

PhD Theses

Doctoral Program in Earth Sciences

**Geological Environment of the ISL
Uranium Ore Deposits of
Southeastern Transdanubia and
Their Comparative Study**

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1. Scientific Precedents and Targets

The ISL uranium ore deposits represent a type of the sedimentary, sandstone-type uranium mineralization, formed and developed by the syngenetic, diagenetic and epigenetic processes controlled by geochemical – primarily redox – conditions within the host rock. This type of deposits is primarily distinguished from other uranium mineralization types by the exploitation technology: the uranium can be extracted from the porous rock through drill holes, using the so-called in situ leaching (ISL) method.

Uranium exploration in Hungary has a history of more than 50 years. Following to the discovery of the mineralization in the Western Mecsek Hills, in Permian formation (1953), that deposit was explored in a detailed way, then the activity was extended over numerous other, prospective areas of the country. The exploration for ISL deposits started at the beginning of the 80s, just after the accidentally discovery of the Dinnyeberki ore body (1981). The work was focused on the Neogene sedimentary basin around the Mecsek Hills. Within the course of this exploration, several small radiological anomalies and an ore deposit (Southeastern foreland of Mórágý Hills, 1989) were found. According to the precedents above, the choosing Southeastern Transdanubia as target area for my scientific research was self-evident.

There are several conditions needed for forming an ISL uranium ore deposit: 1) presence of permeable beds, predominantly sand; 2) source rock with higher than average uranium content on the erosional area; 3) significant hydraulic pressure head between the infiltration area of groundwater and the zone of uranium mineralization; 4) presence of considerable amount of organic matter in the host rock; 5) arid or semiarid climate, providing water of high oxygen content for infiltration, thanks to the little vegetation; and 6) long enough persistence of the previous conditions. All of these conditions have to be met for the development of an ore deposit.

The above conditions indicate clearly that the sedimentary, facies, tectonic, palaeogeographical and geochemical circumstances, the geological history of an area – shortly the geological environment – basically determine the forming of ISL deposits. No successful exploration can be performed on a given area without knowing them. Therefore I considered the geological modeling of the uranium deposits of Southeastern Transdanubia as my first objective. Of course, I relied upon the plenty of

exploration precedents (primarily the works of CHIKÁN, G., HÁMOR, G., JÁMBOR, Á., SZEDERKÉNYI, T., VÁRHEGYI, A.), but especially the information acquired, but not really processed in the course of the exploration of the ISL deposits had to be interpreted and fitted into the geological model by myself.

Although all of the known uranium mineralizations of Southeast Transdanubia are sedimentary deposits, there are significant differences between the mineralizations developed in the Permian of the Western Mecsek Hills, the Miocene of Dinnyeberki and the Pannonian s.l. of the southeastern foreland of the Mórág Hills. My objective was to find those common features through studying the differences and similarities that can help the future explorations.

The exploration of uranium ore deposits and the applied methods have very plentiful literature going back for decades. In addition to the classic methods (airborne and ground gamma-ray survey, geochemical sampling and mapping, drilling, etc.), a new method was developed and used in Hungary called Complex Deep Radiological Exploration (CDRE) which was – according to its name – a complex exploration method, providing a relatively simple and fast way to acquire various (lithological, hydrogeological, radiological) information from a large area to determine its uranium potential. I targeted to evaluate the results and suitability of this method, based on the experience gained in practice.

2. Research Methods

The applied research methods can be categorized as follows:

1. data acquisition,

2. data processing according to the direct objectives of the thesis.

The primary, field data acquisition was done mainly during the uranium exploration of the 80s (Mecsek Ore Mining Co.), completed by the restarted exploration jobs from 2007 (WildHorse Energy). I took part in the field works of both exploration phases.

The main method of prospective and initial phase explorations was the Complex Deep Radiological Exploration developed by the Mecsek Ore Mining Co., comprising the exploration of the selected area with network arranged, 50-100 m deep PCD drilling holes. The drillings were lithologically logged and complex geophysical logging, alpha trace detector and radiohydrogeological tests were performed in the holes. Based on the

results obtained this way, and taking into account the theoretical and prognostic considerations the target areas for more detailed exploration were selected.

The data from the shallow drilling network of the Complex Deep Radiological Exploration were completed by the so-called “stanchion drillings” that were drill holes penetrating through the Neogene basins around the Mecsek Hills down to the pre-Cenozoic basement, drilled with full coring. Their primary target was to reveal the geological structure and history of the area, which is essential for the successful uranium exploration, as I discussed above. With other words, while the shallow drillings focused primarily on the finding of radiological anomalies, the stanchion drillings rather on the establishment of geological background needed for the interpretation of anomalies.

The preliminary and detailed phase exploration of the ISL uranium deposits consisted of the reduction of the drilling network spacing, even to 25 m drill hole distance. Such a detailed exploration was done only in the southeastern foreland of the Mórágý Hills (Bátaszék ore deposit) and on the territory of the Dinnyeberki ore body.

The data processing used for the direct objectives of the thesis comprises the following elements:

- Sedimentological studies: Grain size distribution analyses of drill core samples and the processing of results according to the method by VISHNER, G. S. (1969); heavy mineral tests; sedimentological interpretation of macroscopic lithological observations.
- Stratigraphic revision and classification: Although the age of the studied Neogene formations had been pretty well-known before my work and their lithostratigraphical classification also had been done, the new data made their revision necessary. For this job, I used the results of paleontological studies, radiometric age of volcanic tuffs and the lithological correlation of formations.
- Tectonic analysis: I defined the important elements and events of the tectonic evolution of the area during the Neogene period based on professional papers and literature.
- Paleogeographical modeling and defining the geological history: I built the paleogeographical model of the studied areas of Neogene sedimentation for different geological periods, based on the data processed from sedimentological, stratigraphical and tectonic points of view. Through the modeling of the paleogeography of successive geological periods, finally the Neogene evolution of the studied areas became clear, representing the summary and conclusion of geological analyses.

- Analysis of mineralogical and geochemical parameters of the ISL uranium mineralizations: Laboratory tests of drill core samples, interpretation of results (U and Ra content, radioactive equilibrium; mineral composition; trace element composition); definition of redox conditions.
- Modeling the mineralization processes: Analysis of the mobilization, migration and accumulation of uranium within the frame defined by the geological structure and history of the studied areas.
- Comparative evaluation: Studying the similarities and differences of ore deposits, revealing their reasons.

3. Summary of Results

1. I ascertained that the age of the terrestrial, clastic sedimentary formations of the Cenozoic bed sequence in the Western Mecsek Hills is predominantly Miocene, and not Palaeogene or Oligo-Miocene, as it had been suggested by some palynological studies. This is primarily based on the petrographical studies and age determination tests of the acidic volcanic tuffs interbedding the sedimentary rocks, conducted by MÁTHÉ, Z. and on the interpretation of their results. I explained the presence of fossils older than Miocene age in the rocks through re-deposition. Formations older than Miocene occur only on the territory of the Mecsekalja Dislocation Zone.
2. Through the study of the so-called stanchion drillings made for the exploration of the ISL uranium ore deposits (drill holes going down to the pre-Cenozoic basement) I have proved that the Miocene terrestrial sedimentation lasted longer on the territory of the Western Mecsek Hills as it had been assumed previously. This is primarily based on also the interpretation of the results of tuff studies and the comparative analysis of drill hole findings. According to the previous interpretation, the terrestrial sedimentation was limited to the Eggenburgian and Ottngian, and on a small area also to the Karpathian ages on the territory of the Western Mecsek Hills, but I revealed that it lasted till the middle of the Badenian age on some parts, while on other parts the starting of sedimentation happened only in the Karpathian age.
3. I ascertained that the deposition of the Komló Member of the Budafa Formation – the so-called “clay marl with fish scales” – started already at the beginning of the Ottngian age to all probability, unlike the

previously accepted opinion that it was limited to the Karpathian age. This is based on the fact that the thickness of the Komló Member in drill holes significantly exceeds the previously known one, and the position of volcanic tuffs within the member makes probable the sedimentation during the Ottnangian age.

4. According to the previous two establishments I propose to re-classify the terrestrial-alluvial sediments of the Western Mecsek Hills currently in the Komló Member to the Szászvár Formation, the Komló Member should remain as it was originally defined as a succession of clay marl, silt and sand, deposited under lagoonal environment.
5. I revealed that the delta facies sediments have much bigger importance within the Miocene beds of the Western Mecsek Hills than they had been considered before. This sedimentary environment predominates the northern part of the territory, around the villages Ibafa and Horváthertelend, especially within the upper part of the bed sequence. This was proven by the brackish-water interbeddings with mollusks any the sedimentological study of the rocks.
6. I ascertained through making geological sections and thickness maps that the Miocene facies zones – from the terrestrial-alluvial environment through the delta area to the euxinic lagoon, finally normal marine environment – clearly interfinger each other. Although the heteropy of the Miocene formations in the Mecsek Hills had been mentioned several times before, it hadn't been taken into account in practice, and there had been no precise image about the place and way of interfingering.
7. Taking into account the previous statements I developed the paleogeographical model and evolution history of the Miocene sedimentation in the Western Mecsek Hills, containing numerous changes and refinement compared to the previous models. I clarified the position and temporal changes of Miocene facies zones, and the changes of the material and morphology of the areas of erosion. I ascertained that the most important paleogeographical features of the area during the Miocene period were the area of erosion on the south, the main detrital transportation channel along the Szentlőrinc-Bükkösd-Horváthertelend line, the delta prograding into the sea on the north and the brackish-water bay of euxinic character separated from the sea by the river delta. This arrangement existed for a long period during the Ottnangian and Karpathian ages, until the detritus transport decreased by the Badenian age, the delta became smaller and the bay opened.

8. I revised and completed the theories of the development of the Dinnyeberki uranium ore deposit, assuming a complex, multi-phase, physical and chemical re-deposition of uranium and the rearrangement of the mineralization via remobilization. I demonstrated the still existing impacts of the test leaching in 1988 with the study of the latest control drill hole, that are shown by the slow, vertical uranium migration.
9. Through the processing of the information from the drill holes completed in 1988-89-ben I cleared up the bed sequence of the Neogene basin and the structure of the pre-Cenozoic basement in the southeastern foreland of the Mórágý Hills, between the granite hills and the Máriakéménd-Bár Range. On this area Mecsek-type, Mesozoic formations build up the basement, while the Neogene, initially terrestrial, predominantly coarse clastic sedimentation started from the Upper Karpathian age. This is overlain by Badenian brackish water marl, clay marl and lignite seams. During the Upper Badenian, calcareous clastic sediments belonging to the Leitha beds deposited under normal salinity marine conditions. The rocks of the Sarmatian stage are very various, the most common ones are the sand, marl, limestone and oolite. The Lower Pannonian s.l. is characterized by lagoonal clay marl, while the Upper Pannonian s.l. by near-shore sand and open lacustrine fine-grained sand, clay and silt. The bed sequence is closed by Lower Pleistocene red clay, Upper Pleistocene loess and Holocene alluvial sediments.
10. I established the paleogeographical model and the evolution history of the southeastern foreland of the Mórágý Hills, for different periods of the Neogene time. In the basin opened to the southwest, while bordered by granitic erosion area on the north and by calcareous one on the south, paralic swamp environment developed with lignite deposition and volcanic tuff fall, following the built up of alluvial fans. This was followed by alluvial sedimentation in the middle of the Badenian age, after a regression period, which is overlain by normal salinity marine, shallow water deposition as a result of transgression. During the Sarmatian age, the so-called Bátaszék Basin became separated from the main basin on the northeast and was an erosion area until the end of the Lower Pannonian s.l. On the other parts of the basin the Sarmatian stage is characterized by brackish water, then for a short period hypersaline sedimentation environment. The Lower Pannonian s.l. was predominated by lagoon facies, replaced by interfingering near-shore and off-shore environments during the Upper Pannonian s.l. age. By that time the Bátaszék Basin was covered by

- water again, in the beginning as a bay, later as a channel with a small island on the south of it, finally became fully a part of the main basin.
11. I studied the Upper Pannonian s.l. beds of the northeastern protrusion of the Neogene basin called Báticasék Basin in more detailed way. I defined the changes of the one-time sedimentation environment from the alluvial facies through the delta environment to the near-shore, shallow water, finally open lacustrine facies.
 12. I evaluated the layer oxidization phenomena within the Upper Pannonian s.l. beds and the connected uranium mobilization. Based on the natural gamma-ray log and laboratory sample tests of the exploration drill holes I ascertained that the uranium mineralization developed firstly at the end of the layer oxidization zone as roll-front type deposit, while secondly behind the redox front, on the basis of the oxidized zone, on the boundary of sediments of high organic matter content. There is a clear correlation between the basement level of the Upper Pannonian s.l. formations, the morphology of the basement and the depth and intensity of mineralization. The mineralization is very young, hasn't reached the radioactive equilibrium status yet, its formation and rearrangement still goes on. It is connected strongly, although not exclusively to the Upper Pannonian s.l. alluvial facies.
 13. Based on the above findings I completed the model of the development of the Báticasék uranium mineralization. The rainwater containing oxygen and carbon dioxide infiltrate on the elevated area of the Mórágý Hills, and enter into the Neogene sedimentary basin in the deep zones, where they oxidize the originally reduced rocks. The oxidative water mobilizes the uranium primarily from the upper weathered zone and tectonic zones of the granite, secondarily from the Upper Pannonian s.l. sediments of granite clast material. Within the zone where the oxidization capacity of the groundwater comes to its end, the uranium becomes reduced and precipitates. The lignite-bearing beds rich in organic matter in the bottom of the Upper Pannonian s.l. facilitate the reducing process.
 14. I ascertained through the comparison of the ISL uranium ore deposits of Southeastern Transdanubia and the Permian uranium ore deposit in the Western Mecsek Hills that the sedimentary deposit type is strongly connected to the alluvial facies host rocks. Its reason is firstly the high permeability of the usually coarse-grained, clastic rocks of the alluvial deposits, facilitating the migration of the dissolved uranium, secondly the high organic matter content of the flood plain and swamp deposits being always present within the alluvial sediments. The proximity of granitic rocks as uranium sources contributed in all of the uranium

mineralizations of the region, including the Western Mecsek Hills deposit. Based on these findings, the sedimentological studies, facies analyses and the developing of an appropriate paleogeographical model – including the areas of erosion for the one-time sediment accumulation territories – have crucial importance during the exploration of new uranium ore deposits.

15. I found within the course of the evaluation of the so-called Complex Deep Radiological Exploration (CDRE) developed by the Mecsek Ore Mining Co. for the exploration of ISL uranium ore deposits that this was an original and mature method, proving its usefulness in the practice. The up-to-date, computerized processing of its data could produce additional, new results.

4. Opportunities to Utilize the Results

The subject of the thesis comes from the direct, practical geology, from the industrial mineral exploration, defining immediately the first utilization option of the results. These explorations would become easier on the one hand by the geological modeling of some Neogene basins of Southeastern Transdanubia, on the other hand by the definition of the local features of the ISL-type uranium mineralization. The uranium ore, as energy source commodity has become into the focus of interest worldwide during the last years, since the nuclear energy can be an answer for the global heating challenge.

Even if there will be no uranium exploration and mining in the region in the future, the results will be able to be used for the potential environmental tasks in connection with the ore deposits. The better understanding of geological set-up can assist in the exploration of other minerals. Last, but not least, the results of my work can contribute to the further scientific research regarding the Neogene of southeastern Transdanubia.

5. List of Publications in Connection with the Subject of Thesis

Papers:

- [1] BARABÁS, A. 1992: *Results of the prospection for ISL uranium ore deposits in the Southeastern foreland of the Mórágý Hills (SW-Hungary)*. Acta Geol. Hun. vol. 35/1, pp. 59-82.
- [2] BARABÁS, A. – LENNERT, J. – HUM, L. – SZÓNOKY, M. 1992: *A Mórágý-rög délkeleti előtere felső-pannóniai képződményeinek fejlődéstörténete és Mollusca faunája*. Ősl. Viták 38, pp. 21-26. (*Geological history and mollusk fauna of the Upper Pannonian formations of the southeastern foreland of the Mórágý Hills*. – In Hungarian.)
- [3] BARABÁS, A. 2001: *A Kovácsszénájai-Füstös-lik földtani környezete (Baranya megye)*. Folia Comloensis, Tom. 10, pp. 21-28. (*Geological environment of the Füstös-lik cave at Kovácsszénája*. – In Hungarian.)
- [4] BARABÁS, A. – KONRÁD, GY. 2001: *A magyarországi uránércutatósról és a nyugat-mecseki uránércbányászatról szóló zárójelentés*. Bányászati és Kohászati Lapok, Bányászat. 134/4., pp. 212-219. (*Summary report on the uranium exploration in Hungary and on the uranium ore mining in the Western Mecsek Hills*. – In Hungarian.)
- [5] BARABÁS, A. – KONRÁD, GY. 2008: *A mecseki kőszén és uránérc bányászatának múltja és lehetséges jövője*. Földrajzi Közlemények 132. I. pp. 3-19. (*History and potential future of the mining of coal and uranium ore in the Mecsek Hills*. – In Hungarian.)
- [6] BARABÁS, A. – BALOGH, Z. – MÁZIK, J. 2008: *Uránérctelepek kutatása a Mórágýi-hegység délkeleti előterében*. Bányászati és Kohászati Lapok, Bányászat, 141/6., pp. 2-9. (*Exploration for uranium ore deposits in the southeastern foreland of the Mórágý Hills*. – In Hungarian.)
- [7] BARABÁS, A. 2009: *Historia górnictwa węgla kamiennego i uranu terenie gór Mecsek (Południowe Węgry)*. A „Dziedztwo i historia górnictwa oraz wykorzystanie pozostałości dawnych robót górnictwowych” c. konferencia kiadványa, Tom 2, pp. 17-29. (*History of coal and uranium ore mining in the Mecsek Hills [South Hungary]*). – In Polish.

- [8] BARABÁS, A. 2009: *Dinnyeberki uranium ore deposit – new exploration results and current status*. Modern Geográfia, 2009. 2. szám.

Presentations:

- [1] BARABÁS, A.: *Újabb adatok a Mórággyi-begység DK-i előterének földtani felépítéséhez. (New data to the geology of the SE foreland of the Mórággy Hills.)* Presented on 20th February 1990, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian.
- [2] BARABÁS, A.: *Hidrogenitikus uránércesedés a Bátaszéki környéki pannóniai képződményekben. (ISL uranium ore deposit in the Pannonian formations at Bátaszék.)* Presented on 28th May 1990, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian.
- [3] BARABÁS, A.: *Az ISL-uránérctelepek kutatásának eredményei a Mórággyi-begység délkeleti előterében. (Results of the exploration for ISL uranium ore deposits in the southeastern foreland of Mórággy Hills.)* Presented on 22nd September 1990, in Pécs, on the Mecsek conference of the Hungarian Geological Society, in Hungarian.
- [4] BARABÁS, A. – CSICSÁK, J. – MÁTHÉ, Z.: *Újabb adatok a Ny-mecseki miocén ismeretéhez. (New data to the understanding of the Miocene of the W-Mecsek Hills.)* Presented on 22nd September 1990, in Pécs, on the Mecsek conference of the Hungarian Geological Society, in Hungarian. Presented by: A. Barabás.
- [5] BARABÁS, A. – MAGYAR, I. – SZÓNOKY, M.: *A mórággyi rög DK-i előtere Balaton emeletbeli képződményeinek üledékföldtani és biosztratigráfiai vizsgálata. (Sedimentological and biostratigraphical study of the Balaton stage formations in the SE foreland of the Mórággy Hills.)* Presented on 13th November 1990, in Szeged, on the session of the Great Plain Group of the Hungarian Geological Society, in Hungarian. Presented by: all three authors.
- [6] BARABÁS, A. – CSICSÁK, J.: *A Ny-mecseki miocén kutatásának eredményei. (Results of the exploration of the Miocene in the W-Mecsek Hills.)* Presented on 22nd September 1992, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian. Presented by: A. Barabás.

- [7] BARABÁS, A. – MÁTHÉ, Z.: *A Horvátbertelend-1. fúrás neogén alatti képződményei.* (The formations below the Neogene beds in the drill hole Horvátbertelend-1.) Presented on 17th November 1992, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian. Presented by: both authors.
- [8] BARABÁS, A. – VÁRHEGYI, A.: *A Délkelet-Dunántúl bázaltos földtani kutatásának eredményei.* (Results of the network geological exploration of Southeastern Transdanubia.) Presented on 17th November 1992, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian. Presented by: A. Barabás.
- [9] BARABÁS, A. – MÁTHÉ, Z. – ÁRVA-SOÓS, E.: *A nyugat-mecseki neogén rétegösszetétel kutatásának újabb eredményei, különös tekintettel a vulkáni tufák vizsgálatára.* (New results of the exploration of the Neogene beds in the Western Mecsek Hills, with special regard to the study of volcanic tuffs.) Presented on 2nd April 1996, in Debrecen, on the session of the Great Plain Group of the Hungarian Geological Society, in Hungarian. Presented by: all three authors.
- [10] ÁRVA-SOÓS, E. – BARABÁS, A. – MÁTHÉ, Z.: *A Nyugat-Mecsek neogén vulkanizmusa.* (Neogene volcanism of the Western Mecsek Hills.) Presented on 23rd November 1999, in Pécs, on the session of the South Transdanubian Group of the Hungarian Geological Society, in Hungarian. Presented by: Z. Máthé.
- [11] BARABÁS, A.: *Kirándulásvezető előadások a Magyarhoni Földtani Társulat mecseki neogén terepbejárásán.* (Guiding presentations on the excursion for the studying the Neogene of the Mecsek Hills, organized by the Hungarian Geological Society.) 19th March 2005, in Hungarian.
- [12] BARABÁS, A.: *A WildHorse Energy uránérc-kutatási projektjei Magyarországon.* (Uranium ore exploration projects of WildHorse Energy in Hungary.) Presented on 3rd September 2007, in Pécs, on the conference titled “Uranium ore exploration and mining – international and Hungarian processes”, in Hungarian.
- [13] BARABÁS, A.: *A bátaszéki terület kutatása.* (Exploration of the Bátaszék area.) Presented on 3rd September 2007, in Pécs, on the conference titled “Uranium ore exploration and mining – international and Hungarian processes”, in Hungarian.
- [14] PALLÓSI, J. – MÁTHÉ, Z. – BARABÁS, A.: *Röntgenfluoreszcenciás elemzés az uránkutatásban.* (X-ray fluorescent analysis in the uranium exploration.)

Presented on 30th June 2008, in Nyíregyháza, on the conference titled “51st Hungarian Spectrochemical Conference”, in Hungarian. Presented by: J. Pallósi.

- [15] BARABÁS, A.: *A WildHorse Energy uránérc-kutatási projektjei Magyarországon. (Uranium ore exploration projects of WildHorse Energy in Hungary.)* Presented on 10th March 2009, in Tapolca, on the session of the Hungarian National Mining and Metallurgical Society, in Hungarian.
- [16] BARABÁS, A.: *Coal and uranium ore mining in the Mecsek Mts.* Presented on 22nd April 2009, in Łądek Zdrój (Poland) on the conference titled “Dziedzictwo i historia górnictwa oraz wykorzystanie pozostałości dawnych robót górniczych”.
- [17] BARABÁS, A.: *Uránérc-bányászati lehetőségek Magyarországon. (Uranium ore mining opportunities in Hungary.)* Presented on 14th May 2009, in Budapest, on the conference titled “Day of the Hungarian Engineers”, in Hungarian.