# Critical Raw Materials Hungary Data Collection: Rare earth elements indications in Hungary

# A Kritikus Nyersanyagok Maraton Adatgyűjteményéből: Ritkaföldfém-indikációk Magyarországon

CSILLA BALASSA, PhD student, CSILLA PATAKY, MSc student,
CSABA TÁTRAI, MSc student, KRISZTIÁN ANTAL, MSc student,
IVÁN GYENES, BSc student, SÁNDOR SZAKÁLL, professor emeritus,
JÁNOS FÖLDESSY, professor emeritus

TEKH College, University of Miskolc

*The Natural Resources Research and Utilization (TEKH) Special College of the Faculty of Earth and Environmental Sciences and Engineering, University of Miskolc set a goal in 2023 to pay special attention to critical raw materials (CRM). In addition to presenting the individual raw material types, it is also important to describe the Hungarian CRM anomalies. This article is dedicated to presenting the various rare earth elements (REE) indications, regardless of the type of geological formation containing the anomaly. Our starting point was the CriticEl project running in the 2010s, but where possible, we expanded the previous results with new ones. Although volcanic formations can also carry exceptionally high concentrations (Mecsek phonolite, Velence beforsite), from an economic perspective, sedimentary deposits (Transdanubian bauxites, Mecsek coals) are more promising.*

***Keywords:*** *Critical Raw Materials, rare earth elements, Hungary, metamorphites, alkaline magmatites, metamorphic volcanics, sedimentary deposits*

*A Miskolci Egyetem Műszaki Föld- és Környezettudományi Karán működő Természeti Erőforrás Kutatás és Hasznosítás (TEKH) Szakkollégium 2023-ban célul tűzte ki, hogy az Európai Unió törekvéseivel összhangban kiemelt figyelmet szenteljen a kritikus nyersanyagoknak. Az egyes nyersanyagtípusok bemutatása mellett fontos a magyarországi kritikuselem-előfordulások ismertetése is. Cikkünk a különböző ritkaföldfém-előfordulásainkat mutatja be függetlenül azok földtani típusától. Kiindulópontunk a 2010-es években futó CriticEl project volt, de ahol lehetséges, a korábbi eredményeket újakkal bővítettük. Bár vulkáni képződmények is hordozhatnak kiemelkedően magas koncentrációkat (mecseki fonolit, velencei beforsit), gazdasági szempontból az üledékes telepek (dunántúli bauxitok, mecseki szenek) ígéretesebbek.*

***Kulcsszavak:*** *kritikus nyersanyagok, ritkaföldfémek, Magyarország, metamorfitok, alkáli magmatitok, metamorf vulkanitok, üledékes telepek*

## Introduction

Rare earth elements (REE) are crucial for today's technology. which are used in a range of modern technologies. A number of research projects, including the EURARE and ASTER projects, have been funded in Europe to investigate various steps along the REE supply chain. This paper addresses the initial part of that supply chain, namely the potential geological resources of the REE in Europe. Although the REE are not currently mined in Europe, potential resources are known to be widespread, and many are being explored. The most important European resources are associated with alkaline igneous rocks and carbonatites, although REE deposits are also known from a range of other settings. Within Europe, a number of REE metallogenetic belts can be identified on the basis of age, tectonic setting, lithological association and known REE enrichments. This paper reviews those metallogenetic belts and sets them in their geodynamic context. The most well-known of the REE belts are of Precambrian to Palaeozoic age and occur in Greenland and the Fennoscandian Shield. Of particular importance for their REE potential are the Gardar Province of SW Greenland, the Svecofennian Belt and subsequent Mesoproterozoic rifts in Sweden, and the carbonatites of the Central Iapetus Magmatic Province. However, several zones with significant potential for REE deposits are also identified in central, southern and eastern Europe, including examples in the Bohemian Massif, the Iberian Massif, and the Carpathians (Goodenough K., et al., 2016). Because their high economic importance and supply risk, REEs are belonging to the group of Critical Raw Materials (CRM) in the EU. Jancsek (2023) made a brief review about REE potential and mining in a global perspective.

Natural Resources Research and Utilization Special College (after Hungarian abbreviation TEKH) is the association of talent-building for students at the Faculty of Earth and Environmental Sciences and Engineering, University of Miskolc. With this article the College continues the update the former CriticEl project, collect available new data about CRMs, as well as about Hungarian mineralizations , build a database from the collected data, and publish the results.

***Table 1.*** *List of the mineralizations presented in this paper, with the postal ID of the nearest settlement (indicated on Figure 1), rock type,, and the other occurring CRMs or other trace elements*

| Location | Mineralization | ID | Rock type | Other CRMs + trace elements |
|---|---|---|---|---|
| Buda Mts. | Budaörs | 2040 | alkaline magmatites, clays, hydrothermally altered dolomites | Th |
| Bükk Mts. | Lillafüred | 3517 | Siliciclastic sedimentary rocks, metavolcanics | Th, Zr, Nb, Ta (Li?) |
| | Bükkszentkereszt, Southern Bükk | 3557 | phosphatite layer, neighbouring volcanics | Be, Mn, U, W, As, Sn |
| Uppony Mts. | Dédestapolcsány | 3643 | siliciclastic sedimentary rocks | U, Ba, V, Ti, Cu, graphite |
| Rudabánya Mts. | Rudabánya | 3733 | siliciclastic sediments | Ba, Sr, Cu, Zn, Pb, Ag |
| Szendrő Mts. | Irota | 3786 | phyllite | Zr, Au, As, graphite |
| | Rakacaszend | 3826 | | |
| Mecsek Mts. | Magyaregregy | 7332 | phonolite | Nb, Ta, Th, Hf, Zr |
| | Hosszúhetény | 7694 | | |
| | Nagymányok | 7355 | hard coal | Nb, Ta, Zr, Hf, Ge |
| | Pécs-Vasas | 7691 | | |
| Villány Mts. | Nagyharsány | 7822 | bauxite | Ga, Sc |
| Velence Mts. | Gánt | 8082 | bauxite | Ga, Sc, |
| | Pákozd | 8095 | granitoids<br>oxidized beforsite<br>monchiquit | F, Nb, Ta, Th, Pb, Zn |
| | Sukoró | 8096 | | |
| Balaton Highlands | Balatonrendes | 8255 | sand, limonitic concretions | U, Th, |
| Bakony Mts. | Úrkút | 8409 | carbonatic Mn-ore | Mn, Co |
| | Halimba | 8452 | bauxite | Hf, Ta, W, Pb, Bi, Th, U |
| | Nyirád | 8454 | | |
| Sopron Mts. | Sopron | 9400 | mica schists | Th |
| | Felsőrákos | 9421 | | Th, U, Ti, P |

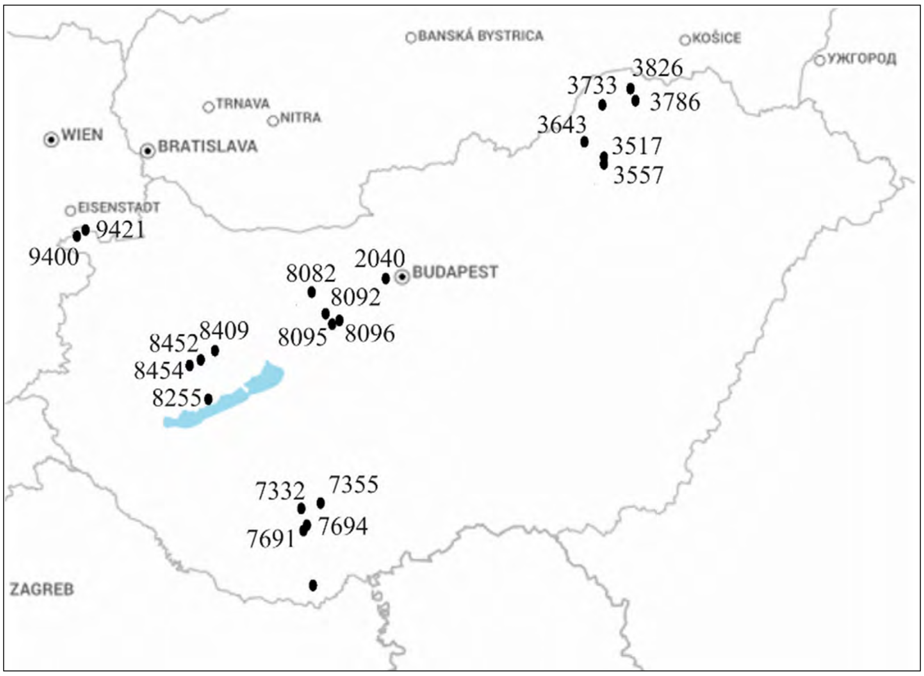


***Figure 1.*** *Location of theREE mineralizations presented in this paper. Numbers indicate the postal ID of the nearest settlements. List of IDs can be found in Table 1*

The University of Miskolc coordinated the CriticEl project between 2012 and 2014, which was aimed at at researching CRMs (at that time 14 raw materials compared to 34 items on the 2023 list). One of the main focus was on REEs. A whole volume of the CriticEl Monography Series was dedicated to this topic (Szakáll, 2014). In this paper we summarize the results of former CriticEl, and integrate it with the follow-up work, with new results. *Table 1* summarizes some relevant information about the occurrences, while the location of these are shown in *Figure 1*.

## Hungarian REE-indications

*Metamorphites*

### Sopron Mts.

The Sopron Metamorphic Complex (Babinszki et al., 2023) is one of the few metamorphic formations which was examined from the point of view of Rare Earth Elements during the 20th century. Results of the study made by the Mecsek Ore Company were summarized by Fazekas et al. (1975). More recent studies were made published by Nagy et al. (2002); Nagy and Draganits (1999); and Török (2020). The occurrence was not included in the CriticEl project.

Sopron Metamorphic Complex consists of mica schists, orthogneiss varieties and special metasomatic rocks. Early-stage metamorphic processes were connected to the Variscan Orogeny and the subsequent extension process, followed by the Alpine metamorphic period. Exhumation occurred during the late Cretaceous – early Paleogene. REE-indication is connected to boulders occurring at elevated terrains (Nagyfüzes, Szarvas Hill, Ház Hill), as well as to quartzite from Szarvas Hill. Altogether five different REE + Th-bearing rock types, kyanite-muscovite schists, quartz-muscovite-chlorite schist were distinguished. Trace elements were measured by semiquantitative and quantitative spectrographic analysis. Based on these early assays. the REE + Y concentration ranges between 0.7 and 8%, (Fazekas et al. 1975). The dominant REE-minerals are florencite and monazite. Probably the monazite is partly the alteration product of the florencite. Thorium is incorporated into thorite and thorianite (Fazekas et al., 1975). Nagy and Draganits (1999) and Nagy et al. (2002) also distinguished several generations of monazite, furthermore they detected the presence of rhabdophane.

In the Sopron Mts., the Fertőrákos Metamorphic Complex also has high REE concentrations (Vincze et al., 1996). This formation consists of graphitic phyllite, paragneiss, amphibole schists, pegmatites. The metamorphism has amphibolite and greenschist facies (Babinszki et al., 2023). Alpine metamorphism led to the mobilization of various chemical elements, including the Th, U and REEs, as well as Ti, P and base metals. Sulphide ore indications are present. The beginnings of the exploration are dated back to 1969, when a chlorite-apatite mica schist was explored with uranium anomaly, by Mecsek Ore Company. Observed rock alteration processes are chloritization, sericitization, tourmalinitization, pyritization. Total REE concentrations are between 0.013 and 0.038%. The most important

REE-bearing mineral is apatite, but epidote also occurs. Ház Hill occurrence is LREE-dominant, the Fertőrákos occurrence is HREE-dominant.

*Alkaline magmatites*

**Mecsek Mts.**

Mecsek Phonolite was a target during the CriticEl project for REE research (Szakáll et al., 2014). In the East Mecsek, two large shallow intrusive masses of phonolitic rocks are known, which can be examined over a large area at the surface: 1) the Köves-tető deposit north of Hosszúhetény and 2) the Somlyó - Szamár Hill deposit south of Szászvár. There is also a tephritic-tephriphonolite layer with greater thickness in the Réka Valley with pegmatoid nests, and an iron-sulphide contact belt along the Toarcian black shale outcrop (Jáger & Molnár, 2006). The phonolite of Hosszúhetény, Köves-tető was quarried. The Köves-tető phonolite body can be followed with an average thickness of 100 m, traced in 1.7 km width (Némedi Varga, 1995), and it was intruded into the Jurassic coal-bed assemblage during the Lower Cretaceous magmatism. We can only extrapolate the depth of the intrusion from the sediment thickness data for the East Mecsek, as about 2 km. The known other intrusion at Somlyó and Szamár Hill near Szászvár is also a sill-like body, which intruded into the Jurassic fine-grained clastic assemblage (mainly Mollusca shell-bearing quartz bearing aleurolite) at a calculated depth of about 1.5 km. The thickness of this subvolcanic body reaches 300 m. The greater thickness and slower cooling have resulted in a higher degree of differentiation, with coarse-grained, pegmatoidal rock varieties occurring in some places.

Among the alkaline igneous rocks of Mecsek, phonolite has the highest total REE values (between 460–500 ppm), which is about 3–3.5 times enrichment compared to the average of the continental upper crust. The phonolites carry a wide range of REE minerals. To date, 14 such phases have been identified, including, for example, fluornatropyrochlore among the oxides; lanthanite-(Ce), ancylite-(Ce), calcioancylite-(Ce), and bastnäsite-(Ce) among the carbonates; and joaquinite-(Ce), cerite-(Ce), and eudialyte among the silicates. REE minerals formed coeval with the predominant rock constituents and the phases formed in the miarolitic cavities during the mobilization of REEs. REE-bearing smectite was also detected. At the same time, the amount of REEs is strongly reduced at the contact of coal bearing sediments in contact with phonolite.

**Velence Mts.**

Occurrences of Velence Mts. were also examined in the frame of the CriticEl project (Szakáll et. al. 2014). The geological investigation of the Velence Mts. has been mainly focused on the granite, the contact shale surrounding the granite from the north and east, the andesite intrusions within the granite and the secondary, altered rocks (Eocene magmatic formations) east of the granite body. A major part of the Velence Mts. is composed of granite, intruded into a Paleozoic metamorphic assemblage. Upper Permian and Triassic sediments also appear from boreholes to the south-east part of the mountain. In the northeastern part of the mountain range, Eocene-Oligocene andesite and metamorphic varieties are found. The older formations of the mountain range are covered by Upper Miocene (Pannonian) and Quaternary sediments.

The granite porphyry is a characteristic feature of the mountain (Pákozd Granite Porphyry Member). The large number of dikes predominantly 5–25 m thick, were often detached from the granite and created a special relief. Two types can be distinguished, the Sukoró and the Pátka type. The Sukoró type is purplish-grey to purplish-red, slightly more basic (less porphyritic quartz, more common potassic feldspar and plagioclase porphyries), the Pátka type is greenish-grey to orange-brown, slightly more acidic, with porphyritic quartz crystals. In the late phase, microgranite intrusions were formed (Kisfalud Microgranite Member). Contact metasedimentary rocks have formed on the granite margin. Late Cretaceous carbonatite dikes (beforsite) intrude the earlier formations (Szakáll et al., 2014).

The total REE concentration values of the granitoids of the Velence Mts. range from 60 to 225 ppm. Practically, the REE concentration depends on the amount of accessories – among which biotite is the most important – because accessory phases are associated with the REE-bearing phases, such as monazite-(Ce), cheralite, xenotime-(Y), REE-bearing apatite, allanite-(Ce), REE-bearing epidote. REE concentration is around the crustal average, with slight relative enrichment of heavy REE (HREE).

The TREE concentration of oxidized beforsite can reach 600–740 ppm. It is worth to mention that while the REE carrier of the intact beforsite (from drillhole) is monazite-(Ce), in the oxidized rock collected at the surface is the florencite-goyasite mixed crystal, which was formed from REE mobilized during weathering processes in the oxidation zone. REE-concentration of monchiquite is also low. In this rock type the REE-bearing minerals are various phosphates, silicates and carbonates, which are difficult to identify because of their very small size (mainly REE-bearing apatite, monazite, britholite). The other alkaline magmatite, spessartite (for which trace analysis has not yet been carried out), is REE-bearing monazite-(Ce), xenotime-(Y) and zirconolite. Overall, beforsite is the most promising rock for REE but its poorly known extension its potential cannot be judged.

### Buda Mts.

The Buda Mountains is the extreme eastern segment of the Transdanubian Mountains built mainly from Mezozoic carbonate and siliciclastic sediments. The highest rare earth metal content was detected in relation of the Upper Cretaceous alkaline lamprophyres and carbonatit dikes similar to beforsites found in the Velence. In the Buda Mts., indications of Th and REEs (Sc, Y, La) have become known. Th is found in clays filling fracture zones of tectonic origin in the Triassic basement. Their presence indicates hydrothermal processes. Sc, Y, La occur both together with Th and separately. Their presence indicates hydrothermal processes.

The other type of Th occurrence is associated with the fractures that cut through the layers of dolomite or Dachstein limestone of the Triassic bedrock, with the yellowish-brown, grayish-yellow or red clay with limestone and dolomite debris filling between the fault or strata-bound displacement planes. The source rock of the REEs is a deep alkaline igneous rock consisting predominantly of biotite. The thicknesses of the zones vary between 5 cm and 2 m and contains 0.2–0.3% Th on average. Th is also found in the youngest formations of the surface, directly on or below the surface, in the slope debris of the bedrock, in the clay fraction.

In two drillholes at the Nagykopasz Hill, dike rock was intersected consisting predominantly biotite, which also contains chlorite, apatite, zoisite, epidote, amphibole, enstatite, tourmaline and corundum. Orthoclase and feldspar, a little muscovite and quartz can also be found in it. The rock was subsequently carbonated, it contained 100 g/t Sc, 10–100 g/t Y and 100 g/t La. This rock may be the source rock of the indicated REEs.

### Villány

In the northern foreground of the Villány Mts. hydrothermal sulphide bearing hydrothermal veins in riolites and microgranites contain 1300–2000 pmm REEs. No further information is known about this enrichment (Konrád et al., 2000). Polymetallic ore deposits Mátra, Recsk.

## Metamorphic sedimentary and volcanic environments

### Bükk Mts.

Metavolcanics near Bükkszentkereszt were the target of several radiometric measurements and field investigations (Barabás, 1957; Csáki and Csáki, 1973; Kubovics et al., 1989; Szabó, 2002; Wéber, 1975, 1968, 1967; Wéber and Csáki, 1971). First integral airborne gamma measurements were carried in 1955, followed by spectral airborne measurement between 1967 and 1969, which indicated elevated Th and U concentrations, and led to a detailed radiometric survey field investigations, drillings and trenching. Based on the results, a high U phosphoritic layer was found, (in Triassic Bagolyhegy Metarhyolite) near to Bükkszentkereszt, Hősök Spring, with 100–400 g/t U, as well as significant amount of P, Mn, Pb, Zn, REEs and Be (about 100–300 g/t). This layer was designated as a target of CriticEl project (Zajzon et al., 2014). In Mn-oxide rich phosphorite layers the average total REEs content is 143 ppm, from which the HREE + Y is 64 + 195 ppm. In the neighbouring chlorite-rich metavolcanics the average total REEs is 162 ppm (HREE+Y is 24+34 ppm). The occurring REE-and other critical element minerals are xenotime-(Y), monazite-(Ce), columbite-(Fe), REE-bearing titanite, pyrochlore-(Y) / nioboaeschynite-(Y) and fluorapatite. The relative enrichment of the REEs (especially HREEs) probably occurred due to element mobility because of the interacton of two metavolcanic layers. The source of the critical elements can be the wall rock, or the magma residuum enriched in incompatible trace elements.

Beside Bükkszentkereszt, other mineralizations from the Southern Bükk Mts. also have REE potential. During the CriticEl project several other metavolcanics were sampled and analyzed for trace elements. A sample from SE Bükk showed extraordinarily high REE and other trace elements (e.g. Zr, Nb, Th, Ta) content (Németh et al., 2016). This result was followed by further research conducted by University of Miskolc, with the help of natural gamma measurements, taking advantage of the presence of radioactive Th (Németh et al., 2023). Samples with similar trace element geochemistry were found in two different territory, both of them are situated next to structural boundary zones: 1) in Vesszős Valley, near Lillafüred, NE Bükk., where Triassic siliciclastic metasedimentary rocks (Hegyestető Formation) contain enrichments, and 2) in a relatively wider territory of SE Bükk (Középszék, Kőris Valley, Felső-Kecskevár), where Triassic siliciclastic metasediments (Felsőtárkány Formation) and metavolcanics (Szinva Metabasalt) are found.

High values were measured in a grab sample from Vesszős Valley, where REE+Y content reach 1890 ppm, Nb 200 ppm, Ta 24 ppm, Zr 3600 ppm; Average concentrations of the above-mentioned elements taking into account all the enriched bodies are REE+Y 317 ppm, Nb 59 ppm, Ta 4 ppm and Zr 534 ppm, respectively, lower values are often the result of peperitic mixing of metavolcanics. The most usual REE mineral is monazite-(Ce), but for individual rock bodies other minerals, like

REE-F-carbonates (parisite-(Ce), bastnäsite-(Ce) or REE-Nb-oxides (aeschynite-(Ce), aeschynite-(Y), as well as their niobian varieties), can be characteristic. Other trace elements which usually occur are zircon and niobian Ti-oxide. The enrichment of the critical elements probably the result of metasomatic processes and connected to an unknown source body.

In addition to these in addition to these relatively more significant values, smaller REE-indications can be found in the Triassic Szentistvánhegy Metavolcanics and in the various Miocene tuffaceous and ignimbrite bodys.

**Szendrő Mts.**

The territory of the Szendrő Mts. was the object of airborne radioactive and magnetic measurements in the 1960s, followed by drillings by MÉV in the vicinity of Irota (Szabó, 2002; Wéber, 1975). Here relatively high non-ferrous metal- and Fe-sulfide content were found, probably in the Irota Formation or in the Szendrő Phyllite. During the CriticEl project, the territory was assigned to further research, originally for metals and PGSs, but based on their initial results REEs are also promising (Földessy and Németh, 2014). In the frame of the project, surface rock and soil sampling, as well as drill core re-sampling were carried out. Among REEs only Ce, La, Y and Sc were measured. The average values are Ce 66, La 34, Y 3, and Sc 13 ppm, respectively, while the maximums are Ce 147, La 75, Y 10 and Sc 70 ppm. Generally higher values were measured on the drill cores. Typical REE-minerals are monazite-(Ce) and various REE-F-carbonates (synchizite, parisite), rarer ones are REE-silicates (allanite, thorite) and REE-Nb-oxides (Czeglédi, 2013). REE-minerals are partly transported to the siliciclastic rocks as detrital components, but later they suffered coupled dissolution- reprecipitation processes due to hydrothermal alterations connected to metamorphism.

Leskóné Majoros (2019, 2021) investigated graphite occurrences in Rakaca Valley, in the vicinity of Rakacaszend. Graphitic samples often contain REE-minerals, which prompted the researchers of the University of Miskolc to explore the REE potential of the area, with the help of radiometric method (Balassa et al., 2024). New samples were collected from Szendrő Phyllite Formation. The highest REE+Y concentration measured by ICP-MS is 690 ppm, but Zr content is also noteworthy with its 360 ppm. The average values are REE+Y 265 and Zr 280 ppm. REEs are incorporated into monazite-(Ce), xenotime-(Y), and rarely to REE-F-carbonates (parisite, synchysite) or cheralite. Probably this occurrence has similar origin that in case of Irota, and presence of REE-minerals partly the result of element mobilization due to the Cretaceous metamorphism.

**Uppony Mts.**

In the Uppony Mts. MÉV conducted uranium prospecting in the 1970s, based on detected airborne radiometry anomaly (Elsholtz, 1973; Elsholtz et al., 1974; Szabó, 2002; Wéber, 1975). The U was found present as trace element in a hydrous Al-phosphate, kingite. Iron ore was historically mined in Uppony Mts. (Pantó, 1954). Later Leskóné Majoros (2019) examine the graphite occurrences in Rágyincs Valley, near Dédestapolcsány, and detected the presence of REE minerals. University of Miskolc are conducting new research in the territory, with radiometric measurements (Balassa et al., 2023, 2024). Analyzed samples are mainly siliciclastic sedimentary rocks, occasionally unconsolidated sediment from the Ordovician – Devonian Tapolcsány Formation. Samples are often (but not exclusively) from former iron ore adits *(Figure 2)*. New samples were analyzed by ICP-MS. Maximum REE+Y concentration is 510 ppm, the average is about 300 ppm. Some other maximum (and average) minor and trace element concentrations: Zr: 285 ppm (163 ppm), U: 28 ppm (12 ppm), V: 2220 ppm (604 ppm), Ba: 3190 ppm (1070 ppm), $P_2O_5$: 1.9% (0.54%), $TiO_2$: 1.8% (0.92%). Based on correlation analysis, V, Ba and U show strong correlation relationships with each other and moderate to strong correlation with HREEs. The REEs are incorporated into monazite-(Ce), xenotime-(Y), and cheralite-huttonite solid solutions. Similarly to Szendrő Mts., presence of the REE minerals is partly the result of sediment supply, but metamorphism led to element mobilization and precipitation of new REE minerals.

***Figure 2.*** *Unconsolidated gamma-active siliciclastic sediment from the Uppony Mts., with the scintillation detector (on the left) and a formerly iron-ore adit (Alsó Mihály adit) (on the right)*

## Úrkút

The Úrkút manganese mineralization is the most significant manganese deposit in the Bakony Mts. In the vicinity of Úrkút, production has been going by open-pit and underground mining since 1925 (Horváth et al., 2014). Rare earth elements in the area were first noticed during a research on the distribution of P content in the 1960's (Grasselly et al., 1988). The most favorable values were found a drillhole U-307, with REE oxide values between 0.09–0.12 t% and on the surface at Csárdahegy with REE oxide values between 0.145 – 0.26 t% (Pálfy et al., 1970).

The appearance of REEs is mainly related to the phosphate minerals. In Eplény and Úrkút there are phosphorus rich fine-grained (2–5 μm) layers in the transition zone between Mn carbonate and Mn-oxide (Polgári et al., 2003). The manganese mineralization was briefly mentioned in relation to its cobalt content (Badawi et al., 2024). The total REE content of the carbonate ore samples varies between 90 and 387 ppm, with an average of 259 ppm and standard deviation of 66 ppm. The Sm, Eu, Gd, Tb and Dy are enriched the mostAccording to the SEM measurements, the correlation of phosphorus and REEs indicates that the phase carrying REEs in the carbonate ore is mainly apatite of biogenic origin.

## Mecsek coal deposits

Among the Hungarian coal basins the Mecsek coals have the highest minor element potential. The main generation period of the Mecsek coal was in the Lower Jurassic, originally in limnic environment, but later the environment was changed to paralic, so the deposits can be divided into a limnic, a mixed and a paralic part. Several programs produced data in the more than fifty years after the first detailed publication of Csalagovits and Vígh-Fejes (1971). A study of 100 samples have been published by Kádas (1985). 66 samples have been taken for assay during the CriticEl program, and assayed by ICP-OES, ICP-MS in two laboratories. The average TREE content of black coals was 647 ppm in Pécs-Vasas, 528 ppm in Nagymányok, 545 ppm in Pécs-Szabolcs. In the last occurrence shales also contain 596 ppm total REE (Horváth, 1014). The average of all samples were 390 ppm TREE, 445 ppm TREE+Y+Sc, 10% of HREE ratio in total REE. The maximum values are 1231 ppm TREE, 1370 ppm TREE+Y+Sc. Research and exploration is recently going on the Nagymányok property. Other associated enrichments of minor elements include Nb, Ta, Zr, Hf, Ga and Ge. The results were evaluated and interpreted in regional context by Püspöki at al. (2018).

## Bauxite deposits

The bauxite minerals that dominate the Hungarian deposits are böhmite, gibbsite and occasionally diaspore. The most common accompanying minerals of the deposits are hematite, goethite, kaolinite, anatase, rutile and quartz (Bárdossy, 1977).

Among the trace elements found in bauxites, mainly Ga, Sc, REE+Y, and the so-called High Field Strength (HFS) elements (U, Th, Nb, Ta) can be of any economic importance.

During the CriticEl project 10 bauxite samples were examined (Szabó et al., 2014). In the case of Halimba samples, SEM observations revealed a diverse mineralogical composition. Several types of terrigenous mineral grains were identified in these, such as zircon, monazite, xenotime, Fe-oxide, anatase and rutile. The size of the grains is around 5–10 μm, their shape varies from angular elongated to rounded grains. Several types of monazite with different rare earth metal content and xenotime grains with REE content were identified. LREEs appeared in monazite, while HREEs were enriched in xenotime.

During SEM examinations of the Nyirád samples zircon appears as an identifiable grain in the raw material, furthermore in some places Fe-oxide in an amorphous form and rarely with a spheroidal-veined, fibrous structure. Independent REE+Y-containing mineral phases were hardly found in the samples. A very small amount of 2–3 μm monazite can be classified here.

Immobile HFS elements during chemical weathering in the studied bauxite samples show small amounts and narrow concentration ranges (Zr: 40–550 ppm, Hf: 1–13 ppm, Nb: 7–51 ppm and Ta: 0.4–3.7 ppm).

Based on the geochemical tests, it can be established that the source rock of the studied bauxites is basic to neutral magmatic rock, or less probably sedimentary rock. The bauxites show a 3–6 times enrichment of total REE+Y elements compared to the modern continental upper crust.

The total REE+Y content of the examined Nyirád, Bakonyoszlop, Gánt, Halimba bauxites varies between 392–788 ppm. The largest TREE concentrations were detected in the Nagyharsány bauxite samples (969–1204 ppm)

## Balaton Highlands

MÁFI has conducted research in the area of the Balatonrendes REE-uranium anomaly formerly investigated by the MÉV (former mining company) at the end of the 1960's.

By gamma spectrometry and dosage measurements at Balatonrendes were located the anomalous zones, where the collected samples discovered that high ΣREE concentration is associated with samples with high U content. The uranium content is around 0.1 wt% and the amount of rare earth metals is also high between 0.04–0.21 wt%.

The total REE+Y contents of the sand samples are 115–222 ppm, these values are close to the average of the earth's crust. Significant enrichment can be detected in limonitic concretions, where four times the average of the earth's crust was measured (683 ppm). The high Y-content of the sample (254 ppm) is particularly noteworthy. According to the main element analysis, this sample contains a significant amount of iron and manganese. This sample also has the highest U (66 ppm) and Th (11.9 ppm) contents. This finding correlates to the MÉV report, as rocks with the highest U content contains the most REE. The U content of iron concretions is generally higher (12.3–66 ppm) than that of sands (2.1–13.4 ppm) and they show enrichment in heavy REEs compared to sands. In addition to radioactive trace elements, As, Mo, Cd are enriched in iron concretions, and Rb, Zr, Nb and Cs in sands.

## Pathfinder radioactive elements for REE enrichments in coals

In earlier coal explorations REE chemical assays were seldom done, meaning that these databases have only small value to obtain direct REE information. However, air-borne gamma ray spectrometry was a customary reconnaissance method. Also, radioactive logs, like natural gamma were regularly measured in coal exploration drillholes. For the CriticEl coal assay data (71 samples) >100 ppm TREE were summarized and correlated with K, Th, U assay values. It was found, that both U and Th data are strongly correlated with TREE content (0.90 and 0.75 coefficients), while K does show weak correlation with TREE (0.45 co-

***Table 2.*** *Selected results of the CriticEl project. Chemical data represent average values of samples with TREE > 130 ppm. The number of the samples considered are given in the second column. (Pzo = Paleozoic, C = Carboniferous, T = Triassic, J = Jurassic, K = Cretaceous, Pg = Paleogene, M = Miocene; LREE: La, Ce, Pr, Nd, Sm, Eu; HREE: Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu)*

| | Number of samples | Age | TREE | TREE+Y+Sc | HREE | HREE% |
|---|---|---|---|---|---|---|
| | | | ppm | ppm | ppm | % |
| Erdőbénye | 1 | M | 205 | 249 | 27 | 13 |
| Gánt | 3 | Pg | 550 | 669 | 61 | 11 |
| Bakonyoszlop | 2 | K | 495 | 586 | 44 | 9 |
| Nyírád | 2 | K | 362 | 386 | 32 | 9 |
| Nagyharsány | 4 | K | 969 | 1204 | 66 | 7 |
| Halimba | 8 | K | 747 | 862 | 69 | 9 |
| Hosszúhetény | 12 | K | 461 | 502 | 30 | 7 |
| Nagymányok | 5 | J | 476 | 539 | 40 | 8 |
| Szászvár | 4 | J | 618 | 684 | 49 | 8 |
| Váralja | 4 | J | 499 | 583 | 53 | 10 |
| Máza | 7 | J | 457 | 517 | 39 | 9 |
| Komló | 4 | J | 386 | 436 | 31 | 8 |
| Pécs-Szabolcs | 18 | J | 448 | 509 | 35 | 8 |
| Pécs-Vasas | 22 | J | 259 | 303 | 28 | 11 |
| Eplény | 3 | J | 333 | 378 | 29 | 9 |
| Úrkút | 89 | J | 325 | 384 | 34 | 10 |
| Nagykovácsi | 2 | T | 620 | 656 | 26 | 4 |
| Rudabánya | 7 | T | 177 | 216 | 19 | 11 |
| Bükkszentkereszt | 13 | T | 170 | 308 | 49 | 32 |
| Szendrőlád | 5 | C | 143 | 188 | 19 | 17 |
| Szakácsi | 4 | C | 195 | 235 | 21 | 11 |
| Irota | 6 | C | 315 | 375 | 32 | 10 |
| Velence hg. | 39 | C | 179 | 244 | 33 | 23 |
| Sopron | 1 | Pzo | 4750 | 4762 | 92 | 2 |

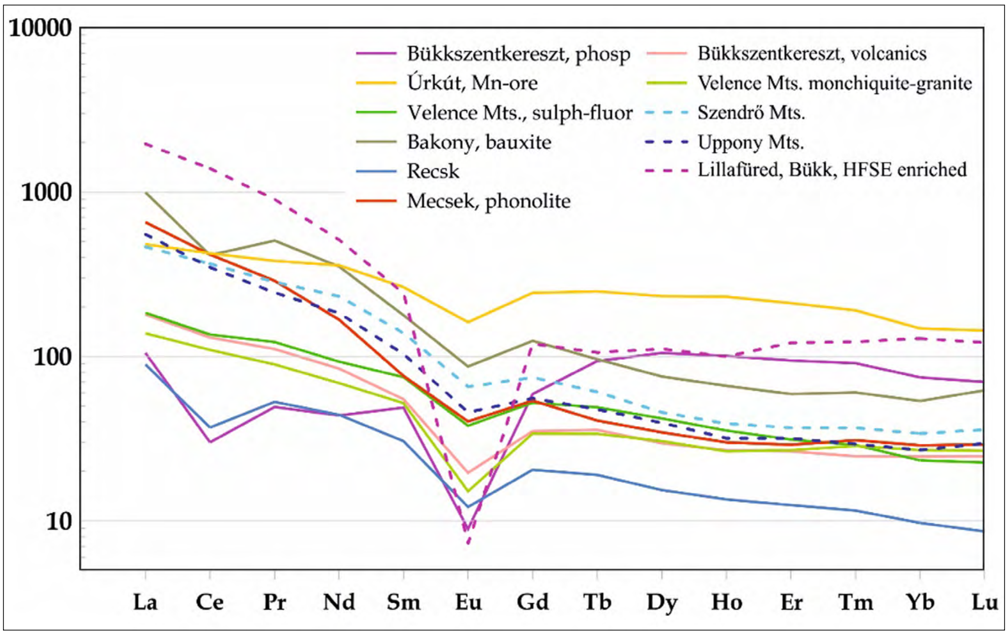


***Figure 3.*** *Chondrite-normalized plots of selected samples studied during the CriticEl, as well as of same new samples (with dashed line). The main aspect of the selection was the high REE content*

efficient). This is a promising early finding to work out an exploration tool revising coal outcrops and coal drillhole logs.

Of course, natural gamma measurements are useful for REE-exploration also in other type of rocks, as it could be seen in the example of Bükk, Uppony, and Szendrő Mts. in this paper.

## Summary and conclusions

REEs are one of the important element groups considered as Critical Raw Materials. In Hungary, the first attempt to make a brief review about REEs was made during the CriticEl project, led by the University of Miskolc. As a part of its activity, the Natural Resources Research and Utilization Special College tries to summarize its previous results and supplement them with new ones, if possible. Average REE concentrations measured during the CriticEl project are summarized in *Table 2*. *Figure 3* compares the REE-characteristics of some samples, which has relatively high REE-concentrations. Among the volcanic deposits, exceptionally high values can also be measured in the Mecsek phonolite and in the oxidized beforsite of Velence Mts. On the other side, sedimentary deposits might be also promising from the point of view of economic utilization. From this group Mecsek coal deposits, Bakony bauxite deposits and Úrkút Mn-deposits can be highlighted. In the future further research of these deposits could provide important results for the evaluation of Hungarian REE-potential.

## References


Babinszki, E., Piros, O., Budai, T., Gyalog, L., Halász, A., Király, E., Harangié Lukács, R., M. Tóth, T. 2023: Magyarország litosztratigráfiai egységeinek leírása I.: Pprekainozoos képződmények / Description of the lithostratigraphic units of Hungary I.: Precainozoic formations. Szabályozott Tevékenységek Felügyeleti Hatósága, Budapest. (in Hungarian)

Balassa, Cs., Kristály, F., Németh, N., 2023: Ritkaföldfém-hordozó ásványok ÉK-magyarországi földtani képződményekben / Rare Eart Element bearing minerals in NE Hungarian geological formations. In: Szabó, N. P., Virág, Z. (eds.), Új Eredmények a Műszaki Föld- és Környezettudományban 2023. Miskolci Egyetem / University of Miskolc Műszaki Föld- és Környezettudományi Kar / Faculty of Earth and Environmental Sciences, Miskolci Egyetem. pp. 209–221. (in Hungarian)

Balassa, Cs., Németh, N., Kristály, F., 2024: Radioaktív anomáliát mutató kőzettestek az Upponyi- és Szendrői-hegységekből / Rock bodies with radioactive anomalies from the Uppony and Szendrő Mts (MTMT). Tert. Quat. STRATA 2, 4–7. (in Hungarian)

Balassa, Cs., Pataky, Cs., Antal, K., Tátrai, Cs., Gyenes, I., Etaraf, H., Földessy, J. 2024: Critical Raw Materials Hungary Data Collection 2. Minor element enrichments in certain sedimentary mineral formations. BÁNYÁSZATI ÉS KOHÁSZATI LAPOK 157, II., 25-31.

Barabás, A., 1957: Jelentés a Bükk hegységben 1956. évben végzett radiológiai kutatásokról / Report on the radiological research carried out in the Bükk Mountains in 1956 (Kézirat / Manuscript No. J–0446). MÉV Adattár / Database. (in Hungarian)

Bárdossy Gy., 2007: A halimbai bauxit-előfordulás / Bauxite occurrence of Halimba. A Magyar Állami Földtani Intézet Alkalmi Kiadványai, 208, pp. 73–119. (in Hungarian)

Barnabás K. 1968: A nyírádi bauxit terület további kutatásának várható eredményessége / Expected effectiveness of further research in the Nyírád bauxite area, Földtani Kutatás, 11(2), pp. 10–16. (in Hungarian)

Biró L., Pál-Molnár E., 2015: A bakonyi primer ooxidos mangánércek nyomelem- és ritkaföldfém- geokémiai vizsgálata / Trace element and rare earth geochemical analysis of primary oxide manganese ores in Bakony, Földtani Közlöny, 145/2, pp. 119-126 (in Hungarian)

Csáki, F., Csáki, Fné, 1973:. Összefoglaló jelentés a bükkszentkereszti kutatási területen 1969-1973 között végzett kutatómunkáról / Summary report on the research work carried out in the Bükkszentkereszt research area between 1969-1973. (Kézirat / Manuscript). Mecsekérc Zrt. Adattár / Database, Kővágószőlős. (in Hungarian)

Csalagovits I., Vígh-Fejes M., 1971: Geokémia – A meddőkőzetek és a kőszén nyomelemei. / Geochemistry – Trace elements of the barren rocks and coals, MÁFI Yearbook 51.2. b, 520-574. (in Hungarian)

Czeglédi, B., 2013: A Gadna-Irota terület kutatási adatainak, geokémiai és geofizikai viszonyainak együttes értékelése / Joint evaluation of the research data, geochemical and geophysical conditions of the Gadna-Irota area. MSc diplomaterv / MSc thesis, Miskolci Egyetem / University of Miskolc. (in Hungarian)

Elsholtz, L., 1973: Összefoglaló jelentés az 1968-69-70. évi kutatásokról az Uppony-hegységben / Summary report for 1968-69-70. on research in the Uppony Mountains (Kézirat / Manuscript No. 07 téma). MÉV Adattár / Database. (in Hungarian)

Elsholtz, L., Selmecziné Antal, P., Selmeczi, B., 1974: Kingit előfordulás Magyarországon, a kingit derivatogramja / Kingite occurrence in Hungary, kingite derivatogram. Földtani Közlöny, 104, 328–335. (in Hungarian)

Fazekas, V., Kósa, L., Selmeczi, B., 1975: Ritkaföldfém ásványosodás a Soproni hegység kristályos paláiban / Rare earth mineralization in the crystalline schists of the Sopron Mountains. Földtani Közlöny, 105, 297–308. (in Hungarian)

Földessy, J., Németh, N., 2014: Ritkaföldfémek a Cserehát néhány földtani képződményében / Rare earth elements in some geological formations from Cserehát in: Szakáll, S. (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monográfia Sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc, pp. 203–210. (in Hungarian)

Goodenough, K., Schilling, J., Jonsson, E., Kalvig, P., Charles, N., Tuduri, J., Deady, E.A., Sadeghi, M., Schiellerup, H., Müller, A., Bertrand, G., Arvanitidis, N., Eliopoulos, D., Shaw, R., Thrane, K., Keulen, N., 2016: Europe's rare earth element resource potential: An overview of REE metallogenetic provinces and their geodynamic setting. Ore Geology Review 72(1), 838–856. https://doi.org/10.1016/j.oregeorev.2015.09.019

Horváth, R., 2014:. Mecseki széntelepekhez kötődő ritkaföldfém anomáliák / Rare earth element anomalies connected to Mecsek coal deposits, in Szakáll, S. (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monográfia Sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc, pp. 159–170. (in Hungarian)

https://edit.elte.hu/xmlui/bitstream/handle/10831/37811/MacsaiCecilia.pdf;jsessionid=23FB18C0AFC6CB929050592613277868?sequence=1

https://library.hungaricana.hu/hu/view/SZAK_ASVA_Kozl_13/?pg=0&layout=s

Jáger, V. &, Molnár, F. 2006: Metasomatic-hydrothermal processes along the contact zone of Lower Cretaceous magmatic sills intruded into Lower Jurassic coal beds at Pécs-Vasas, Mecsek Mts., Hungary. Acta Mineralogica-Petrographica, Abstract Series 5, 50

Jancsek, K., 2023: A ritkaföldfém-bányászat jelene és perspektívái a világban / The present and perspectives of rare earth elements mining in the world. Bányászati és Kohászati Lapok, 156, 16–23.

Juhász E., Polgári M. 1987: A halimbai bauxit az elektron-mikroszondás vizsgálatok tükrében / Halimba bauxite in the light of electron microprobe studies, Magyar Állami Földtani Intézet Évi Jelentése az 1985. évről / Annual Report of the Hungarian State Geological Institute for the year 1985. pp. 261–278. (in Hungarian)

Kádas M. (1985): A mecseki feketekőszén nyomelem vizsgálatának újabb eredményei / Newer results of the research of trace elements from the Mecsek black cole. Földtani Kutatás 26, 81–82. (in Hungarian)

Konrád Gy., Ádám I., Barabás A., Barabás A., Hámos G., Csicsák J., Barabásné Stuhl Á., Csóvári M., Gerzson I., Harsányi L., Lenvai L., Majoros Gy., Máthé Z. 2000: Zárójelentés a magyaroszági uránérc-kutatásról és a Ny-mecseki uránérc-bányászatról (1 CD, szén, bauxit, szulfidos ércek, festékföld, tűzállóagyag, talk, perlit, víz, ritkaföldfém, gipsz-anhidrit, környezetvédelem) / Final report on Hungarian uranium ore exploration and W Mecsek ore mining (1 CD, coal, bauxite, sulfide ores, pigment earth, refractory clay, talc, perlite, water, rare earth metals, gypsum anhydrite, environmental protection)., MÉRCE Bt. Kézirat. Mecsekérc Zrt. Adattár, Kővágószőlős, 457 p. (in Hungarian)

Kovács Z., 1970: Ritkaföldfémek koncentrálódása az oxidos mangánérc átmeneti övezetében / Concentration of rare earth elements in the transition zone of oxidic manganese ore, Földtani Közlöny 100. pp. 91-95 (in Hungarian)

Kubovics, I., Nagy, B., Nagy-Balogh, J., Puskás, Z., 1989: Beryllium and some other rare element contents of acid volcanics (tuffs) and metamorphites in Hungary. Acta Geologica. Hungarica, 21, 219–231.

Leskóné Majoros, L. 2019: Upponyi- és Szendrői-hegységi feketepalákban lévő grafitos anyagok ásvány- és kőzettani vizsgálata, illetve kárpáti kapcsolataik / Mineralogical and petrological examination of graphite materials in the black shales of the Upponyi and Szendrő Mountains, and their Carpathian connections. MSc szakdolgozat / MSc thesis. Miskolci Egyetem / University of Miskolc, Műszaki Földtudományi Kar / Faculty of Earth Sciences and Engineering (in Hungarian)

Leskóné Majoros, L., Leskó, M.Z., Szakáll, S., Kristály, F., 2021: Kristikus ásványok és elemek a Szendrői Fillit Formációban (Szendrói-hegység, ÉK-Magyarország) / Critical minerals and elements in the Szendrő Fillite Formation (Szendrő Mountains, NE Hungary). Multidiszcip. Tudományok, 11, 90–97. (in Hungarian) https://doi.org/10.35925/j.multi.2021.1.9

Mácsai C. 2014: Ritkaföldfémek bauxitból való kinyerésére vonatkozó technológiák összehasonlítása / Comparison of technologies for the extraction of rare earth metals from bauxite. TDK work, ELTE, Budapest (in Hungarian)

Mindszenty A., 2020: A magyarországi bauxitok kutatásának rövid története (1903–2020) / A brief history of bauxite research in Hungary (1903–2020), Földtani Közlöny, 150/4, pp. 529–544. (in Hungarian) https://doi.org/10.23928/foldt.kozl.2020.150.4.529

Nagy, G., Draganits, E., 1999: Occurrence and mineral-chemistry of monazite and rhabdophane in the Lower and Middle Austroalpine tectonic units of the southern Sopron Hills (Austria). Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich, 42, 21–36. https://doi.org/10.1016/S0009-2541(02)00147-X

Nagy, G., Draganits, E., Demény, A., Pantó, G., Árkai, P., 2002: Genesis and transformations of monazite, florencite and rhabdophane during medium grade metamorphism: examples from the Sopron Hills, Eastern Alps. Chem. Geol., Chemistry and Physics of Accessory Minerals: Crystallisation, Transformation and Geochronoloigical Applications 191, 25–46. https://doi.org/10.1016/S0009-2541(02)00147-X

Némedi Varga, Z. (ed.) 1995: A mecseki feketekőszén kutatása és bányaföldtana / Research and mining geology of Mecsek hard coal. Miskolci Egyetem / University of Miskolc, Miskolc. 472 p. (in Hungarian)

Németh N., Baracza M.K., Kristály F., Móricz F., Pethő G., Zajzon N. 2016: Ritkaföldfém- és ritkaelem-dúsulás a Bükk hegység délkeleti részének vulkáni eredetű kőzettesteiben / Rare earth element and rare element enrichment in the volcanic rock bodies of the SE part of the Bükk Mountains. Földtani Közlöny, 146, 11–26. (in Hungarian)

Németh, N., Kristály, F., Balassa, Cs. 2023: Hydrothermal high field strength element enrichment in the Bükk Mts. (NE Hungary). Journal of. Geochemical Exploration, 246. https://doi.org/10.1016/j.gexplo.2023.107159

Pantó, G., 1954: Bányaföldtani felvétel az Upponyi-hegységben / Mining geological survey in the Uppony Mts. Magyar Állami Földtani Intézet Évi Jelentése 1952-ről / Annual Report of the Hungarian State Geological Institute for 1952, 91–111. (in Hungarian)

Pécsi M. 1974: A Budai-hegység geomorfológiai kialakulása, tekintettel hegytípusaira / The geomorphological formation of the Buda Mountains, with regard to its mountain types Földrajzi Értesítő XXIII(2). pp. 181–192. (in Hungarian)

Püspöki Z. (szerk.) (2018): A hazai szénvagyon és hasznosítási lehetőségei / National coal resources and their utilization possibilities. MBFSZ, Budapest, 282 p. (in Hungarian)

Szabó Cs., Mádai V., Márkus I. (2014): Ritkaföldfémek dunántúli bauxitjainkban / Rare Earth Elements in Transdanubian bauxite occurrences. In: Szakáll S. (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monográfia Sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc. 133–160.

Szabó, I., 2002: Az Upponyi- és a Bükk hegységi sugárzóanyag-kutatások története / History of the radioactive material exploration in the Uppony and Bükk Mts. In: Szakáll, S, and Morvai, G. (eds.): Érckutatások Magyarországon a 20. században, Közlemények a Magyarországi Ásványi Nyersanyagok Történetéből / Ore Explorations in Hungary in the 20th Century, Publications from the History of Hungarian Mineral Resources. Miskolci Egyetem / University of Miskolc, Miskolc – Rudabánya. pp. 217–234. (in Hungarian)

Szakáll, S. (ed.) 2014: Ritkaföldfémek magyarországi földtani képződményekben / Rare earth elements in Hungarian geological formations. CriticEl monográfia sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc. 210 p. (in Hungarian)

Szakáll, S., Gyalog, L., Kristály, F., Zajzon, N., Fehér, B. 2014: Ritkaföldfémek a velencei-hegységi granitoidokban és alkali magmas kőzetekben / Rare earth elements in granitoids and alkaline igneous rocks of the Velence Mountains. In: Szakáll (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monográfia Sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc. pp. 67–90. (in Hungarian)

Szakáll, S., Jáger, V., Fehér, B., Zajzon, N. 2014: A mecseki fonolit ritkaföldfém-tartalma és ásványi hordozói / The rare earth element content and mineral carriers of Mecsek phonolite. In: Szakáll (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monograph Series / CriticEl Monográfia Sorozat. Milagrossa Kft., Miskolc. pp. 47–66. (in Hungarian)

Szakáll, S., Morvai, G., (eds.) 2002: Érckutatások Magyarországon a 20. században / Mineral exploration in Hungary in the 20th century, Miskolci Egyetem / University of Miskolc, Miskolc – Rudabánya, 247 p. (in Hungarian)

Török, K., 2020: Multiple fluid migration events and REE+Th mineralisation during Alpine metamorphism in the Sopron mica schist from the Eastern-Alps (Sopron area, Western Hungary). Földtani Közlöny, 150, 45–61. https://doi.org/10.23928/foldt.kozl.2020.150.1.45

Vincze, J., Fazekas, V., Kósa, L., 1996: A fertőrákosi kristályospala összlet urán-tórium-ritkaföldfém és szulfidos ásványosodásai / Uranium-thorium-rare earth and sulphide mineralization of the Fertőrákos crystalline schist assemblage. Földtani Közlöny, 126, 359–415. (in Hungarian)

Wéber, B., 1967: Jelentés a 193 és 195–196a. (Bükkszentkereszt) légi anomáliák földi azonosításáról / Report on 193 and 195–196a. (Bükkszentkereszt) on ground identification of aerial anomalies. (Kézirat / Manuscript No. J–0240.). MÉV Adattár / Database. (in Hungarian)

Wéber, B., 1968: A Bükkszentkereszt környéki anomáliák kutatása / Research of anomalies in the vicinity of Bükkszentkereszt (Kézirat / Manuscript). MÉV Adattár / Database. (in Hungarian)

Wéber, B., 1975: Az urán és a tórium eloszlása az Északi-középhegység földtani képződményeiben a légi-gammaspektrofotometriai mérések alapján / The distribution of uranium and thorium in the geological formations of the Northern Central Mountains based on airborne gamma spectrophotometric measurements. Földtani Közlöny, 105, 309–319. (in Hungarian)

Wéber, B., Csáki, F., 1971: Éves jelentés a Bükkszentkereszt környéki kutatásokról / Annual report on research around Bükkszentkereszt (Kézirat / Manuscript). MÉV Adattár / Database. (in Hungarian)

Wein Gy. 1977: A Budai-hegység tektonikája / Tectonics of the Buda Mts. Magyar Állami Földtani Intézet Alkalmi Kiadványa. 77p. (in Hungarian)

Zajzon, N., Németh, N., Szakáll, S., Gál, P., Kristály, F., Móricz, F. 2014: Ritkaföldfémek a bükkszentkereszti Mn-U-Be geokémiai anomáliában / Rare earth metals in the Bükkszentkereszt Mn-U-Be geochemical anomaly. In Szakáll, S (ed.): Ritkaföldfémek Magyarországi Földtani Képződményekben / Rare earth elements in Hungarian geological formations, CriticEl Monográfia Sorozat / CriticEl Monograph Series. Milagrossa Kft., Miskolc. pp. 91–108. (in Hungarian)