct use of GIS and geological-geophysical analytical software, which enable on-site analysis of data, rapid comparison of different parameters and support for professional decision making.

When preparing the program, we considered it particularly important to take into account the need to stop the decline in the number of domestic geoscience and mining engineering professionals oriented toward mineral exploration. Involving university training centers makes it possible to set clear long-term goals for the professional next generation and thereby provide a future vision, ensuring the future success of young Hungarian professionals.

A key objective of the CRM National Exploration Program is knowledge sharing and capacity building. Therefore, the following forms should be exploited jointly with the partners to the greatest possible extent, aligned with the professional results:

- Workshops/seminars/conferences: Organization of thematic professional events that bring together stakeholders from the geoscience and mining sectors and provide an opportunity to share their insights, research and case studies related to implementation of the CRMA. It should be particularly emphasized that during these opportunities, professionals can meet, exchange ideas and establish new contacts with one another.
- Joint publications/research documents: We encourage the creation of jointly authored articles and studies that can contribute to expanding the knowledge base.
- Training and education: We trust that as the program progresses, development may also begin on programs aimed at improving the skills of the workforce, research specialists and relevant civil organizations with regard to appropriate technologies, methods and approaches. To support implementation of the CRM Regulation and the National Exploration Program, the National Mining Authority of SARA will organize a three-part UNFC training in 2025 for mining supervision and geological survey staff who are involved in mineral resource management or in tasks supporting UNFC classification under the Program.

8. Monitoring, Evaluation and Updating Tasks Related to the National Exploration Program

According to Article 19(1) of the CRM Regulation, the National Exploration Program must be reviewed at least every five years and updated if necessary. In addition, according to Article 19(5) of the CRM Regulation, Hungary has an annual reporting obligation on progress in implementing the measures included in the National Exploration Program.

The performance of these tasks is ensured by the fact that the CRM Roundtable will meet at least annually and evaluate progress based on the annual professional report prepared by SARA and its academic and industrial partners participating in the development of the domestic CRM program and related research. On this basis, it will propose further measures, changes and the professional plan for the following year. The resulting document may form part of the annual report in which the Ministry for National Economy informs the European Commission. The advisory function of the CRM Roundtable will also fill a gap in further policy and regulatory issues at Member State level related to implementation of the CRM Regulation.

With this method, SARA will be able to preserve unified professional support in critical mineral raw material exploration and continuously build the professional community. This will be particularly important in cases where individual research projects do not produce the expected or desired results, and a significant review may become necessary.

Another important element of the monitoring process is that, after submission of the annual Member State report, SARA will organize a CRM professional day, during which interested professionals can learn about the progress of individual projects through professional presentations.

As defined in the CRM Regulation, SARA operates the website on which, with the help of maps, all deposits and metadata systems relating to deposits that contain critical raw materials and that were collected under the measures defined in the National Exploration Program will be publicly accessible. In addition to the existing information platforms, this website will also provide detailed information concerning the CRM data room.

9. Resource Requirements of the National Exploration Program

During implementation of the Program, the individual research projects may have different work programs, but the following general grouping applies to all of them:

- Collection and re-evaluation of previous research and existing data: reassessment and re-evaluation of earlier exploration activities carried out in the area and its wider surroundings, including old drilling data, mining records and previously identified indications.
- Geological mapping: Understanding the geological characteristics of the area through mapping that meets the needs of mineral exploration, usually at a more detailed scale than existing geological maps (1:5000 - 1:2000), is of critical importance. This helps identify mineralized zones and potential resource targets.
- Geophysical measurements and mineralogical, petrographic and geochemical laboratory investigations: Data derived from geophysical surveys (e.g. magnetic, gravity, electromagnetic) and mineralogical, petrographic and geochemical analyses can provide further insight into the subsurface area and contribute to understanding the formation of deposits containing critical raw materials and, on this basis, to developing geological and process models applicable in mineral exploration.
- Exploration drilling: In certain projects, drilling is required for more precise understanding even during the state exploration phase. The results of drilling programs, such as core samples, are essential for determining the quantity and quality of mineral resources.

Four types of resources are required for implementation of the National Exploration Program:

1. Human resources: The necessary expert and technical staff who can carry out the above tasks at a high level for each project according to the work program. Internal trainings support staff participating in the tasks (e.g. application of the United Nations Framework Classification for Resources, i.e. UNFC, prescribed by the CRM Regulation).
2. Digital infrastructure: Computing resources and data systems of the required performance, as well as data recording, processing and interpretation software.
3. Research infrastructure: Access to laboratories and data repositories is essential for scientific or technological exploration. This also includes special measurement equipment or technologies (e.g. analytical or geophysical measurement instruments).
4. Financial resources: Geological research requires significant financial investment, and its return can be expected in the medium-to-the-long term. More costly exploration is also required for the quantitative and qualitative determination of mineral raw materials.

It is particularly important to emphasize that although the available data have largely been organized, even in the best cases they can only be used at the technological and methodological level of the 1970s and 1980s; in this form, their national economic utility cannot yet be discussed. At European level, it is a professional fact that while until the 1990s approximately 20 elements were in the focus of mineral exploration, today this number has doubled and continues to increase. Furthermore, while in the past the focus was on volumes shallower than 300 m, today there is practical benefit in prospectivity studies down to depths of 1500-2000 m.

When compiling the program, a particularly critical objective in resource planning was to create only competences that produce lasting national economic utility. This means that during preparation of the development and operational expenditures of the research work programs, the following aspects prevailed:

- only activities interpretable from the perspective of the national economy were included in the program;

- where infrastructure developments are justified (whether laboratory or digital), they should support other work programs horizontally to the greatest possible extent, and unused or narrowly particular capacities should not be created;
- regarding human resources, the program supports the training and involvement of young experts in domestic CRM exploration, so that the expertise and competence generated can be utilized as broadly as possible, inducing further research results.

On this basis, the CRM National Laboratory Network will be established within the framework of the Program. It will provide central laboratory capacity for the research groups involved in CRM research by using the accredited and non-accredited geoscientific laboratory capacities of SARA and the participants of the CRM Roundtable. This will ensure that, in cooperation with partners and in a cost-effective manner, the highest possible laboratory utilization and measurement capacity are created, forming a competence that can become a pillar of mineral exploration. Infrastructure development (instrumentation) of the CRM National Laboratory Network is also required for those analytical competences that are necessary for producing modern data of a quality accepted also by investors, but which are currently not yet available among the cooperating partners.

Following adoption of the National Exploration Program, the resource planning of the individual work programs awaits precise breakdown and prioritization. At present, resource requirements are only available in aggregate form in order to preserve professional and policy flexibility.

Once the National Exploration Programme has been adopted, resource planning for the individual working programmes takes place. Accordingly, the precise programme of work and budget for the National Exploration Programme must be planned and implemented independently each year. Market participants should be involved in financing the National Exploration Programme wherever possible, with market and state financing needs being separated in the current budget plan. The amount financed by the budget is determined when the central budget is planned.