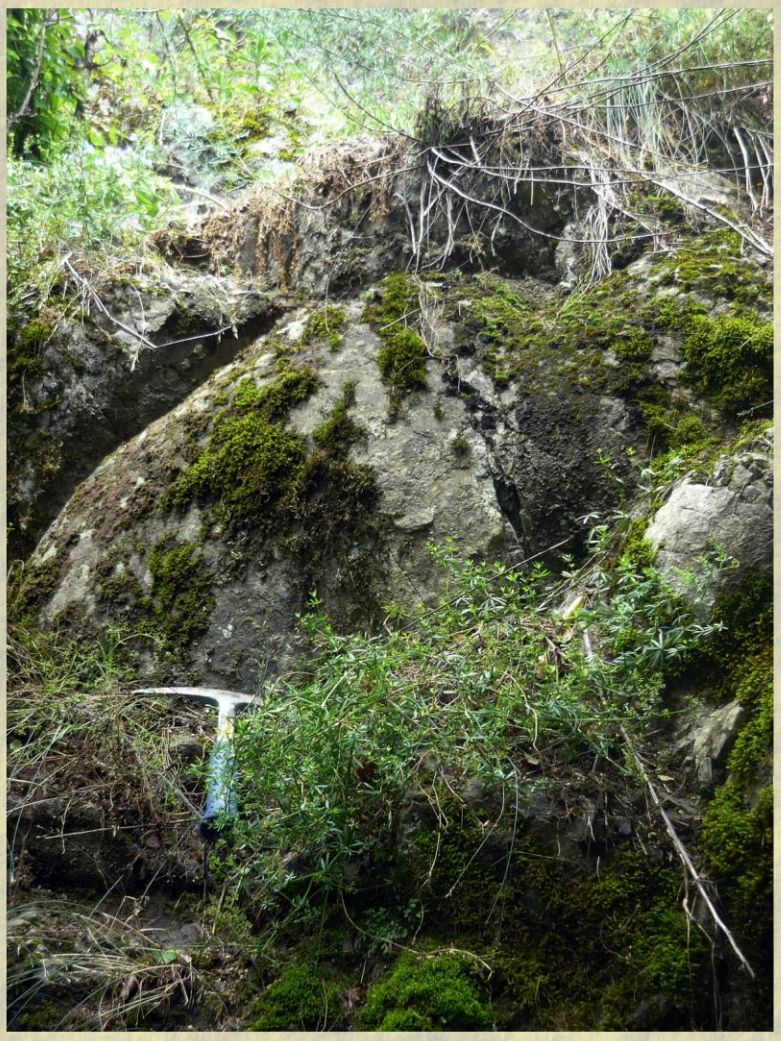
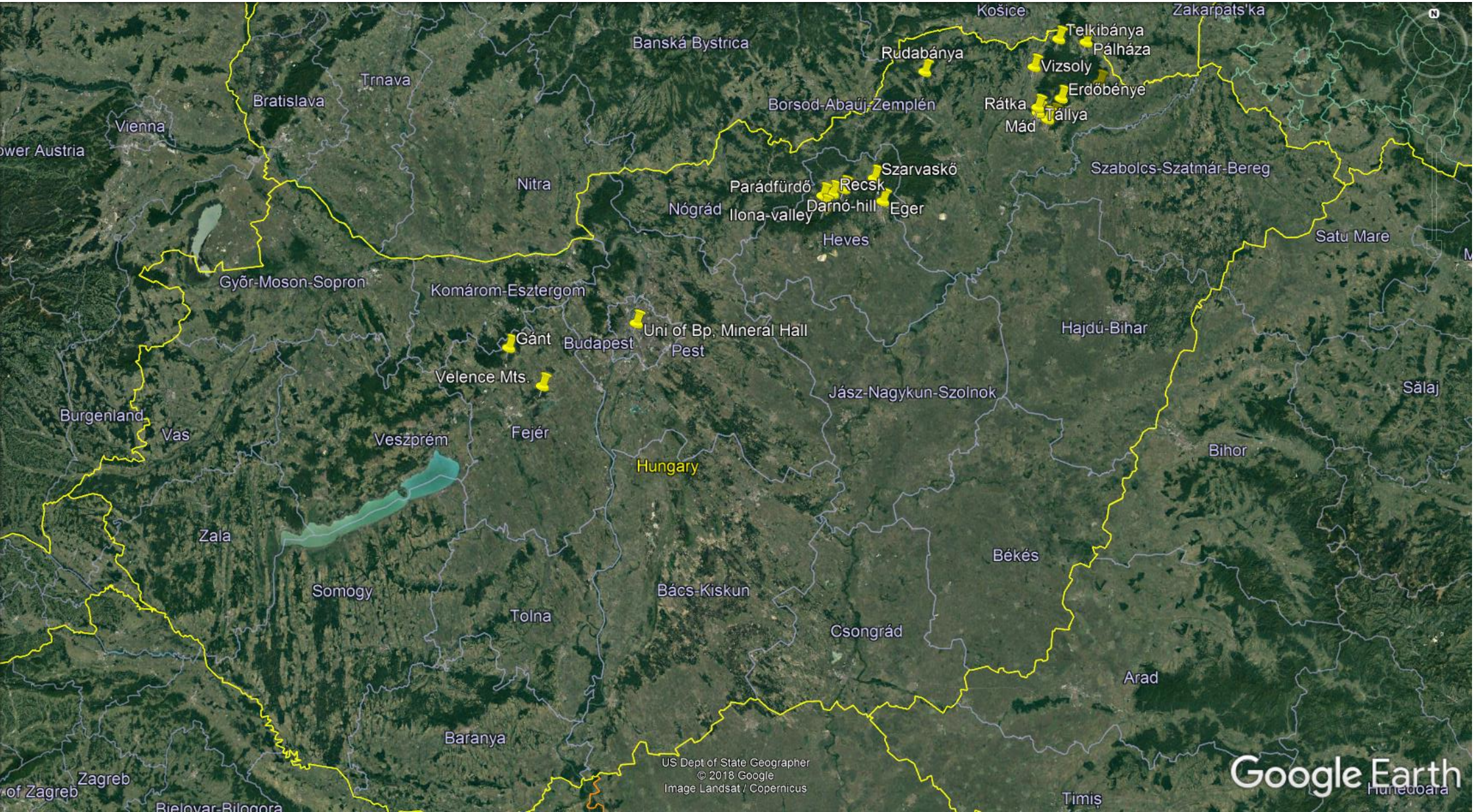
Ore geology field trip in central and NE Hungary



26-30. March 2018

Guided by Ferenc Molnár, Geological Survey of Finland


Košice
Zakarpats'ka
Telkibánya
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Banská Bystrica
Rudabánya
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Bratislava
Borsod-Abaúj-Zemplén
Rátka
Tállya
Vienna
Mád
Szarvaskő
Szabolcs-Szatmár-Bereg
Nitra
Parádfürdő
Recsk
Darnó-hill
Eger
Nógrád
Ilona-valley
Heves
Satu Mare
Győr-Moson-Sopron
Komárom-Esztergom
Uni of Bp. Mineral Hall
Gánt
Budapest
Pest
Hajdú-Bihar
Velence Mts.
Jász-Nagykun-Szolnok
Sălaj
Burgenland
Vas
Veszprém
Fejér
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Ore geology field trip in central and NE Hungary

Edited by

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Program

Monday, 26. March, 2018

- Greetings and an introductory lecture from Ferenc Molnár in the room 00.523 (Mauritz room), Eötvös Loránd University (ELTE) building "C", 9:00 am
- Visiting the Mineral and Rock Collection at the ELTE
- Field Stop 1. Gánt
- Field Stop 2. Velence Mountains
    - 2.1. Nadap, andesite quarry
    - 2.2. Zsidó Hill Quarry

Tuesday, 27. March, 2018

- Departure: Eötvös Loránd University building "C" North Entrance, car park, 7:00 am
- Field Stop 3. Recsk
    - 3.1. Parádfürdő, Ilona-völgy. Natural outcrop (called "Timsós") of a Au-bearing hydrothermal breccia dyke
    - 3.2. Parádfürdő, Egyezség adit
- Lunch in the Hangulat Restaurant, Recsk
- Field Stop 4. Darnó and Szarvaskő Unit
    - 4.1. Nagy-Rézoldal, Darnó
    - 4.2. Tóbérc Quarry, Szarvaskő
    - (4.5. Várhegy, Szarvaskő, if we have time)
- Eger

Wednesday, 28. March, 2018

- Breakfast: 8: am
- Departure: 9:00 am
- Sightseeing in Eger
- Field Stop 5. Rudabánya
- Dinner in Telkibánya: 6:00 pm
- Presentation by Ferenc Molnár: Metallogeny of the Tertiary volcanic arc of Hungary and introduction to the epithermal system of the Tokaj Mts.

Thursday, 29. March 2018

- Breakfast: 7:30 am
- Departure: 8:30 am
- Field Stop 9. Pálháza, perlite quarry
- Lunch in the Tölgyfa Restaurant, Pálháza
- Sárospatak, Rákóczi's castle, sightseeing
- Erdőbénye, Ligetmajor bentonite and diatomite mine
- Dinner in Telkibánya: 6:00 pm

Friday, 30. March 2018

- Breakfast: 7:30 am
- Departure: 8:30 am
- Field Stop 8. Telkibánya, Király Hill
- Field Stop 4. Vizsoly, abandoned ignimbrite quarry
- Field Stop 6. Mád, Király Hill, abandoned kaolinite quarry
- Field Stop 7. Mád, Kerektölgyes quarry, clay and siliceous bed deposit
- Arrive back to Budapest at around 7:30 pm

Introduction: Metallogeny of Paleogene and Neogene volcanic arcs in Hungary

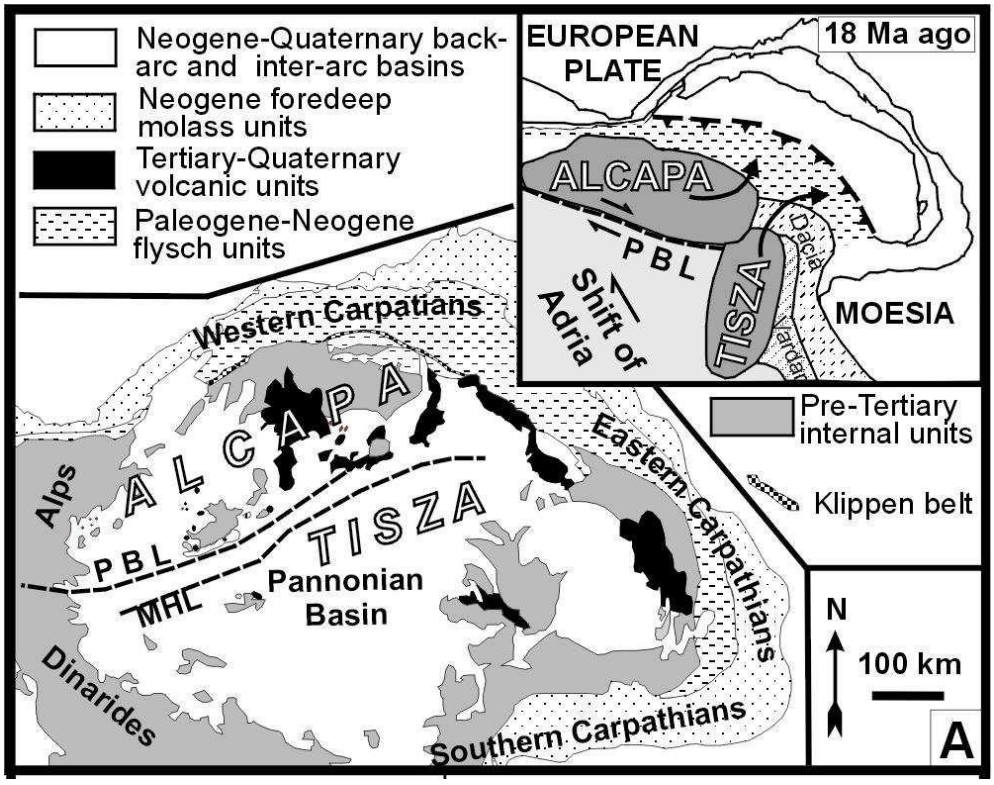
Ferenc Molnár in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

Tertiary evolution and volcanism of Hungary

The present day geological setting of Hungary is dominated by the Pannonian Basin (PB) located in the back-arc zone of the oblique subduction-collision system of the Carpathians (Fig. 1A). The basement of PB consists of two major composite terranes with contrasting Triassic-Middle Cretaceous sedimentary sequences. They are separated by the Mid-Hungarian Line (MHL) and Periadriatic-Balaton Line (PBL) strike slip faults (Fig. 1B). ALCAPA in the north includes the Transdanubian Unit (TU) with Mesozoic comparable with the Southern Alps, whereas TISZA in the south is characterised by Mesozoic sequences deposited in the northern (European) margin of the Neo-Tethys ocean (Csontos 1995; Haas et al, 1999). The strongly tectonised zone between MHL and PBL also contains blocks of Dinaridic origin (i.e. Bükkium, Fig. 1B). The pre-Tertiary continental units had been juxtaposed along MHL during the Late Oligocene and Miocene as a result of collision between Africa (Adriatic plate) and Europe. TU was located between the East- ern and the Southern Alps at about 30 Ma ago; it has been dis-placed and rotated eastward along PBL in the order of 400 to 500 km as part of ALCAPA (Kázmér & Kovács 1985; Csontos 1995). The 'continental escape' of ALCAPA and TISZA from the Alpean colli- sion zone initiated the south-southeastward oriented Carpathian subduction and collision between the northeastern and eastern margins of escaping micro continents and Europe (Fig. 1A, 1B).

The Hungarian Paleogene Volcanic Arc (HPVA) is a 300 km long and 30-50 km wide NE-SW trending belt in TU along PBL (Fig. 1B). Intrusive-vocanic complexes crop out near Recsk and in the Velence Mts., but they are covered in the Zala Basin. Other pyroclastic deposits are also known from drillings. Basaltic-andesite, andesite, dacite and diorite of intrusive-volcanic complexes have medium- to high-K calk-alkaline character. REE-patterns, Sr-, Nd-Sm- and Pb-isotope ratios are compatible with subduction-related origin (Benedek, 2002). Biostratigraphy and K-Ar age dating (44-27 Ma) indicate that magmatism took place in Upper Eocene - Lower Oligocene (Balogh & Pécskay, 2000). HPVA can be correlated with the post-syncollisional Paleogene igneous belt along the Periadriatic Lineament in the Alps and Paleogene volcanic-intrusive units in the northwestern part of the Sava-Vardar belt (Benedek 2002, Pamic et al., 2002).

Exposures of the Hungarian Neogene Volcanic Arc (HNVA) consist of intermediate- acidic medium- to high-K calc-alkaline volcanic units of Miocene age. The major units (Börzsöny Mts., Mátra Mts. and Tokaj Mts.) form an approximately 250 km long, E-W oriented belt along the northern margin of PB (Fig. 1C). HNVA is a part of the subduction- related Neogene-Quaternary Carpathian Volcanic Arc (Fig. 1A). Units of HNVA are situated on strike-slip fault duplexes that were active during the Carpathian continent-continent collision resulting in development of zones of crustal extension that host to volcanic complexes (Drew *et al.,* 1999). Mineraliza-tion in these volcanic units occurs in association with differentiated (andesite + dacite ± rhyolite) stages of the volcanic evolution that were followed by barren, late stage andesite eruptions. Geochemical features of these volcanic units most probably reflect contamination of upper crust rocks in mantle derived melts with compositions that had already been modified by the subducted slab (Szabó *et al.,* 1992).



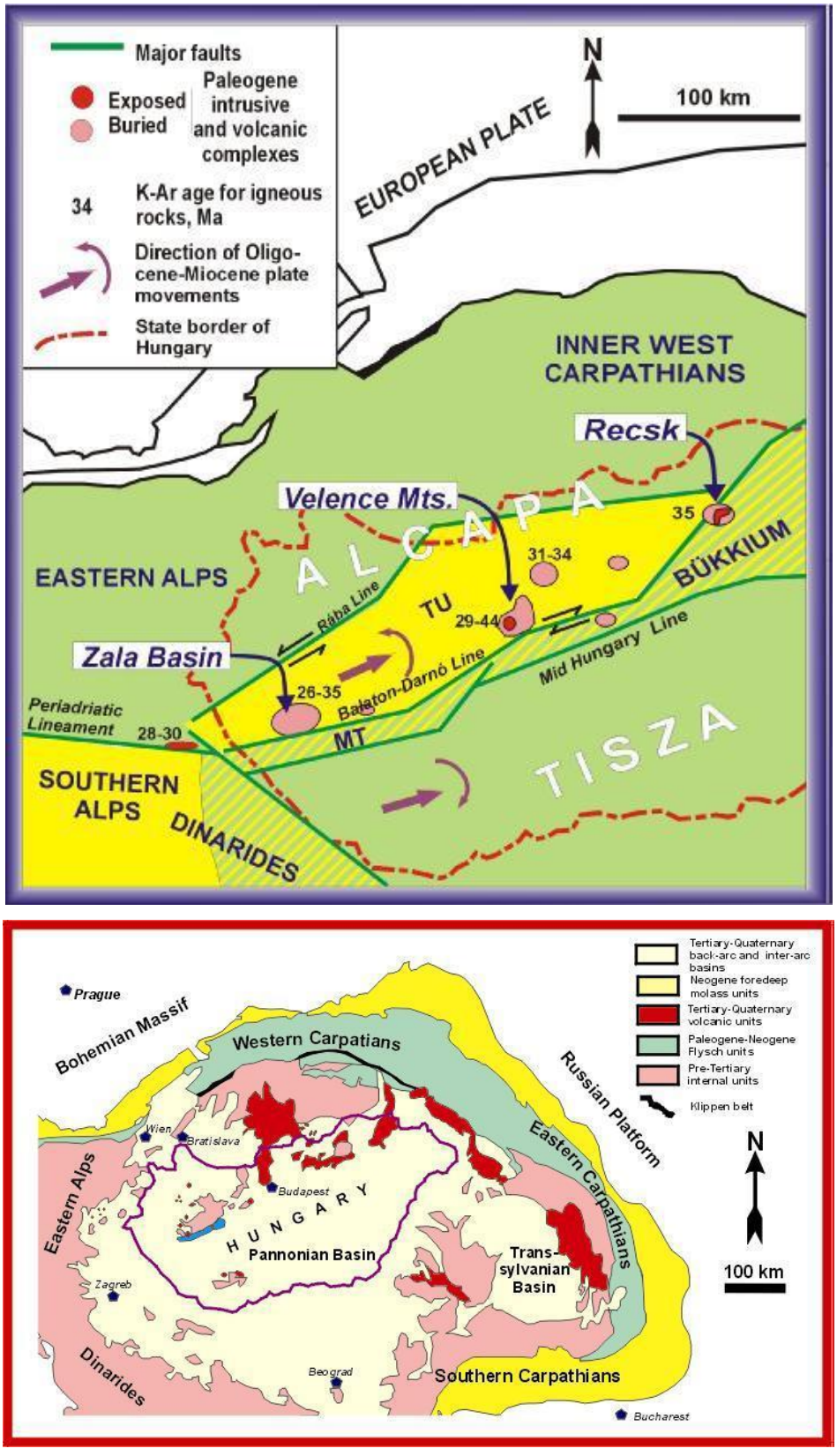


Fig. 1. Regional geology of Hungary and surrounding areas. A – The Pannonian Basin and the surrounding mountains. In set shows geodynamic interpretation of Tertiary evolution (after Bada, 1999). B – Distribution of Paleogene volcanic rocks in Hungary. C - Distribution of Neogene calk-alkaline volcanic rocks in Hungary and in the Western Carpathians (CSVF: Central Slovakia Volcanic Field).

Calc-alkaline ignimbrite and tuff sheets of Miocene age which are distributed along MHL under young sediments of PB (Fig. 2) and the small alkali basaltic and shoshonitic volcanic units of Neogene-Quaternary age with sporadic distribution in PB do not have ore mineralization.

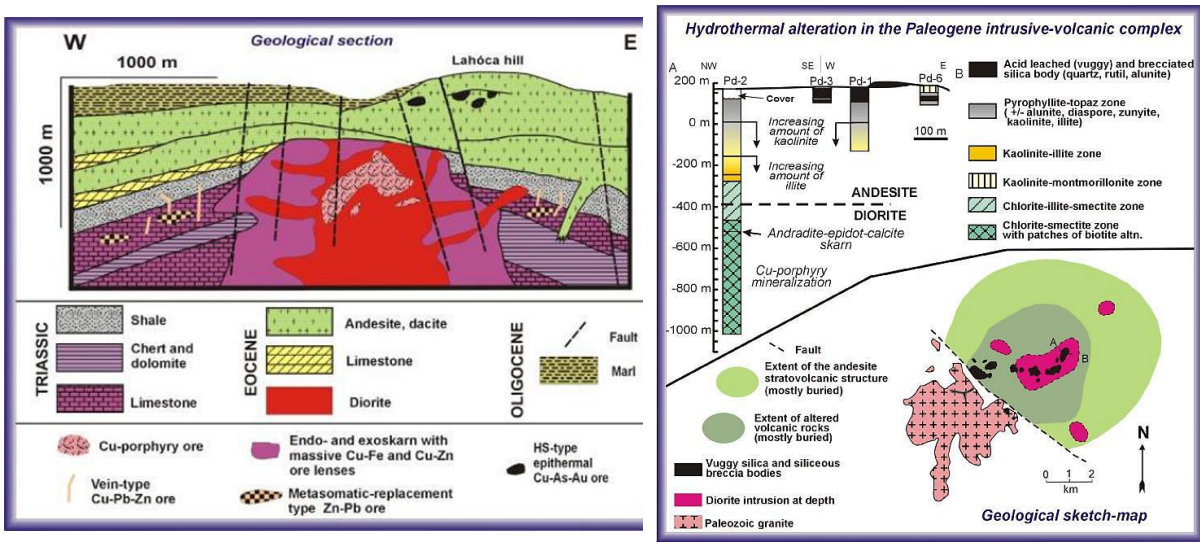


Fig. 2. Palaeogene mineralization of Hungary. A - simplified section across the intrusive-volcanic complex at Recsk with location of ore types (modified after Gagyi-Pálffy, 1975); B -hydrothermal alteration in the Velence Mts.

Mineralization of HPVA

Early eruptive products are interbedded with nummulitic limestone confirming Upper Eocene age of the partly subaqueous volcanism at Recsk (Fig. 2A). Emplacement of diorite porphyry - quartz diorite intrusion followed the second eruptive stage (Baksa, 1988). Along the contact with the Triassic sedimentary basement, endo- and exoskarn formed. Deposition of Cu-Fe- (36 Mt @ 2.19% Cu) and Zn- (11.5 Mt @4.98% Zn) skarn ore was associated with re-crystallization of limestone and formation of replacement and vein-type base metal ores (22.4 Mt @ 3.56 % Zn, 1.19% Pb and 14.2 Mt @ 3.15% Zn, 2.15% Pb, respectively). The silicified deep core of intrusion is sorrounded by phyllic alteration zones in its apical part and it is laterally fringed by propylitic alteration towards skarn zones. Porphyry copper ore (109.4 Mt @ 0.96% Cu with 0.01% Mo in the phyllic alteration zones) forms sheet-like bodies that are sub-parallel to the contact in the upper part of the intrusion. High sulphidation (HS) type mineralization is associated with the third eruptive stage. Massive enargite-luzonite ore is confined to flat, irregular, siliceous breccia bodies which are surrounded by advanced argillic alteration in the stratovolcanic andesite and dacite. 3.1 Mt @ 0.63 % Cu and 2 g/t Au of this type of ore had been exploited between 1852 and 1979. Recent exploration has discovered enargite-poor, pyrite-rich disseminated ore that is also hosted by siliceous breccias (32.5 Mt

@ 1.4 g/t Au in dicated resource). Disseminated-stockwork type siliceous mineralization with galena-sphalerite-tetra- hedrite-sulphosalt assemblage is also known in dacitic domes. Hydrothermal breccia dikes with low-sulphidation (LS) type epithermal mineralogy cut HS type zones.

A partially covered andesite stratovolcano occurs in the vicinity of a Variscan granite intrusion in the Velence Mts. (Darida-Tichy, 1987; Fig. 2B). Outcrops of altered volcanic rocks in the central part of the structure consist of vuggy silica or siliceous breccia with up to 1 g/t Au surrounded by pyrophyllite-kaolinite-alunite-diaspore (-topaz- zunyite) alteration. Diorite intrusion beneath the volcanic structure has K-silicate (biotite, K-feldspar) and propylitic (chlorite) alteration with overprinting carbonate-zeolite veins. Ore mineralization forms pyrite-chalcopyrite-bornite stockwork. Siliceous breccia veins with disseminated enargite-pyrite-greyore-chalcopyrite, argillic alteration zones, as well as andesite stocks of Paleogene age also occur in the Variscan granite. K-Ar ages are between 42 and 29 Ma for various volcanic and subvolcanic units and are between 33-29 Ma for illite and alunite.

The most intense HS type alteration occurs at about 300-600 m above the apex of porphyry intrusions at Recsk and in the Velence Mts. Fluid inclusion data suggest that vuggy and brecciated silica bodies formed at 300-600 m below the palaeowater table. Due to boiling, high- and low- salinity magmatic fluids coexisted at subvolcanic levels (Fig. 3A). Mixing of those fluids with meteoric water towards the epithermal zones is also inferred from fluid inclusion data. Stable isotope data (Fig. 3B) confirm that mixing of low density/salinity magmatic fluids with meteoric water occurred in the epithermal zones (pyrophyllite, alunite and illite alteration) whereas mixing of high density/salinity magmatic fluids with meteoric water took place at depth (chlorite, kaolinite and illite alteration).

Mineralization of HNVA

The major units of HNVA (Börzsöny Mts., Mátra Mts. and Tokaj Mts.) have LS type epithermal systems with various erosion depths. In the base-metal rich mineralization of the Börzsöny Mts. (Fig. 1C), the most typical veins and stockwork zones have carbonate-pyrrhotite-Fe-rich sphalerite-arsenopyrite major assemblage with Bi-Te minerals, Ag- sulphosalts and local bonanza gold at some places. Veins are hosted by a stratovolcanic andesite sequence and by small intrusions that are characterised by illitic alteration. Some of intrusions host to low grade (0.1 wt. % Cu) porphyry-copper type mineralization and related breccia pipes.

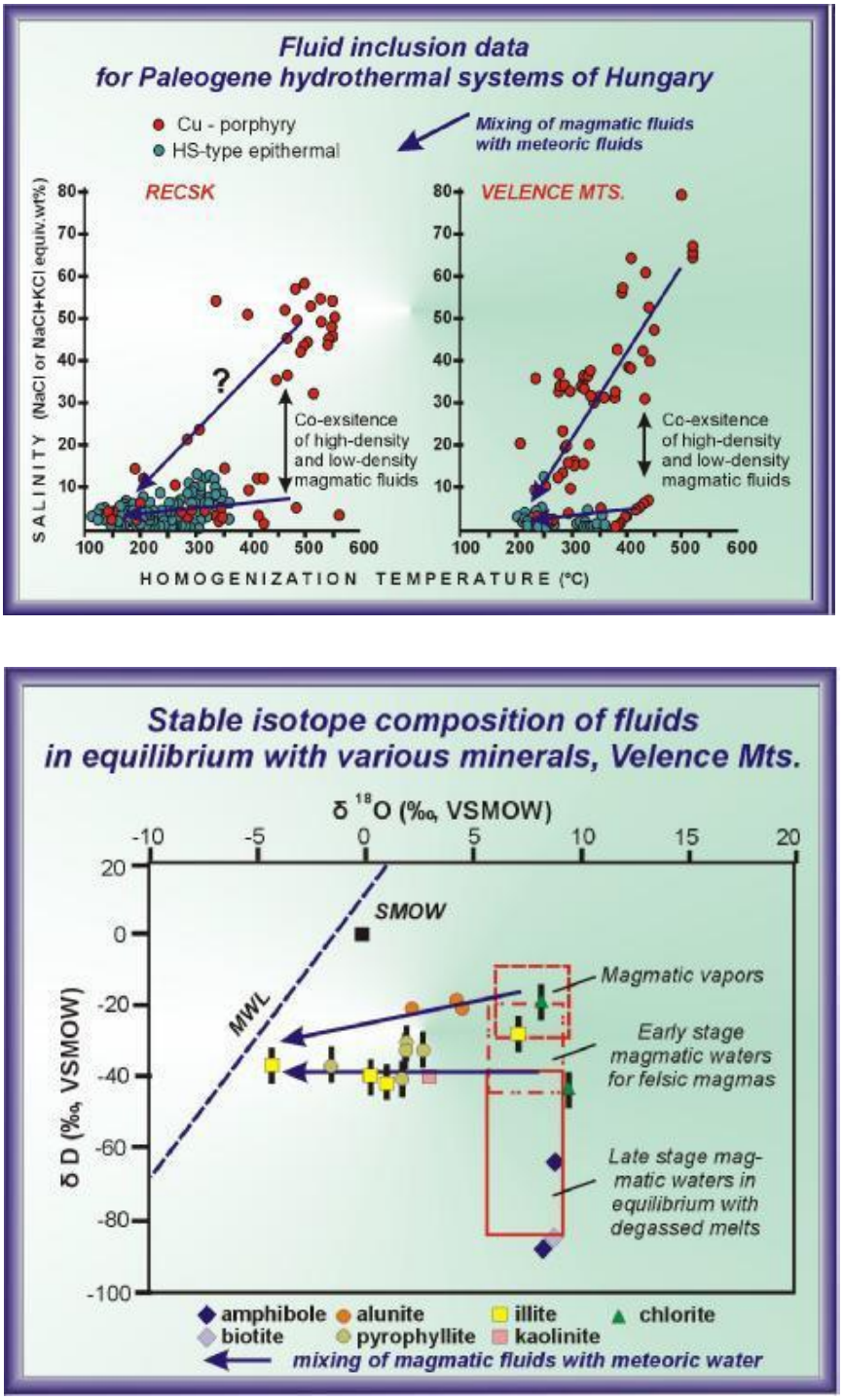


Fig. 3. Fluid inclusion and stable isotope data for Paleogene mineralization of Hungary. A - Fluid inclusion data. B - Stable isotope composition of magmatic and hydrothermal fluids in equilibrium with various minerals in the Velence Mts.

In the Mátra Mts. (Fig. 1C), ore veins are located in the centre of a caldera-like structure and have qu-artz-carbonate-Fe-poor sphalerite-galenite-chalcopy-rite assemblage hosted by propylitic andesite and pyroclastics (4.8 Mt @ 4.8 % Zn+Pb remaining reserves after closing of mine in 1986). In some parts of the mineralized zone, base metal stockwork

with Bi-Te minerals also occur. Upper parts of veins are rich in silica, poor in base metals and their host rocks are characterised by adularia-sericite alteration. Few remnants of steam-heated alteration zones are also preserved, and the centre of the caldera-like depression also hosts to lacustrine silica deposits.

In the Tokaj Mts. (Fig. 1C), ore deposits are characterised by base-metal poor siliceous veins with Au-Ag enrichments. Veins are hosted by various andesitic-dacitic lava flows and shallow intrusions as well as ignimbrite deposits with adularia-sericite alteration. Other mineralized areas are barren steam-heated alteration zones (kaolinite- alunite alteration associated with massive silica bodies formed above and at the palaeogroundwater table) mostly in acidic pyroclastic rocks. Local basins host to voluminous lacustrine silica deposits.

K-Ar ages for the major stages of volcanism and associated mineralization are slightly younger in the eastern segment of HNVA than in its western segment (Fig. 4). Differences in erosion levels of LS systems of HNVA may be correlated with this trend. Fluid inclusion data indicate that deeply eroded zones (stockwork ore with Bi-Te minerals) are characterised by high-salinity and high-temperature flu-ids, presumably with magmatic origin. Low-salinity fluids are typical to veins with adularia-sericite and to the shallower alteration zones (Fig. 4).

Conclusions

Tertiary magmatism and related mineralization of Hungary represents two different, but not independent metallogenetic stages in the Carpathian sector of the Tethyan Eurasian Metallogenetic Belt. HNVA is partially superimposed on the HPVA, however, they were formed in different convergence systems. HPVA is an ‘escaped’ portion of the Periadriatic syn- and post-syncollisional magmatic belt that has been formed in the collision zone between the Adriatic microplate of African origin and the European plate. Northeastward escape of continental blocks from that collision zone initiated the Carpathian subduction. HNVA is genetically connected to the Neogene stages of the Carpathian oblique subduction and collision. HPVA is characterised by development of magmatic-hydrothermal systems producing Cu-porphyry and related HS type mineralization during elongated igneous activities in intermediate intrusive-volcanic complexes. These ore formations are absent in the Alps along the Periadriatic Linea ment, presumably due to deep erosion of magmatic complexes during emergence of Alps; in contrast, HPVA avoided deep erosion due to its escape from the Alpean collision zone. Though Cu-porphyry mineralization and

hydrothermal circulation dominated by magmatic fluids in the more eroded, older parts of HNVA occurred, the Neogene intermediate-acidic volcanic sequences are characterized by LS type mineralization. Differences in the style of LS type deposits from west to east along the HNVA may be correlated with the depth of their erosion due to shift of ages for volcanism and hydrothermal minerali-zation in the same direction. The less eroded and youngest mineralization occurs in the Tokaj Mts. This area has the best exploration potential for LS type epithermal gold deposits in the HNVA.

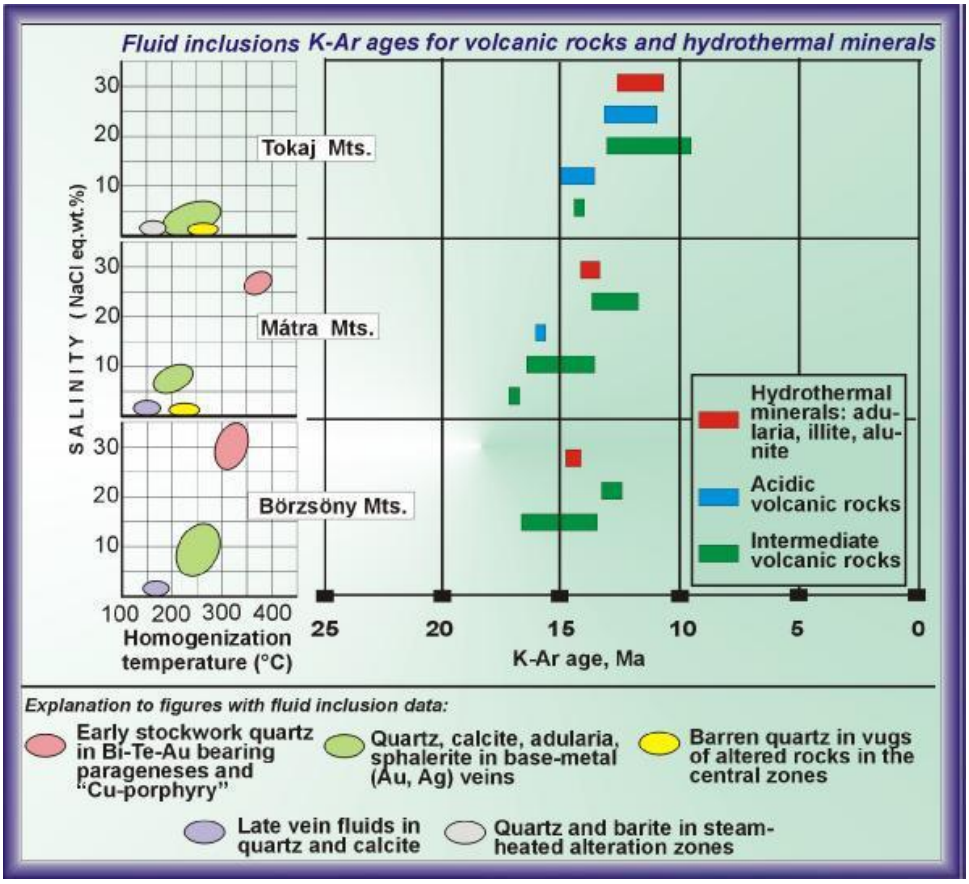


Fig. 4. Fluid inclusion and K-Ar age data for Neogene mineralization of Hungary.

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1. Gánt, Bagolyhegy, abandoned open-pit bauxite mine

Andrea Mindszenty in Mindszenty, A., 2010, Bauxite deposits of Gánt (Vértes Hill, Hungary), IMA 2010 Field trip guide, Acta Mineralogica-Petrographica Field Guide Series, vol. 11

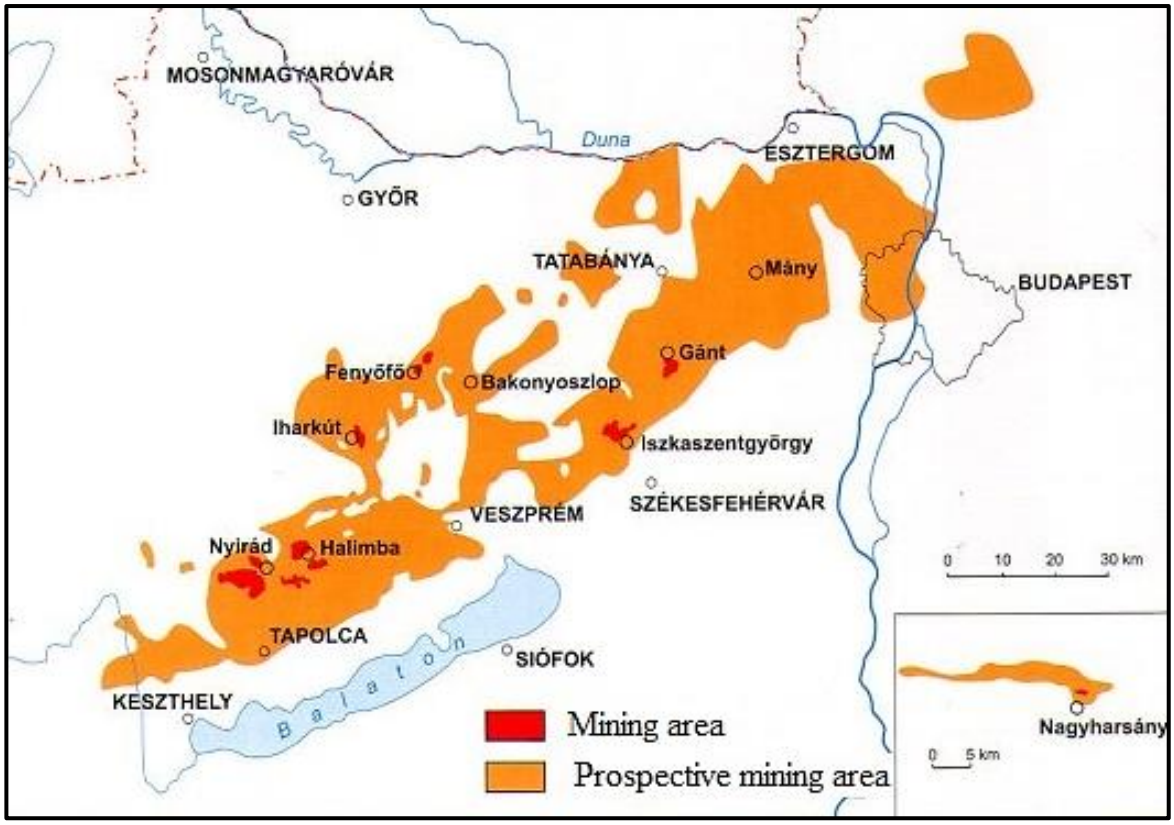

Fig.1. Bauxite deposits in the Transdanubian Central Range

The „cradle" of Hungarian bauxite mining, the Gánt deposit, was discovered by a Transylvanian mining engineer J. Balás in 1924. The discovery was one of the results of the desperate effort of Hungarian geology after World War I, to disclose new mineral resources within the country which, as a result of the peace treaty of Trianon, has lost two thirds of its territory including all its former prosperous mining districts. Mining activity began here in 1925. and was followed soon by the first scientific descriptions of bauxite (Telegdi Roth, 1927; Vadász, 1927; Pobozsny, 1928; Gedeon, 1932 and Dittler, 1931). Ever since then the locality has attracted many mineralogists, geochemists, paleontologists and structural geologists to study the peculiarities of both bauxite and its cover (Szőts 1938, 1953, 1956; Kiss 1953; Strausz 1962, 1964; Kopek *et al*., 1965; Bignot *et al.*, 1985; Deák, 1967; Vörös, 1969; Bárdossy, 1961, 1980; Szantner & Szabó, 1970; Mihály, 1975; Farkas *et al*., 1982; Mihály & Vincze, 1984 and German-Heins, 1994).

By 1936 with 500 000 tons pro year Hungary became the third-largest bauxite producer of the world. Additional deposits were discovered both around Gánt and at other localities of the Transdanubian Range as a result of which production has steadily increased until after 1989 when it totalled to almost 3 million tons pro year (from open-cast and underground mines). In Gánt

exploitation peaked in the mid ’50ies with 477 000 tons pro year from five large open-pits. Since then it has gradually declined until the mid ’80ies when it was finally closed. The Bagoly-hegy open pit, where J. Balas started the exploration in 1924 was converted into a geological park in the early ’90ies by the Bakony Bauxite Mines.

General Geology

The occurrence is situated at the SE foothills of the Vértes Hills which is of an asymmetric monoclinal structure sligthly tilted to the NW and dissected by two major sets of faults (SSW-NNE and NNW-SSE). The bulk of the hilly range is built up of Triassic rocks (Ladinian to Carnian dolomites and marls, Norian dolomites and Rhaetian limestones) Younger Mesozoic members are known from scattered outcrops and boreholes only, from along the SW margins of the area. The Tertiary cover is discontinuously exposed on the surface along both the western and the eastern foothills. Bauxite deposits are known from the eastern part only, where the Eocene succession reflects a stepwise transgression, beginning in the latest Middle Eocene („Marinesian” or „Bartonian” more orless equivalent to P 12/14 and NP 16/17 respectively, according to Bignot et al., 1985 and Pálfalvi, 2007).

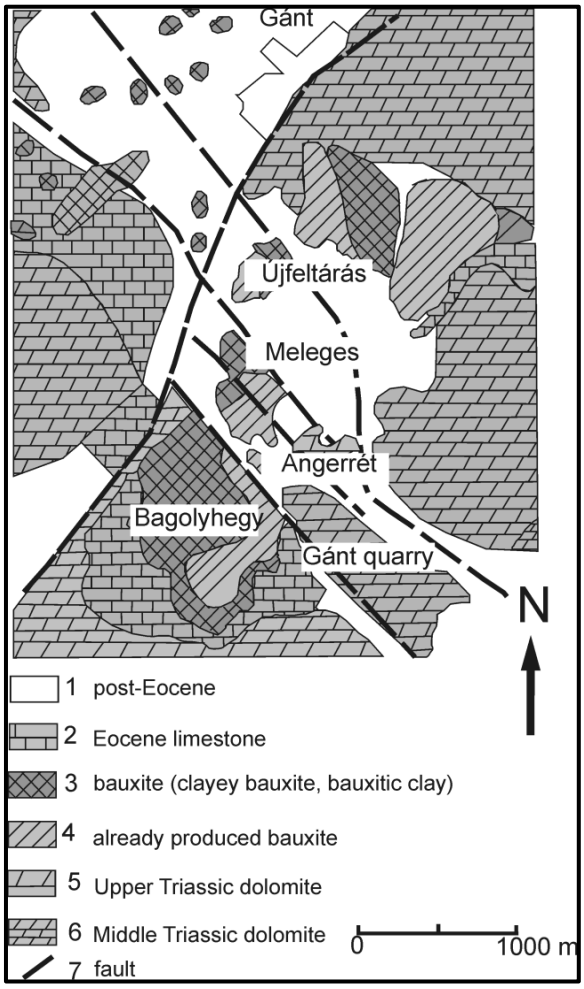

Fig. 2. Geological sketch map of the Gánt bauxite occurrence

The bauxite occurs at a major regional unconformity between Late Triassic and late Middle Eocene strata and is generally considered as of Paleocene-Eocene age. It fills a shallow karst relief formed as a result of long-lasting subaerial exposure. Lateral size of individual deposits is several hundreds of meters, the thickness of the bauxite is moderate (10 to 15 meters) Major bauxite minerals are: boehmite, goethite, hematite, kaolinite and anatase accompanied by minor chlorite (chamosite). There are two lithological types recognized at this locality: pelitomorphic and conglomeratic. Both are of medium-grade with the pebbles being of higher grade (Al_2O_3: 31,6%, SiO_2 1,5%) while the muddy, pelitomorphic material, though richer in alumina (Al_2O_3 46,9%) is richer also in SiO_2 (11,3%). According to Bárdossy

(1961) the average grade of the ore in the Gánt area (all lithotypes considered) was Al_2O_3 50.0% and SiO_2 16.0%). Both lithotypes abound in textures suggesting repeated mobilization and reprecipitation of ironoxide – a sign of accumulation and early diagenesis in a semi-vadose environment, porbably close to the paleo-groundwater table. The predominantly pale red to yellowish coloured bauxite forms an extensive 10 to 12 m thick blanket over the karstified surface of the Triassic bedrock. The amplitude of the karstic mezo- relief is a few meters. The bauxite displays outcrop-scale stratification with the moderately to poorly sorted conglomerate layers forming irregular intercalations in the muddy „matrix". The conglomerate may be matrix-supported or clast supported, the clasts are rounded to subrounded and of 0.5 to 2.0 cm size on the average, occasionally with 10 to 20 cm size boulders, as well. As shown by its sedimentary characters, the Gánt bauxite is of a rather peculiar depositional type. Unlike most karst bauxite deposits, it is not simply the result of parautochthonous transport of the polygenetic weathering product on the karstic terrain. It displays the signs of true allochthony and - as shown by its coarse, chaotically organized conglomeratic textures – it was apparently deposited on a shallow karst terrain from episodic mudflows/debris flows probably triggered by synsedimentary faulting.

The once continuous extensive bauxite blanket is dissected by numerous postdepositional mostly Late Tertiary) faults, some of them clearly visible in the visited outcrop.

Mining activity exposed a major east-west trending normal fault at the far end of the quarry. The exposed length of the fault is about 300 meters. Dissected by the fault plane the karst relief underlying the bauxite is superbly exposed in this outcrop. Based on the numerous fault striae and assocciated Riedel-faults, displacement along the major fault was right-lateral combined with a normal component of about 5 to 6 meters (Fodor *et al.,* 2007). The faulted zone was strongly brecciated/powdered, the estimated thickness of the fault-breccia being several meters or so. In accordance with its increased porosity the fault zone was subject to intense cementation mainly by calcite. Subsequent weathering resulted in peculiar boxwork textures best seen on smaller or larger bedrock-blocks protruding from below the bauxite in front of the fault-plane. Powderization and cementation of the bedrock mainly by calcite and ironoxide is characteristic of this fault-plane related variety of the Triassic dolomite.

Fig. 3. View of the major boundary fault of the Bagolyhegy open-pit

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2. Velence Mountains

Máté Biró

Geology of the Velence Mountains

According to Buda (1985), the Velence Mts. consist of nearly 200 km^2 Variscan (280-290 Ma), post-collision biotitic monzogranite outcrop, which was intruded into Paleozoic shales, showing contact metamorphism along the igneous-sedimentary contact (Jantsky, 1957). However, recent studies suggest a Permian age (283±5 Ma) magmatism, based on zircon U-Pb dating method (Uher *et al.*, 2010). The granite crystallized from water-saturated eutectic melt at temperatures 520-700 °C (Buda, 1993). The igneous body is crosscut by several monchiquite-spessartite and carbonatite dykes of Cretaceous age (Horváth & Ódor, 1984).

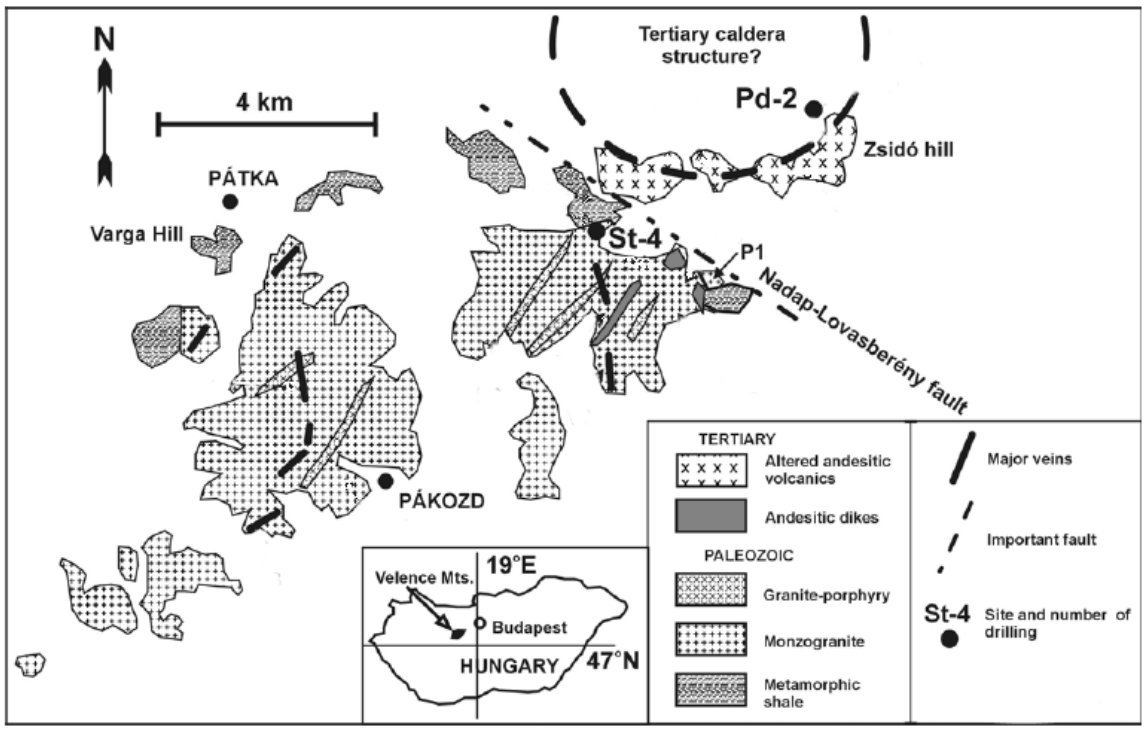

Fig. 1. Sketch map of the igneous units of Velence Mts. P1, and Pd-2 are the two quarries targeted by the field trip (after Molnár 2004).

At the NE edge of the Permian age granite expands a mount-line of six hills, forming a half-circle opened to the north (Fig. 1.). These hills represent the Palaeogene volcanic eruption centre related with the upper Eocene tonalites and granitoids in Alps, and these extrusives are geochemically analogous with the andesitic - dacitic rocks of the Recsk Magmatic Complex. The unaltered stratovolcanic sequence is buried under the Miocene and Quaternary sediments. The extrusives were faulted down during the late Miocene extensional tectonics, thus these occur approximately in the same depth as the shallow intrusive diorite (Dudko *et al.*, 1989).

The three Hungarian Palaeogene magmatic rock occurrences are strongly connected with all those occurring along the Periadriatic (-Balaton) Line (Middle-Hungarian Shear Zone-MHZ), the main tectonic structure of the Southern-Alps and the Pannonian Basin. The structure is a right handed strike-strip fault, crossing the Pannonian Basin in SW-NE direction. The volcanic arc andesites just as the main granitic body are part of the "fault megabreccia", both of those have their "relatives" along the fault, which were found in surface outcrops in Southern-Alps, and in drillings in southern Hungary (Szederkényi *et al.*, 2012.)

The six hills could have been preserved in their recent form, due to the silicification of the andesite in the hydrothermal centres, thus the rocks become more resistant to weathering (Fig 1.). On the silicified breccia surface there are abundant wind erosion grooves, and these wind erosion linings are also observable on the top of the hill in metre size scale.

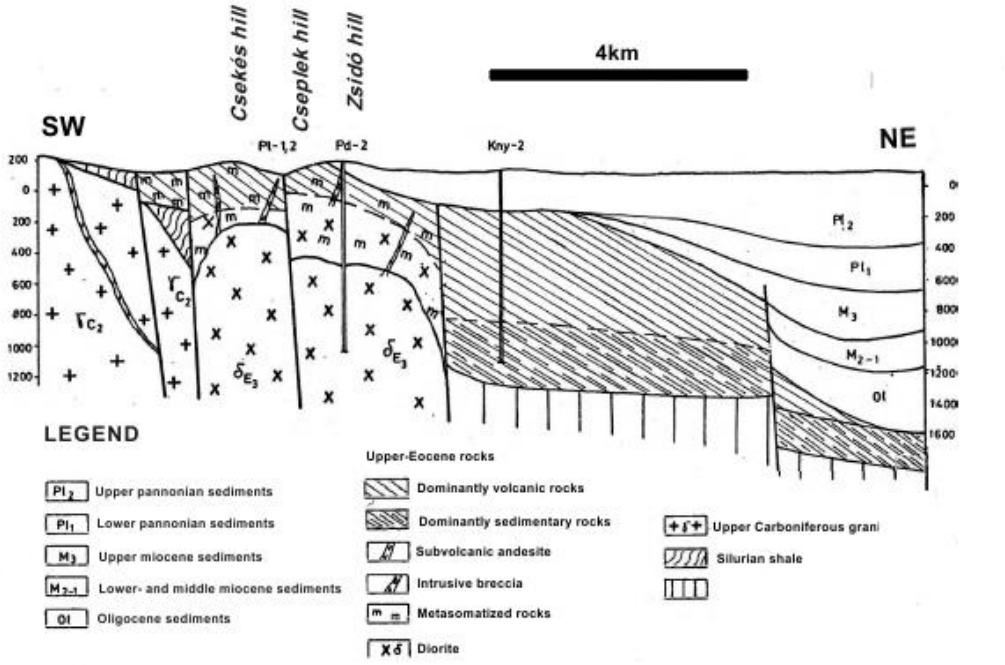

Fig. 2. Simplified cross section of the Nadap volcanic unit -Velence Mts. (after Dudko *et al.*, 1989).

Ore geology and hydrothermal alteration of the Velence Mts.

The perspectives of the field trip are the hydrothermally altered granitic rocks and pegmatites of the Nadap Quarry (P1) as well as the Upper-Eocene – Lower-Oligocene alkaline andesitic rocks, which form a half circle at the north-eastern part of the granite (Pd-2) location (Fig. 2.). This half circle might represent the eroded southern remnant of a caldera-like paleovolcanic centre (Molnár, 2004). Underneath the half-circle of the paleo-caldera structure, also the presence of a subvolcanic diorite intrusion had been proven in the 1200 m deep Pd-2

borehole. Although the andesitic rocks are structurally separated from the main granitic body (Nadap-Lovasberény Fault), dykes and stocks still crosscut the igneous body. These andesites are characterised with the same composition as the ones at the caldera, however granitic quartz and feldspar xenocrystals occur in the andesitic dykes.

Hydrothermal alteration of various types, related to the ore mineralization occurs in both Variscan and Palaeogene magmatic rocks. There are mineralization phases related to the Variscan monzogranite (Jantsky, 1957) (pegmatite, quartz-tourmaline metasomatic stockwork) also Triassic epigenetic quartz-fluorite-barite-Pb-Zn sulphide veins (Benkó *et al.*, 2014), and two phases connected to Palaeogene intermediate volcanism (Molnár, 2004).

Porphyry mineralization occurs at 880-1070 m depth in the Pd-2 drillhole (Fig. 1.). The host diorite is characterised by potassium-silicate (K-feldspar, phlogopite, sericite) and propilitic (epidote-chlorite) alteration (Darida-Tichy, 1987). The quartz stockwork contains pyrite, chalcopyrite and sphalerite. The disseminated ore consists of chalcopyrite, bornite, pyrite, magnetite, and ilmenite in strongly silicified zones. Minor skarn mineralization occurs at 670 m depth with andradite, epidote, quartz and pyrite.

The very target of the field trip is the epithermal high-sulphidation type mineralization and its alteration halo. The remnants of the eroded volcanic sequence are fully altered in the outcrops. The hydrothermal centres are defined by irregular and mushroom shaped massive and vuggy silica bodies surrounded by alunite-kaolinite, and pyrophyillite-dickite-kaolinite-diaspore-alunite alteration (Darida-Tichy, 1987). Topaz, zunyite and native sulphur may also occur in the alteration zones (Nemecz, 1979). Non-weathered silica is characterised by disseminated pyrite, while the weathered silica bodies can be brecciated. These contain abundant iron oxide, and other secondary iron minerals. Alunite crystals from the alteration zones are usually sodium rich and conatin phosphorus minerals (schwanbergite-woodhaosite) in their cores (Bajnóczi *et al*., 2002)

Another type of mineralized siliceous breccia occurs along an E-W contact zone of granite and shale in the north-eastern part of the Velence Mountains, close to Tertiary volcanic centre. Breccias occur as several metre wide dike-like silicified bodies on surface, or few centimetre thick vienlets in drillcores. Sulphide ore minerals in these breccias are pyrite, enargite, chalcopyrite and grey ore minerals. The breccia itself is made up of silicified angular fragments of granite, with highly variable size up to 20 cm. The breccia is cemented by grey silica, but the rock also contains empty vug spaces. This type of ore occurrence is also related to Palaeogene volcanism, as the enargite is a typhomorphic mineral in high-sulphidization

systems (Hedenquist and Arribas, 1999), and the proximity of the mineralization to andesitic epithermal high-sulphidation altered bodies suggests the same.

Widespread comparative fluid inclusion study has been made by Molnár (2004). Fluid inclusions from pegmatite, quartz-molibdenite stockwork, quartz-tourmaline veins and fluorite-base-metal veins were analysed, as well as the inclusions from Palaeogene porphyry, enargite-, and chalcopyrite bearing breccias and the high sulphidation type alteration zones (Fig. 2.).

The Palaeogene hydrothermal system can easily be characterised with two similar, but still different fluids. Homogenization temperatures vary between 250 and 350 °C. Critical homogenization was also observable in several two-phase inclusions, with temperatures between 380-450 °C. Salinity estimations from ice melting temperatures show 1-24 NaCl eqv. wt.%. Critical homogenization temperatures show salinities varying between 1-8 NaCl eqv. wt.%. (Fig. 2.). However, the typical salinities for epithermal inclusions are always lower than 13 NaCl eqv. wt.% (Molnár 2004).

Fluid inclusions found in the copper porphyry system show heterogeneous trapping, there are two and three phase inclusions as well, with varying liquid-solid and vapor contents. Solid phases in these inclusions can be NaCl or KCl daughter minerals, and eutectic temperatures suggest the presence of CaCl in the system as well. Salinity can be calculated from daughter mineral dissolution temperatures, the estimated salt content is between 26 NaCl eqv. wt.% and 79 NaCl+KCl eqv. wt. % in the L+V+S inclusions (Fig. 3.) (Molnár 2004).

Type of inclusion	Phase composition	Pegmatite in granite P1, P2, P3, P4, P5, P6, P7	Quartz-molybdenite stockwork in granite and shale M1, M2, M3, M4	Quartz-tourmaline veinlets in shale T1	Base metal and fluorite veins in granite V1, V2, V3, V6	Cu-porphyry showings in subvolcanic diorite PC-1, PC-2, PC-3	Chalcopyrite bearing breccia vein in granite CBX	Enargite bearing breccia granite/shale contact EBX	High-sulfidatio type alteratio zones in andesite EPI-1, EPI-2
Liquid 1a Vapour	L+V V<10%	S 90-180°C *6 - 23 $CaCl_2$*	-	-	S-P 80-140°C *10 - 25 $CaCl_2$* S-P 170-210°C *7 - 21 NaCl* F - P 110-160 *1 - 10 NaCl*	-	-	-	-
1b	L+V V=10-30%	S-P 90-250°C *2 - 20 NaCl* S 320-350°C (*) *0-2 NaCl* P 320-370°C *3 - 4 NaCl*	S 220-280°C S 280-320°C *1 - 6 NaCl* *8 - 14 NaCl*	S 240-300°C (*) S 330-390°C (*) *0 - 1 NaCl*	-	S 270-370°C *13 NaCl -* *24 NaCl+ $CaCl_2$*	S 260-360°C *1 - 21 NaCl*	S 210-400°C *1-21 NaCl*	S-P 310-380°C S 220-290°C *1 - 13 NaCl*
1c	L+V V=40-60%	S present (*) (sample P1)	-	-	-	-	S-P 400-410°C *3-5 NaCl*	S-P 370-450°C *1-8 NaCl*	-
1d	L+V V>60%	S present (*) (sample P1)	-	S 340-380°C (*)	-	S-P 360-500	S-P 400-460°C	S-P 310-440°C	S-P 280-290°C
2	L+V+H (+Sy+X) V=10-30%	-	-	-	-	S-P 270-520°C *31 NaCl -* *79 NaCl+KCl*	S-P 410-450°C *26 - 40 NaCl*	S-P 260-450°C *26 - 40 NaCl*	-
3	Laq+LCO_2 (+VCO_2) LCO_2= 40-90%	-	S-P 280-300°C *0-11 NaCl*	-	-	-	-	-	-

Fig. 3. Fluid inclusion data from granite-related, diorite porphyry and epithermal ores (Molnár, 2004).

2.1. Epithermal alteration zones in the Zsidó Hill Quarry

The Zsidó Hill shows a zoned alteration profile of an epithermal HS hydrothermal system. The hill is situated NE from the granitoid rocks of the Velence Mts. It is the easternmost member of the Palaeogene andesitic hydrothermal upflow-zones. Advanced argilic and kaolinite-alunite alteration zones occur in the quarry, together with strongly silicified rocks. Most of the host rock is silicified and vuggy porosity is abundant in the altered rocks. In the advanced argilic alteration zone the alteration mineralogy is dominated by pyrophyllite in size 0.1-1 mm, kaolinite and dickite in white powder like masses, quartz which can occur as amorphous grey material, or grown crystals with a maximal size of 1 mm. Less abundant minerals are topaz, zunyite and chalcedony. The vuggy silica in the silicified zones might contain minor amounts of alunite, kaolinite and sericite. (Bajnóczi *et al.*, 2002)

Fig. 4. The Zsidó Hill Quarry, with the oxidized argilic alteration zone. The rusty brown colour is caused by secondary iron oxides (Photo by Gabor Mesics).

2.2. Abandoned Andesite Quarry – Nadap

The main target of the quarrying was the Upper-Eocene – Lower-Oligocene pyroxene-amphibole andesite. As this most of this rock material has been removed from the locality. The recent walls of the quarry are made up of hydrothermally strongly altered – silicified, argilic – granite, "fresh" granite and in few places contact shales or andesite. The granite itself was not a capable building material due to its strong alteration, it occurs often in the most abundant "shovel granite" form. The andesite in this locality occurred as a thick dyke crosscutting both the granitic and contact metamorphic rocks.

The alteration mineralogy of the hydrothermally altered granite is similar to the Zsidó-Hill, strong silicification occurs, and in the vuggy porosity diaspore and zunyite are also observable. In the altered zones pyrite and galena is found in the unoxidized rock. The weathered rocks usually contain iridescent, or rust-like secondary iron-oxihydroxides, or pseudomorphs of sulphide minerals.

Pegmatites in the granite usually consist K-feldspar and quartz, but biotite, tourmaline, and molibdenite might occur as well. Pegmatitic veins and holes occur in the Permian granite, usually not larger than a few metres wide and less than one metre thick.

Pegmatite veins, veinlets and pockets are not abundant, but still observable at the locality, although the most typical occurrence of pegmatite in the granite can be observed in a pit at the top of the Bence-Hill (above this quarry).

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3. The Cu-Au-Ag-Zn-Pb ore complex at Recsk, Hungary: a uniquely preserved and explored porphyry-skarn-epithermal system in the Palaeogene magmatic belt of the Alp-Carpathian-Dinaride system

Ferenc Molnár in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

Exploration history

The ore complex at Recsk consists of Cu(-Mo-Au)-porphyry, Cu-Zn-skarn and metasomatic Pb-Zn ores at depth, as well as high sulphidation (HS) and low sulphidation (LS) type epithermal Cu-Au and Au-Ag-Pb-Zn ores in the shallow zones of the volcanic cover. Exploitation of Ag-rich base metal ores from the LS type epithermal zones has begun in the 19th century followed by mining of massive enargite-luzonite in the HS type epithermal zones up to 1979. A drilling program started to follow mineralization towards depths led to the discovery of the porphyry system in 1967. In total 132, 1200 m deep drill holes were completed until 1984 and results initiated development of a mine with two 1200 m deep shafts and adits with total length of 8456 m from the -500 to -900 m levels. Detailed mine exploration included 90 316 m mine drillings. Resources are summarized in the Table 1. After unsuccessful privatization attempts during the 90's, mine maintenance was terminated in 1999, and nowadays the well-constructed shafts and adits are filled up by groundwater.

Ore type	Resource mill.T	Grade
Cu-porphyry	109.4	0.96 (@ 0.8)
Cu-skarn	36	2.19 (@1.5)
Zn-skarn	11.5	4.98
Pb-Zn metasomatic ore	36.6	3.15-3.56 – Zn 1.19-2.15 – Pb

Table 1: reserves of the intrusion related ores at Recsk deep (after Fodor *et al.*, 1998).

In 1991, the epithermal gold potential of the shallow zones has been recognized by the Enargit Ltd. of Hungary and joint venturing with the Australia based Rhodes Mining Ltd. resulted in completing of 71 diamond drilling and determination of 36.5 mill. The resource of HS type gold ore (1.47 g/t @ 0.5 g/t; Földessy *et al.*, 2002). Exploration of shallow epithermal zones has been revitalized by the Magyar Mining Plc. in 2003. Recent works has been focused on re-interpretation of drill cores, assays, geophysical data etc. supported by academic research for better establishment an ore deposit model and for understanding the regional metallogenetic aspects of the ore complex at Recsk.

Geology and mineralization

The stratovolcanic sequence consists of four major units at Recsk (Földessy, 1975). Early stage pyroxene-amphibole andesite with peperite, agglomerate and lava flows are intercalated with shallow marine carbonate and marl of Upper Eocene age. Peripherial zones of superimposing volcanic sequences are also subaqueous, but their central, thickest zones (up to 700 m thickness) were accumulated under subaerial conditions. These latter units are hydrothermally altered and consist of biotite amphibole andesite lava, agglomerate and crystal tuff-diatrema breccia in the northern part of the area (Lahóca Hill) and dacite dome-flow complexes to the south (Fig. 1.). The youngest volcanic unit without hydrothermal alteration consists of biotite amphibole andesite lava and agglomerate covering the eastern part of the Lahóca Hill (Fig. 1.). The stratovolcanic sequence is underlain by limestone, dolomite, chert and shale of Triassic age which are intruded by diorite porphyry. One apex of the subvolcanic intrusion is located under the northern part of the stratovolcanic sequence and another apex is under the dacite dome- flow compex to the south (Fig. 1.). The depth of these apexes is about 250-400 m below the present surface.

The diorite intrusion hosts to Cu(Mo-Au) porphyry mineralization concentrated in the phyllic (sericite, biotite, illite, chlorite) alteration mantle of the northern apex (Fig. 2.). The average Mo and Au content is 0.009% and 0.13 g/t, respectively (Zelenka and Szebényi, 2002). Garnet-epidote-diopside-amphibole-serpentine-anhydrite endo-, and exoskarns host Cu and Zn ores. Metasomatic-replacement-vein type Pb- Zn orebodies in carbonate units occur further away from the intrusion.

HS type epithermal mineralization occurs in the crystal tuff-ditrema breccia unit of the biotite-amphibole andesite stratovolcanic sequence of the Lahóca Hill (Fig. 2.), in lateral position to the northern apex of the subvolcanic intrusion. The tuff-diatreme breccia unit is underlain by andesitic lava flows with propylitic-argillic alteration and is covered by unaltered biotite-amphibole andesite in the eastern part of the Lahóca Hill (Fig. 1.). Gold mineralization within the tuff-diatreme breccia unit is confined to massive enargite-luzonite lenses, pods of vuggy silica, stockwork of black chalcedony-like microcrystalline silica and polymict hydrothermal breccias with black siliceous-argillic matrix often showing fluidization flow textures. Polymict and monomict hydrothermal breccias with light grey microcrystalline silica and argillic matrix cut earlier formed ore- controlling structures and locally may also carry gold enrichments. Major gold concentrations are related to free gold grains in enargite-luzonite lenses and in vuggy silica and black microcrystalline silica as well as to framboidal to gel-like fine pyrite in black silica (Seres-Hartai and Földessy, 2001). The

host rock shows advanced argillic alteration with dickite and silicification around ore controlling structures. The HS type ore is underlain and truncated by a zone in which banded quartz-carbonate veinlets with sphalerite, galena and grey ore minerals are enveloped by illite alteration. Thus, the HS type ore formation was overprinted by a less acidic LS type hydrothermal event.

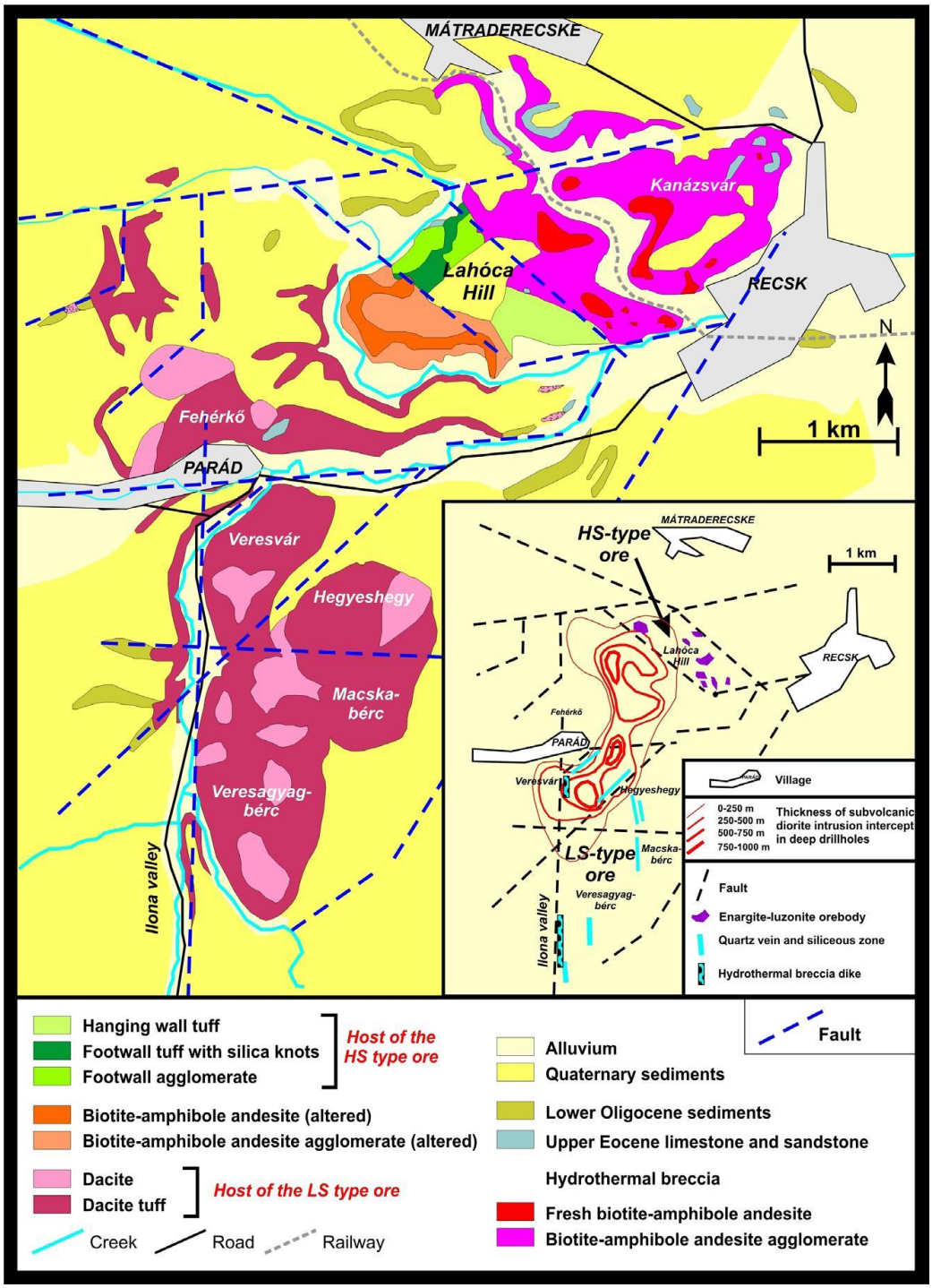

Fig. 1. Outcrops of volcanic units and epithermal mineralization at Recsk with thickness contours of the subvolcanic intrusive bodies cut in 1200 deep drillholes under the stratovolcanic cover.

The LS type epithermal zones south of Parád village are located above the southern apex of the diorite porphyry intrusion (Fig. 2.). Dacite and pyroclastic deposits host to banded and brecciated silica veins, stockworks and polymict matrix- to clast- supported breccia bodies with low contents of sphalerite, galena, grey ore, acanthite, pyrargyrite and rare Au-Ag-Bi-Te minerals. Host rocks are characterised by argillic alteration with predominance of illite and illite-smectite. Occurrences of silicified pods, alunite-kaolinite zones at various elevations and barite enrichments in silicified zones of the highest elevations are interpreted to be results of steam-heated alteration. Boiling of hydrothermal fluids is indicated by occurrences of quartz pseudomorphs after bladed calcite in banded quartz veins as well as by the presence of adularia in the matrix of hydrothermal breccia dikes. In breccia dikes, gold enrichment (up to 1.2 g/t) is connected to adularia-bearing zones.

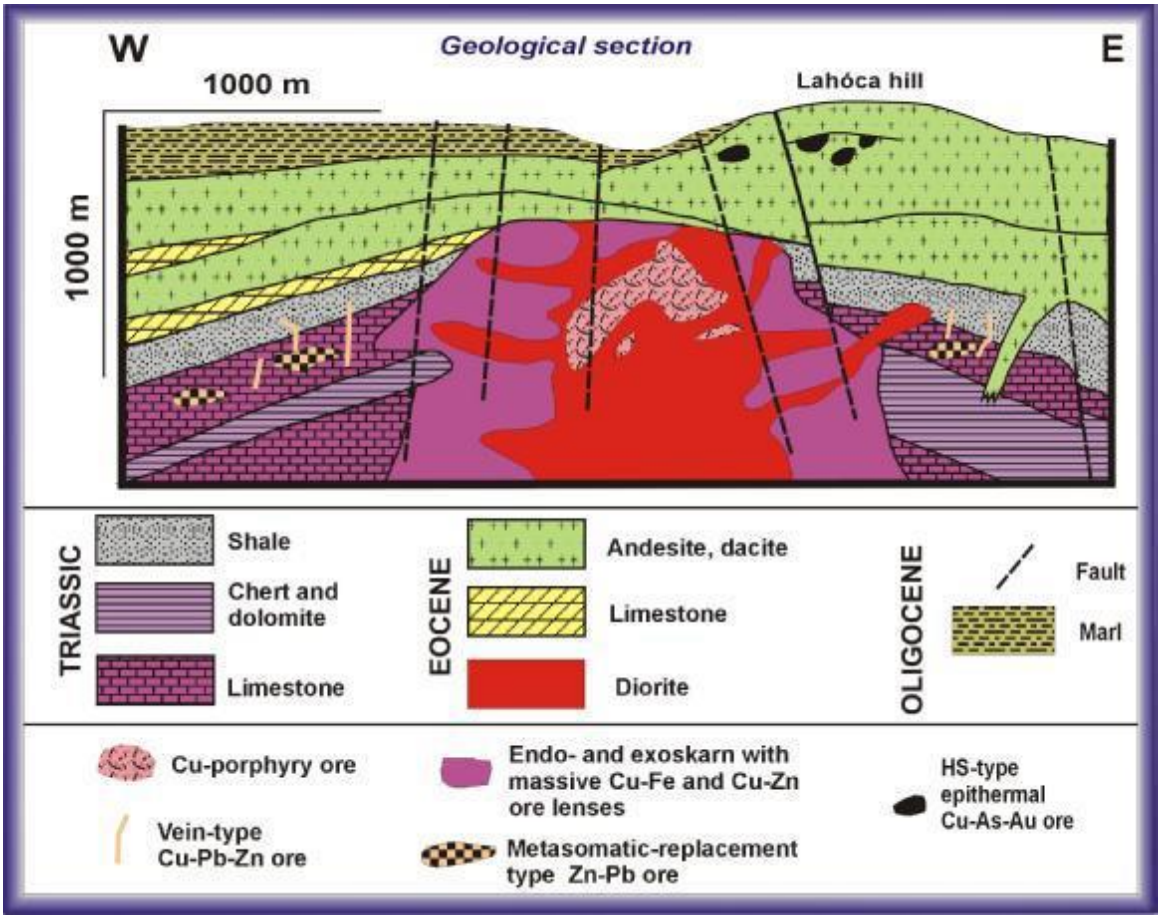

Fig. 2. Section across the northern apex of the intrusion with location of ore types at Recsk.

IR-microscopy supported microthermometry of enargite indicates that Cu-Au-As mineralization of the HS type epithermal zone on the Lahóca Hill was formed from relatively low temperature (150-250°C) fluids with elevated salinities (4-13 NaCl eq.wt.%; Fig. 3.). Textural evidences indicate that enargite precipitation was preceded by circulation of higher

temperature (250-350°C) less saline (0-7 NaCl eq. wt%) fluids trapped in quartz in vugs of vuggy silica. In the deep porphyry copper ore zones, similar less saline fluids were developed as a consequence of boling of magmatic fluids (Fig. 3.). Upraising of these low density-high temperature fluids into the stratovolcanic sequence may have caused the high temperature acidic alteration preceding sulphide deposition in the HS type zones. The high salinity portion of boiling magmatic fluids underwent cooling and dilution (due to mixing with meteoric fluids?) and mobilization of these diluted magmatic fluids could have been responsible for transportation of heavy metals to the volcanic levels. The location of massive enargite-luzonite orebodies in relation to the apex of intrusion (Fig. 1.) indicates lateral flow of these diluted saline fluids. Similar paleohydrologic system for formation of the HS type ore was suggested at Lepanto, Philippines (Hedenquist et al., 1998).

Zones with LS type mineralization south of Parád are characterized by dilute (<4.5 NaCl eq.wt.%) boling hydrothermal fluids with temperatures between 140-280°C (Fig.3.).

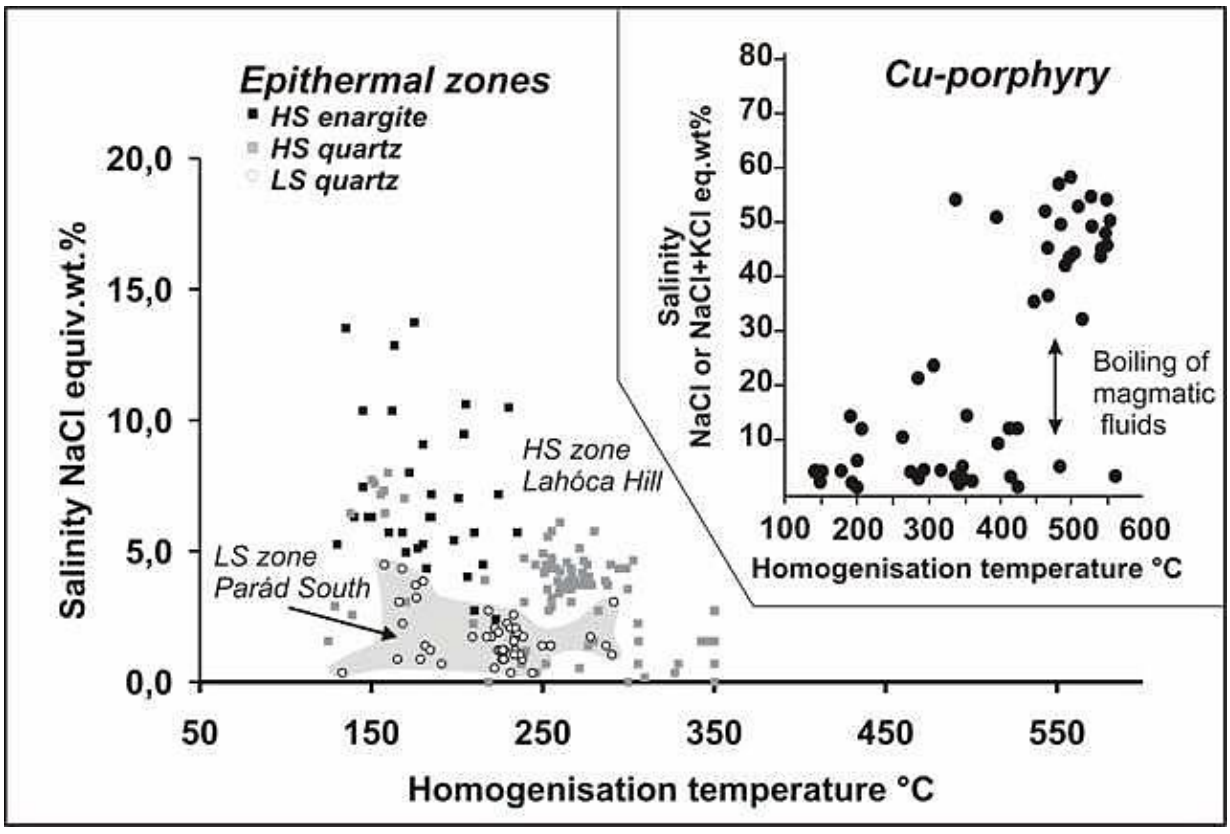

Fig. 3. Fluid inclusion data for the porphyry and epithermal zones at Recsk.

Conclusion

The PVAH avoided deep erosion due to its northeastward escape from the Alpine collision zone during Late Oligocene-Early Miocene therefore intrusive-volcanic levels and related Cu-porphyry and epithermal mineralization are uniquely preserved. The ore complex at Recsk has been explored for 40 years and spatial relationships between the buried porphyry and shallow epithermal zones are well documented and may provide geologic model for exploration of deeper zones under outcrops of shallow epithermal systems in other areas of the Alp-Carpathian-Dinaride system. Refinement of ore deposit model at Recsk supports further drilling program for determination mineable epithermal gold reserves.

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3.1. Ilona-valley

Eszter Kulcsár

(Based on Seres-Hartai, É. (2000): Forms and genetical aspects of native gold in the Lahóca deposit (Recsk, Mátra mountains); Folia Historico Naturalia Musei Matraensis 24. 5-30.)

At the Parádfürdő area the mineralization appears in the second-stage dacites and third-stage andesites and pyroclasts (Földessy, 1975). The alteration connected to the ore formation appears as strong silicification occurring as flat lenses and vein-like bodies that are vertical or subvertical structures, with an extent of 10s meters. Some silicified bodies have vuggy silica texture and quartz stockworks are connected to them. The silicified bodies are surrounded by argilic alteration zone with kaolinite, smectite, alunite and pyrophyllite (Gatter *et al.,* 1999). In the southern part of the Parádfürdő area the mineralization is connected to breccia dykes hosted by the third-stage andesitic-dacitic rocks. The breccia dykes are 10-20 m (at some places 50 m) wide. At the shallow zones the matrix has argillic alteration (illite, smectite, pyrophyllite, dickite), towards deeper zones silicification is more dominant. With increasing silica content adularia and calcite also appear. The ore mineralization occurs in the silicified and argillic alteration zones as well (Gatter *et al*., 1999).

Galena, sphalerite, Pb-Se- and Ag-Sb sulphosalts are connected to the argillic alteration zones as disseminations and veinlets. Tetrahedrite, tennantite and lesser amount of pyrite is characteristic in the silicified bodies and vein fillings. Younger pyrite dissemination is associated with rare Au-Ag-Bi-Te-Sb minerals. The gold appears both as tellurides and in native form (Nagy, 1983). Thanks to the fluid inclusion studies, boiling of the system has been proven which implies forming temperature and pressure of the mineralisation: 220-260 ºC, and it occurred 200-500 m below the paleowater-table (Gatter *et al*., 1999). In the southern areas, local Au enrichment was observed in the adularia-bearing zones in form of native gold. Tetrahedrite is rare, pyrite is common as dissemination in the matrix and the altered fragments (Molnár *et al*., 2008; Takács, 2010). Based on the alteration mineral assemblages, the Parádfürdő area can be considered as an early high-sulphidation stage of hydrothermal activity, contrarily Mozgai (2014) shows that the sulphiditation stage is intermediate.

Considering that in the late veins and cross-cutting breccia bodies adularia and calcite also occur, and sulphide minerals like sphalerite and galena are present, low-sulphidation activity must have overprinted the high-sulphidation mineralization (Molnár *et al*., 2008).

3.2. Egyezség adit

Eszter Kulcsár

(Based on: Fekete, Sz (2012): A Recski Magmás Érckomplexum fehérkői epitermás zónájának vizsgálata (ELTE Msc. Thesis)

The Jószomszéd and Egyezség adits are located at Fehérkő, in the northern part of the Parádfürdő area. The Jószomszéd adit has a more important role in exploration of the local ore mineralization, while the Egyezség adit consists ore indications of lesser importance.

The outcrop next to the Egyezség adit is dominated by a significant argilic alteration but silicification also occurs. The white-yellow host rock is coloured by brownish jarosite in bans and patches, often coating the quartz and barite crystals as well. The outcrop samples vein swarms, divided into two groups: quartz and quartz-barite vein types (Fig. 4.). In the central (hollow) zone of the veins and in the host rock porosity, 1-3-centimetre-sized euhedral quartz and barite crystals are abundant, usually encrusted with jarosite (Fekete, 2012).

In the Fehérkő ore mineralization, tetrahedrite, low-Fe sphalerite, chalcopyrite, galena are the dominant opaque minerals, with major pyrite and marcasite. In addition, Cu, As, Ag, Te and Sb bearing minerals are determinable. Based on the observed ore mineral assemblage, as well as the illite and illite-smectite alteration observed next to the Egyeszség adit, the origin of the hydrothermal fluids can be related to low or intermediate sulphidation systems, as these minerals are usually not associated with high sulphidation systems (Fekete, 2012). As a summary we can see that he Fehérkő ore mineralization is representing a transient stage, between the HS system and the LS system (Fekete, 2012).

Fig. 4. W-E section of the outcrop next to the Egyezség adit. Blue lines: quartz veins, yellow lines: quartz-barite veins (Fekete, 2012).

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4. Mesosoic submarine magmatic and sedimentary sequences: the Darnó and Szarvaskő Units, NE-Hungary

Zoltán Kovács and Anikó Lovász

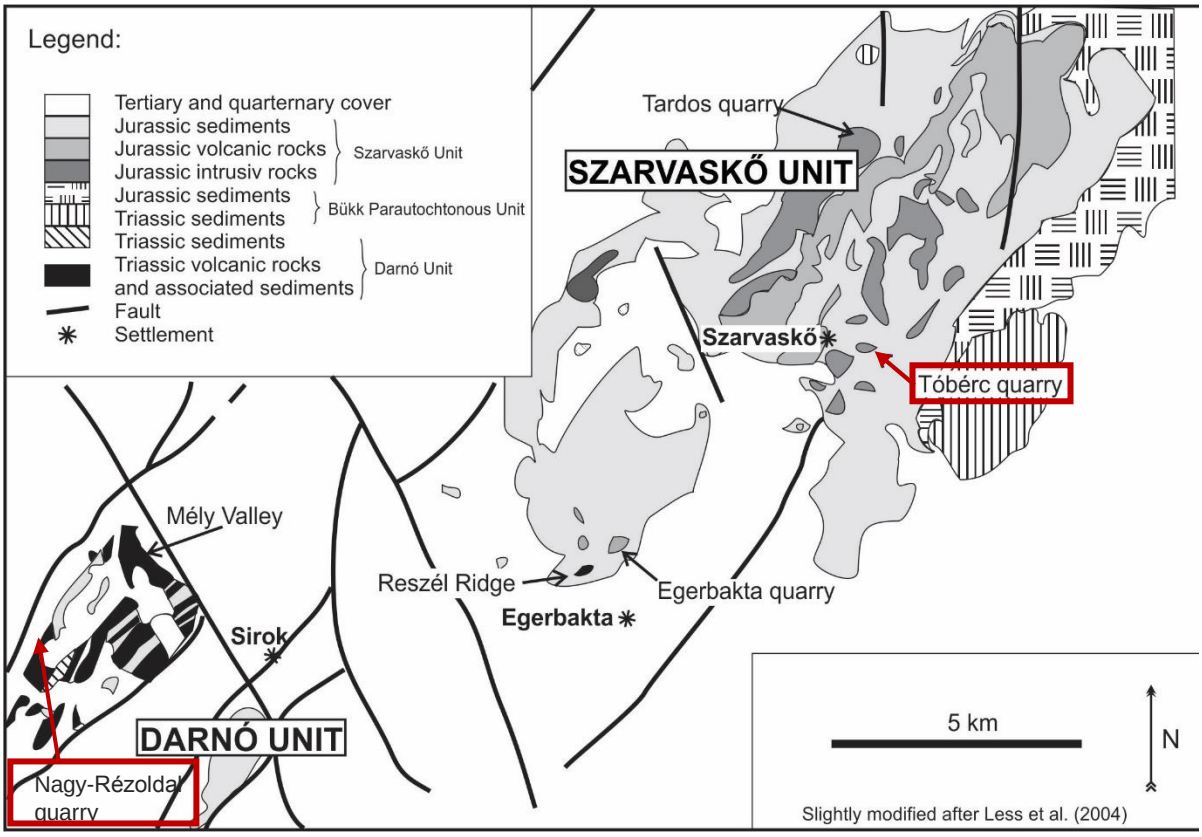

Fig. 1. Geological map of the two magmatic and sedimentary sequences of Hungary (Darnó Unit and Szarvaskő Unit) (after Less *et al.*, 2005).

The Darnó and Szarvaskő Units are situated in NE-Hungary (Fig. 1.). Both are related to the Bükk Unit, which is built up mostly by Mesosoic rocks with Dinaridic affinity. Several authors proved the correlation of the Unit to Dinaridic and Hellenidic occurrences in Croatia, Serbia, Bosnia and Herzegovina and Greece. The two areas are separated by the Miocene Mid-Hungarian strike-slip fault, which has 300-400 km offset.

Triassic-Jurassic sedimentary rocks of the Bükk Parautochtonous were part of the Dinaridic Platform, while the Jurassic siliciclastic successions of the overlying Mónosbél and Szarvaskő Units (the latter one contains Jurassic mafic magmatic rocks as well) were deposited in a deep marine environment in the vicinity of the continent. Subduction of the Neotethyan oceanic basement during the Jurassic-Cretaceous resulted in the nappe stacking of these sequences, where the Parautochtonous became the lowermost and the Darnó Unit the uppermost „nappe” (Fig. 2.).

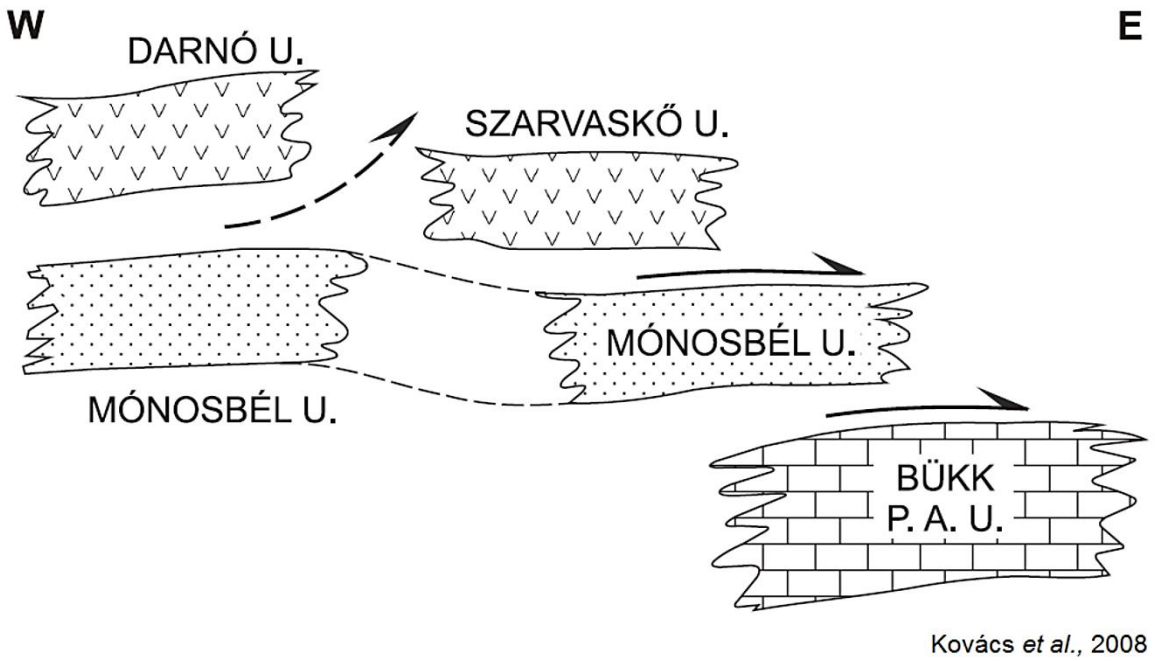

Fig. 2. The three nappes with the Bükk Parautochtonous of the Bükk Unit (U. = Unit, P.A.U. = Parautochtonous).

Darnó Unit

(This chapter is based on: Kiss, G., Molnár, F., Kovács, S., Palinkaš, L. (2010) Field characteristics and petrography of the advanced rifting-related Triassic submarine basaltic blocks in the Jurassic mélange of the Darnó Unit and the references cited therein.)

The Darnó Unit is considered as an ophiolitic mélange (true ophiolitic sequence is not preserved in the area). The matrix is a Jurassic fine grained siliciclastic sediment, containing basalts of Triassic and Jurassic in age as olistostromes. The Jurassic basalts are similar to those of the Szarvaskő Unit (see page next subchapter), which show back-arc-basin-/marginal basin-like geochemical signatures. In contrast, the Triassic basalts have rifting-related affinities and can be correlated with similar occurrences related to the Neotethys Ocean.

4.1. Nagy-Rézoldal Quarry

The Nagy-Rézoldal Quarry is found in the western part of the Darnó Hill, near the village of Recsk (N 47.9273 / E 20.1353). The wall of the quarry (next page, Fig. 3.) is built up mostly by closely packed greenish to greenish-grey pillow basalts with jig-saw veins and amygdales varying in size and frequency along the outcrop. A block of hyaloclastite breccia facies of a submarine lava flow can be found in the middle of the quarry, while sedimentary rocks (possibly Jurassic in age) are exposed in the northern part of the quarry. The microscopic texture of the different basalt types are varying between spherulitic, variolitic and intersertal types, containing plagioclase and pyroxene phenocrysts, pseudomorphs of calcite + chlorite after olivine, and chloritized groundmass (Fig. 4.). The cooling-related jig-saw veins are filled with chlorite, quartz, prehnite and pumpellyite, while the amygdales are filled with calcite, chalcedony/quartz, and chlorite.

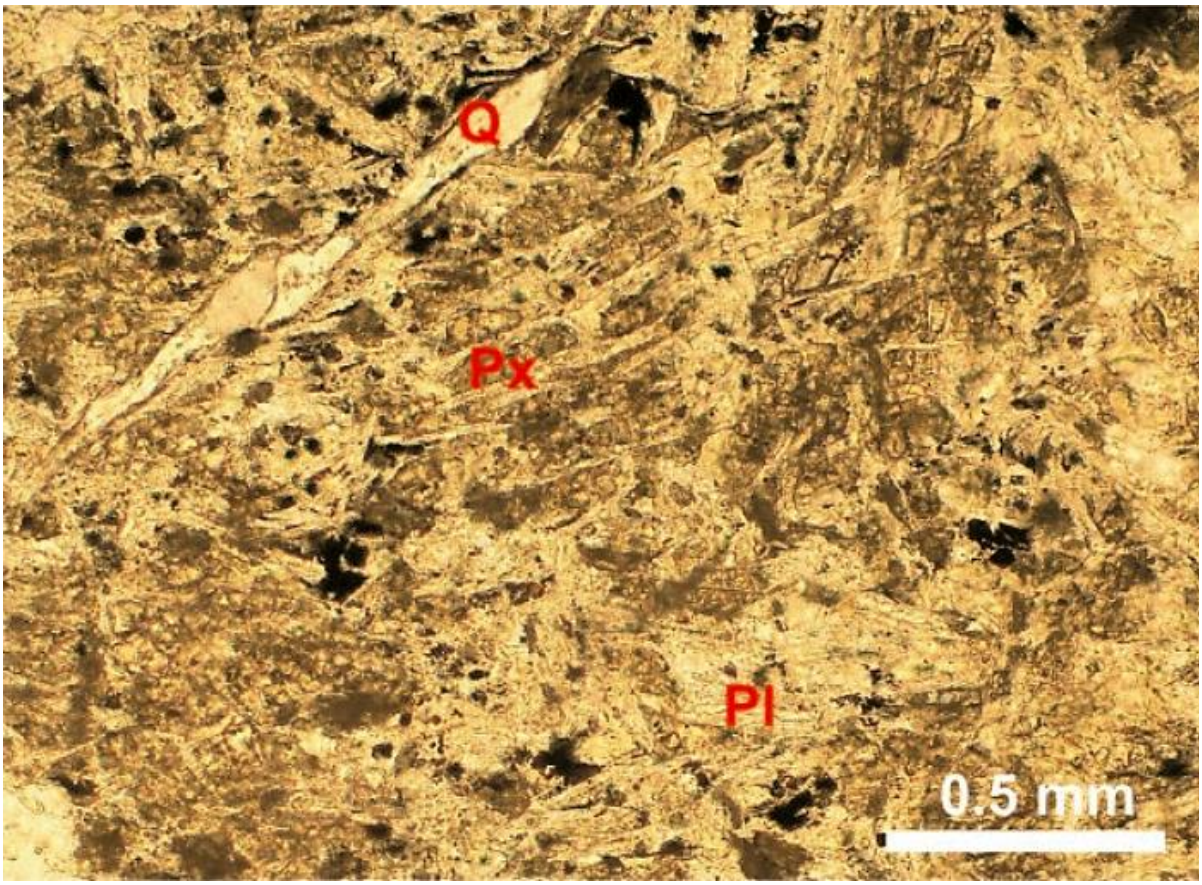

Fig. 4. Intersertal basalt crosscut by a quartz vein from the middle of the Nagy-Rézoldal quarry. 1N, Px-pyroxene, Pl-plagioclase, Q-quartz.

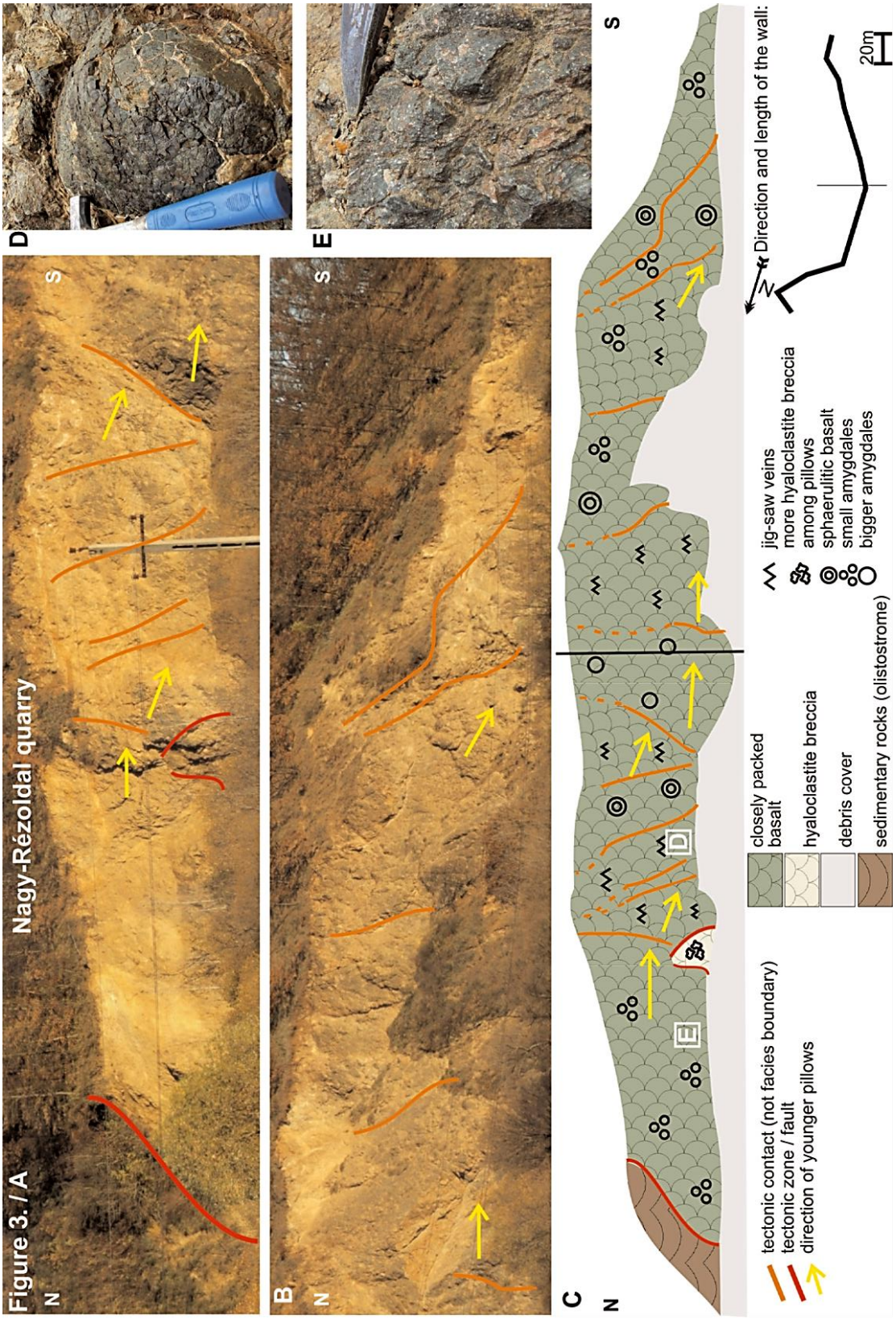

Fig. 3. A, and B, Panorama picture of the Nagy-Rézoldal quarry, taken in 2007, C) Geological interpretation of the Nagy-Rézoldal quarry (white letters show the places where photos D and E were taken), D) Closely-packed pillow with jigsaw veins, E) Closely-packed pillow rich in small amygdales.

Szarvaskő Unit (A Jurassic ocean floor remnant)

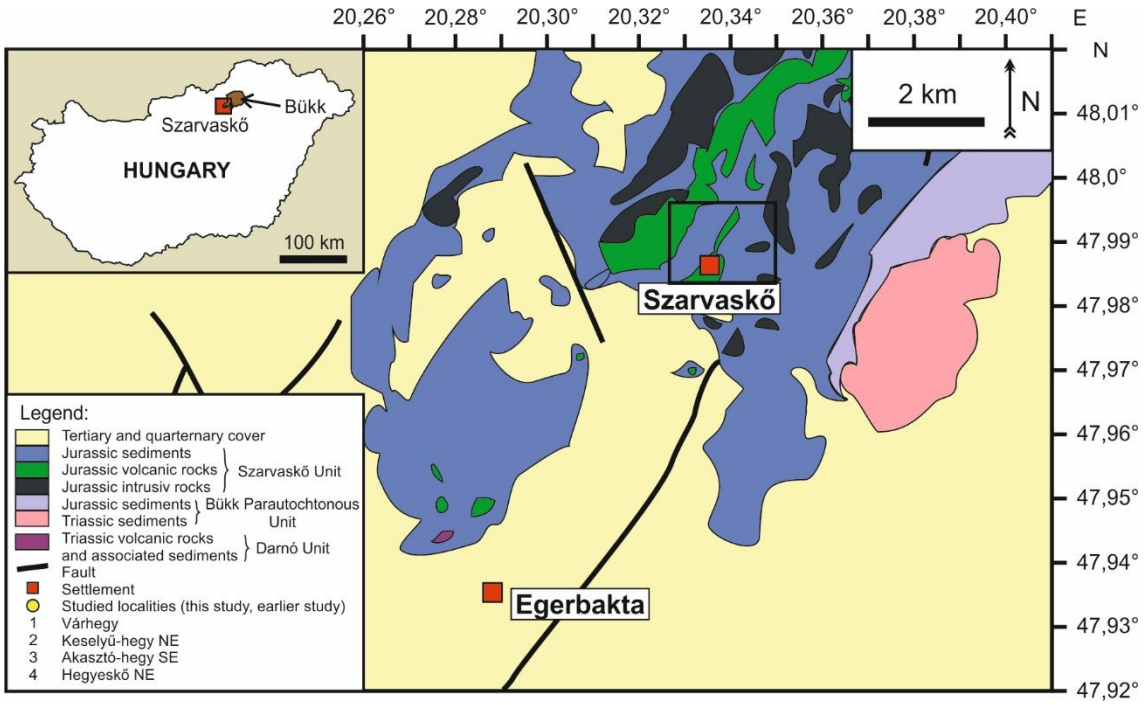

Fig. 5. Geological map of Szarvaskő and its surrounding. Black square shows the location of the field trip stops. Slightly modified after Less *et al.* (2004) by Kiss *et al.* (2012) and Kiss & Zagyva (2017)

Szarvaskő is a little village located in the northern part of Hungary in the Bükk Mountains. An incomplete ophiolitic sequence is found around the village. This area provides a perfect opportunity to get some information about the complex genetics of the Alpine-Carpathian-Dinaric orogeny.

The Szarvaskő Unit is a part of the Bükk Unit, located within the ALCAPA block of the Pannonian Basin (Fig. 5.) (Csontos, 1995, Schmid *et al.* 2008). It is composed of Mesozoic submarine sedimentary and magmatic rocks, formed in the Jurassic Neotethyan Ocean. Submarine sedimentary rocks are represented by deep water, siliciclastic sediments, while magmatic rocks are represented by an incomplete ophiolitic sequence. Beside the well-developed pillow basalt and gabbro series, only scarce plagiogranite, wehrlite, pyroxenite and hornblendite occur, the true ultramafic series is missing (Szentpétery 1953, Balla 1984, Dosztály *et al.* 1998, Pelikán 2005 and the references therein). The Mesozoic sequence of the Unit shows Dinaric relationship. Today's position is the result of the Cainozoic displacement along the Mid-Hungarian Lineament.

According to Árváné Sós *et al.* (1987), the K-Ar age of the magmatic rocks is 165 +/- 5 Ma and 166 +/- 8 Ma, while Balogh & Pécskay (2001) obtained an Ar-Ar plateau age of 162.9 +/-0.9 Ma for contact-metasomatic K-mica found along the intrusive contact of a gabbro

intrusion and host sediments. Kohút & Kiss (2013) reported 170 +/- 9 Ma based on chemical EMP dating of monazite of the plagiogranite associated with the gabbroic intrusion.

The most recent studies suggest that the characteristics (occurring volcanological facies, hydrothermal processes, geochemistry, etc.) of the magmatic rocks at Szarvaskő are different from the typical mid-oceanic ridge related rocks (Kiss *et al*. 2011) and their formation is related to the opening of a back-arc-basin or a marginal basin (Aigner-Torres & Koller, 1999, Csontos, 2000, Haas *et al*., 2011). Árkai (1983), Árkai *et al.* (1995), Sadek Ghabrial *et al*. (1996), Árkai (2001), Péntek *et al.* (2006) and Kiss *et al.* (2012) have also shown the occurrence of a very low and low grade Alpine regional metamorphism related alteration mineral assemblage of Cretaceous age.

4.2. Tóbérc Quarry

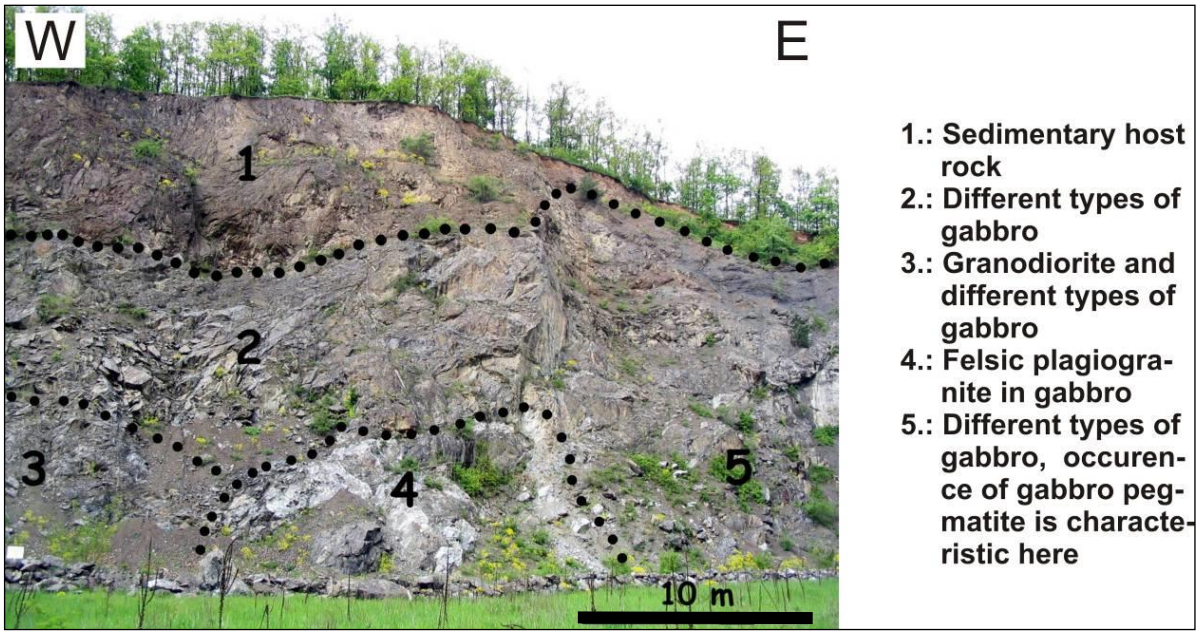

Fig. 6. Panoramic photo of the Tóbérc Quarry (Kiss *et al*., 2011).

Well preserved gabbro and related plagiogranite are found in the Tóbérc Quarry (Fig. 6.). The gabbro is mostly coarse-grained, the major rock-forming minerals are clinopyroxene, plagioclase and amphiboles Besides, the Fe-Ti-oxides are common as well (Fig. 7.). As a curiosity, the oxide-sulphide melt phase differentiation can be investigated as the ilmenite contains roundish pyrrhotite and pentlandite 'drops'. The major rock forming minerals of the plagiogranite are albite and quartz, but one can observe chlorite, garnet, allanite, zircon, monazite and apatite as well.

Occurrence of cm-dm pegmatite lenses are quite common in the gabbro, which were formed between 800-900 °C, according to Péntek *et al.* (2006).

Árkai (2001) has suggested an effect of the Alpine regional metamorphism and Péntek *et al*., (2006) and Kiss *et al.* (2011) could show it with fluid inclusion microthermometry and chlorite thermometry (270 - 285°C, 150 - 200 MPa).

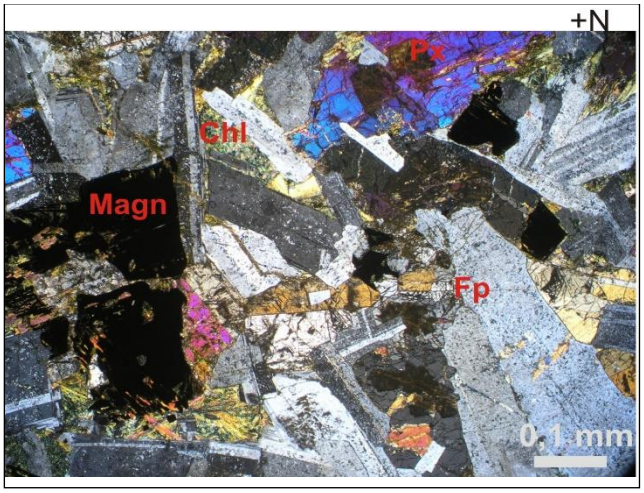

Fig. 7. Typical texture of the Tardosi Gabbro, +N, fp = feldspar, Chl=chlorite, Magn=magnetite, Px=pyroxene. (Kiss and Zagyva, 2017)

4.3. Várhegy

The basalt is well preserved on the Várhegy and composed by albite and augite with porphyry intersertal texture (Kiss *et al.*, 2011 and the references therein). On the Várhegy, basically pillow shaped basalt is found and a low amount of inter-pillow hyaloclastite breccia occurs among the pillows (Fig. 8.). Comparing to other pillow basalts from the area, the pillows of the Várhegy formed in the closest position to the central feeder zone of the lava flow, resulting in the biggest pillow size and the lowest amount of inter-pillow hyaloclastite breccia. The texture of the breccia is matrix-supported. The hydrothermal minerals occur in the matrix (quartz, prehnite, pumpellyite, calcite, chlorite and pyrite), while the material of the clasts is fractured basalt.

Fig. 8. Typical pillow basalt from the Várhegy. (Photo: Tamás Zagyva)

Another type of volcanic facies can be found near to the closely packed pillows, where the pillow shapes are not typical and where the hyaloclastite breccia contains fine-grained siliciclastic material additionally. The small amount of unconsolidated siliciclastic material could have infiltrated into the basalt dominated system at the time of volcanism. It suggests that these are from a more distal part of the former lava flow and the closeness of the two types is an evidence for later tectonic movements (Fig. 9.).

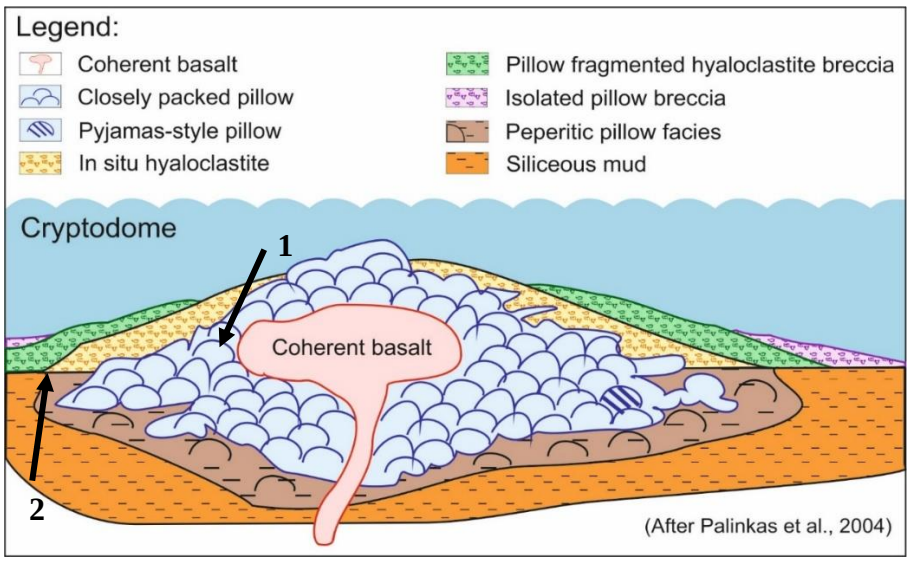

Fig. 9. Volcanic facieses of an ophiolitic series. The 1. arrow shows the proximal, closed packed pillows while the 2. shows the distal pillows of the Várhegy. Slightly modified after Palinkas *et al.* (2004) by Zagyva *et al.* (2015)

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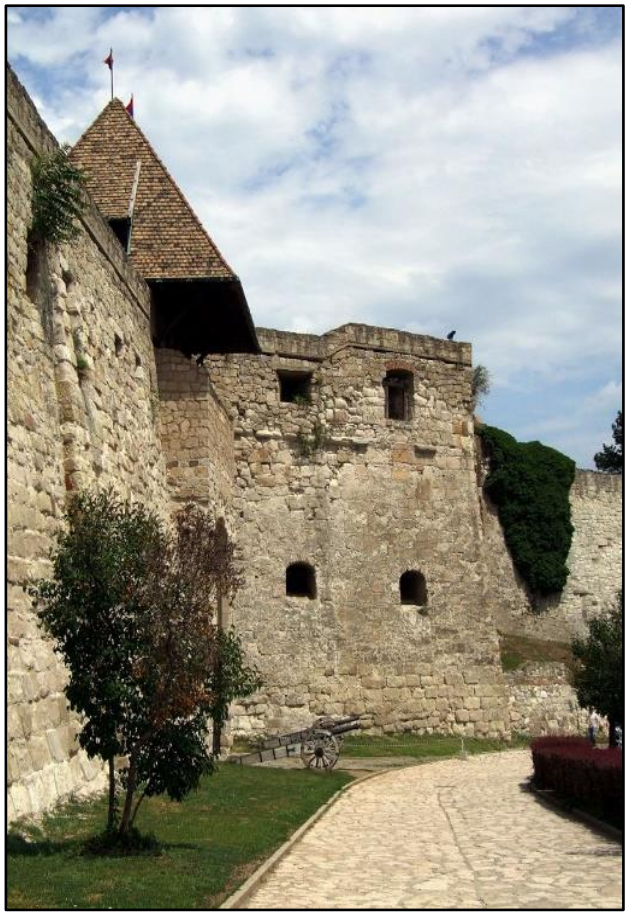
5. Eger

Ákos Kővágó



The castle of Eger

Eger is the county seat of Heves, and the second largest city in Northern Hungary (after Miskolc). Eger is best known for its castle, thermal baths, baroque buildings, the northernmost Ottoman minaret and red wines.

The origin of its name is still unknown. One suggestion is that the place was named after the elder ("égerfa" in Hungarian) which grew so abundantly along the banks of the Eger Stream. There is another theory which says that Eger's name comes from the Latin word: "ager" = earth.

Today's Eger was formed in the 10th century by St. Stephen (997–1038), the first Christian king of Hungary. The first cathedral of Eger was built on Castle Hill, within the present site of Eger Castle. Eger grew around this cathedral and remains an important religious centre in Hungary.

During the mongol invasion in 1241, the town was ransacked and burned down, after the withdrawal of the Mongols, Eger began to flourish all over again. Lambert, the bishop of Eger, received a permit from Béla IV for building a stone fortress. The nearly destroyed town revived and reached the peak of its medieval development in the l4th and 15th centuries. In this period the forests which spread to the limits of the town were cleared for the most part, and vines were planted in their place.

During the reign of King Matthias (1458–1490), Eger began to develop again. The gothic-styled Bishops Palace of Eger which can be seen at the present time was reconstructed by the order of bishop János Bekensloer. After the death of King Matthias, during the bishopric of Hyppolit the so-called Hyppolit Gate was built, this has recently been removed.

In the autumn of 1552, Captain István Dobó and his handful of soldiers were successful in defending the fortress and northern Hungary from the expanding Turkish Empire. The first writer of note to draw on the story was the Hungarian renaissance poet and musician Sebestyén

Tinódi Lantos (c. 1510–1556), whose account may have come partly from eyewitnesses. Géza Gárdonyi wrote his novel, "Eclipse of the Crescent Moon" in remembrance of this battle, and his work has been translated into numerous languages.

Bertalan Székely's "Women of Eger" depicts the siege of 1552

Despite the fact that István Dobó and his soldiers successfully defended the fortress, it was destroyed during the siege, so it was essential to rebuild it. The reconstruction process of the fortress took place between 1553 and 1596. The famous Hungarian poet, Bálint Balassi also served here for a few years beginning in April 1578. However, in 1596 the captain at that time and the foreign mercenaries under his command handed it over. This was the beginning of the 91-year-long Turkish rule in Eger. The minaret, which was built at the end of the 17th century, preserves the memory of this period. Among all the buildings of this type, the minaret of Eger is found in the northernmost point of the former Ottoman Empire. During the Turkish occupation Eger became the seat of a vilayet. Churches were converted into mosques, the castle rebuilt, and other structures erected, including public baths and minarets.

The rule of the Turks in Central Hungary began to collapse after a failed Ottoman attempt to capture Vienna. The castle of Eger was retaken by the Christian army led by Charles of Lorraine in 1687. After the reoccupation the town fell into a very poor state. After the expelling of the Turks Leopold I re-established Eger as a free royal city in 1688, which meant that it was relieved from the ecclesiastic manorial burdens. This state lasted until 1695, when György Finesse, the returning bishop, had the former legal status of a bishopric town restored by the monarch.

Eger soon began to prosper again. The town was reclaimed by its bishops, which caused many local Protestants to leave. The town supported the Hungarian leader Prince Francis II Rákóczi in the 1703–1711 war of independence against the Habsburgs, the Hungarians were eventually defeated by the Imperial army. Soon after that, the town was ravaged by plague. However, immigration into Eger was strong, and the population rose from 6000 to 10,000 between 1725 and 1750.

The Archiepiscopal Palace of Eger

In the history of Eger, the 18th century was the period of development and prosperity. Many new buildings were built in Baroque and later in Rococo and Neoclassical style, including the cathedral, the Archiepiscopal Palace of Eger, the County Hall of Eger, the Eger Lyceum (now housing the Eszterházy College of Education) and several churches, while others were reclaimed from being mosques.

The town population grew suddenly in 1787 more than 17,000 people lived here. At this time, Eger was the 6th largest town of Hungary (based on the number of its inhabitants). Viticulture also reached its brightest period in these days. The wine-growing area was twelve times larger than it had been earlier.

The 18th century was also important because bishop Barkóczy and Eszterházy decided to found a university in Eger patterned after the ones in Nagyszombat and in Vienna. Unfortunately, the university of Eger could not begin its work. In the building which was marked out for the university we can find the Archdiocese's Library (the most beautiful baroque library in Hungary), and an astronomical museum with original equipment, which was the second museum of this type in Europe.

The Period of Reforms (1825–1848) left several lasting marks on the life of Eger, especially on its culture. Pyrker László János, the archbishop of that time, founded a gallery which he donated to the Hungarian National Museum because the town did not guarantee an appropriate place for it. It was Pyrker's present which served as a base for the collection of the Museum of Fine Arts that was opened in 1900. In 1828 Pyrker established the first Hungarian teachers training college in Eger and he was the one who ordered the construction of the basilica which was built in neo-classical style, in accordance with the plans of József Hild. On the basis of its size, this basilica is the second among the churches of Hungary.

The main railway line between Miskolc and Pest bypassed the town, which was only reached later by a branch line from Füzesabony. Unfortunately (unlike other towns) Eger's civil

development did not become faster, as distinguished from other towns, after 1849 and the Compromise of 1867. Industrial development was represented only by the mill, the tobacco factory and the sheet-iron works that were founded in the Reform Age.

During the decades after the turn of the century, the character of a school-town was dominant in Eger. Because of its schools and other cultural institutions, it became known as the Hungarian Athens.

In World War II, the city suffered under the retreating German Army and the arriving Soviet army, but it managed to escape major bombardment.

In the decades after 1945, industrialization of the town commenced because of the change of regime. As a consequence, Eger's former character of a cultural centre began to fade, which diminished the patina of the settlement.

Inner city of Eger

It was a great good fortune that in 1968 the baroque inner city was preserved. So, it was saved from the deterioration (and from the construction of unsuitable, modern buildings).

Beside its historic sights and its thermal baths, Eger is famous for its wines. It produces both red and white wines of high quality. The famous and traditional varieties of the region are Egri Leányka, Egerszóláti Olaszrizling, Debrői Hárslevelű (whites), and Egri Bikavér (a red). Although the quality of the wines deteriorated in the second half of the 20th century, especially the cuvees, Eger is slowly recovering its reputation as a wine region. The most important terroir of the Eger Wine Region is the Nagy-Eged Hill, which is a Grand Cru terroir, where premium Grand Superior wines are produced.

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6. Fe-Cu and Zn-Pb polymetallic ore occurrence in the Rudabánya Ore Bearing Complex

Kristóf Fehér

Historical background

One of the oldest mines in Hungary, the Rudabánya iron mine is located in the Northeastern Range near the town of Miskolc (NE Hungary). The deposit is hosted by Lower to Middle Triassic dolomite and siliciclastic rocks where they are cut by a major NE-striking fault system called the Darno Fault (Fig. 2.) (Hofstra *et al*., 1999). Mining began about 2000 years ago for native copper. In the Middle Ages, Rudabánya was a free mining town and became one of the centres of copper and silver mining. Although mining declined during the 16th and 17th centuries, there was a revival with commencement of the first open pit iron mine in 1878 (Hofstra *et al.*, 1999). The main products were limonite and siderite in the 19-20th centuries (Németh *et al.*, 2013). Intensive exploitation of the limonitic iron ores resulted in the opening of seven pits (Polyanka, Bruinmann, Andrássy I, II and III, Vilmos, Ruda-hegy and Deák Pits) (Fig. 1., 3.) that together form a 5 km long and 1.5 km wide continuous mining belt (Hofstra *et al*. 1999). The open pit and underground iron ore mining in Rudabánya went on from 1872 until 1985 (Bodor *et al*. 2013). Historic exploration activity produced approximately 2.800 boreholes (Németh *et al.*, 2016). ~ 38 Mt of iron ore was excavated during this period, the recent geological resource exhibits 43 Mt of low grade iron ore (including limonite, siderite and ankerite with an average Fe content of 23.5 wt. %, and siliceous siderite) (Balla *et al*., 1987).

Fig. 1. View of the Andrássy II open pit with the mine lake (Photo: Gabriella B. Kiss).

Geological settings

The Rudabánya ore deposit is located in the Aggtelek-Rudabánya Mts. and in a major Oligocene-Miocene shear zone, the Darnó Zone. The Aggtelek-Rudabánya Mts. is part of the Silicicum stratigraphic superunit of the Alps–Carpathians–Pannonian (ALCAPA) region (Fig. 2.) which consists of Upper Permian-Lower Triassic evaporites (Perkupa Evaporite Formation), Lower Triassic marine, siliciclastic and carbonate rocks (Bódvaszilas Sandstone, Szin Marl, Szinpetri Limestone Formations) and Middle-Upper Triassic carbonates (Gutenstein Formation, Steinalm Formation, Dunnatető Limestone, Bódvalenke Limestone, Hallstatt Limestone Formations) (Less *et al.*, 2006).

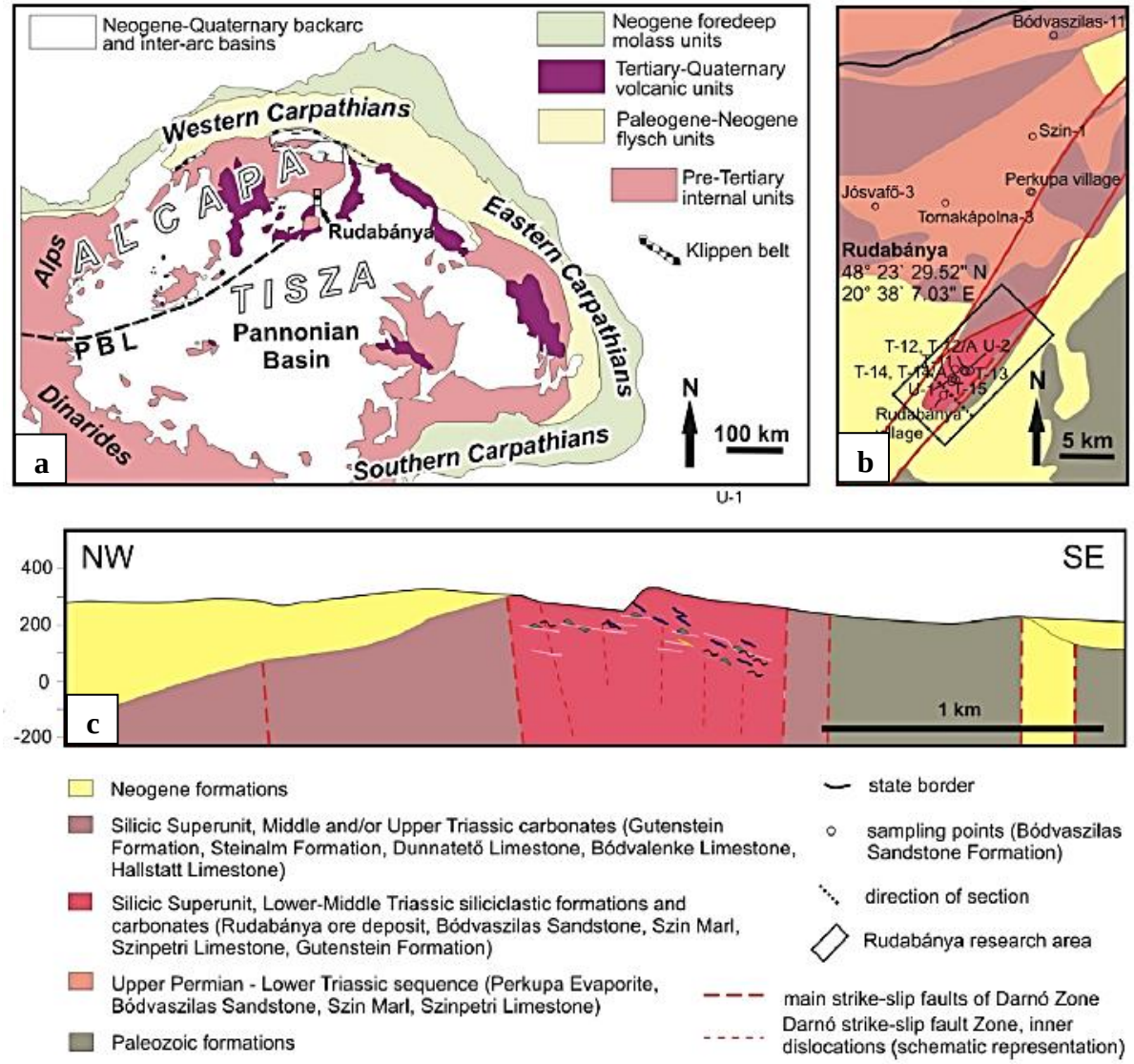

Fig. 2. (a) Location of the Rudabánya iron and base metal deposit in the Alps-Carpathians region. (b) The Rudabánya research area and the sampling points of the Bódvaszilas Sandstone Formation. The entire area of the Rudabánya Mts., which is part of the Aggtelek-Rudabánya Mts. and includes the Rudabánya ore deposit, is located in the Darnó strike-slip fault Zone. The Mesozoic formations located west and east from the Zone, cannot be correlated, as their original facies areas and tectonic locations are different, but the age of the formations is partly the same. (c) Geological section of the Rudabánya ore deposit (Bodor *et al.*, 2016).

The deposits are hosted by tectonically disturbed and metasomatized sedimentary rocks, situated in the Darnó Zone, an approximately 100 km long, NNE–SSW striking regional strike-slip fault zone with variable activity during the Cenozoic (Zelenka *et al.,* 1983; Fodor *et al*., 1999). Along this zone, approximately 65 km SSW from Rudabánya, occurs the significant porphyry and skarn copper ore deposit of Recsk. However, there is no evidence of any magmatism affecting the ore-forming processes at Rudabánya. The zone also contains low-grade metamorphic rocks, Jurassic mélange, and serpentinised ophiolite bodies derived from tectonic units other than the Silica Nappe (Németh *et al*., 2016). Tertiary sediments overlie the basement rocks unconformably. seams. The unconformity implies that a considerable part of the ore bearing complex was exposed on the surface for long periods during the Tertiary, and, in consequence, an oxidized cap was formed before the Pannonian (Németh *et al.,* 2013).

This succession can be identified in the mineralized complex cropping out in the mining area NNE of Rudabánya, situated in an approximately 1.5 km wide zone bordered by master faults of the Darnó Zone, uplifted from the Neogene sediment-covered environment. The rocks in this regional fault zone are fragmented, brecciated and have an imbricate and blocky structure; 10–100 m scale carbonate blocks are embedded in a fine-grained, marly matrix (Németh *et al*., 2016).

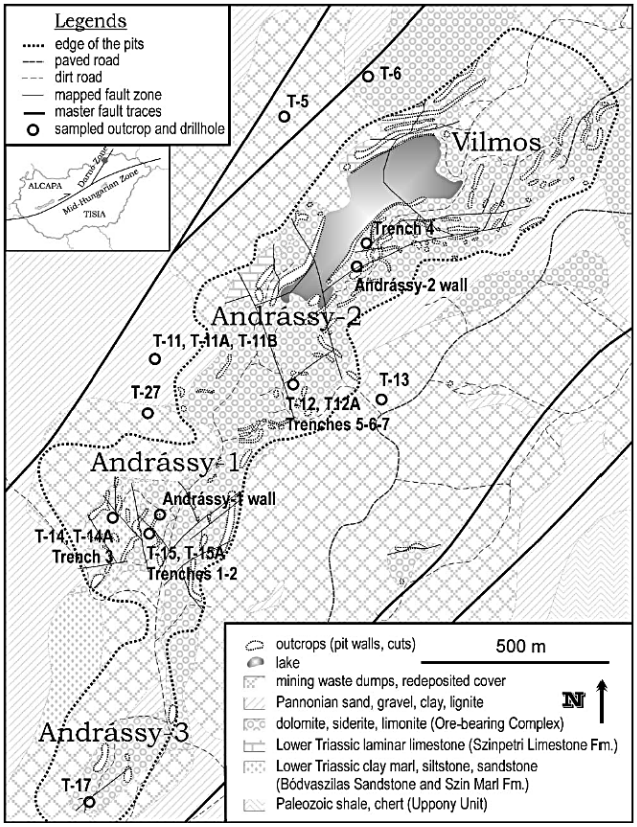

Fig. 3. Geological map of the Rudabánya iron ore open pits (Németh *et al*., 2016).

Ore deposit types

The Rudabánya Ore Bearing Complex hosts iron and copper ore deposits with barite and galena mineralisations.

Iron ore deposit

The siderite ore forms separate dissected blocks of various size from ten to a few hundreds of meters in diameter in a pelitic matrix (Németh *et al.*, 2013). Pantó (1956) attributed this to a metasomatic alteration of tectonically preformed, brecciated and insulated Gutenstein Dolomite blocks, with less impact on other sedimentary rocks.

Fig. 4. Typical photo of the oxidation zone at Rudabánya (Photo: Gabriella B. Kiss).

The sideritisation was strong in the core of the uplifted ridge, weakening toward the edges (Németh *et al.*, 2013). This formation is the primary siderite iron ore and it was also the protolith of the secondary limonite ore (Németh *et al*., 2016). Original (now mostly extracted) outcropping bodies were limonitised together with their country rocks, containing a rich and spectacular secondary assemblage of base metal minerals and forming a rich supergene paragenesis (oxidised cap) (Fig. 4.). These metals occur in the form of sulphides in the siderite bodies along with barite. Ankerite nodes and cement can also be found in the underlying sandstone and siltstone (Bodor *et al.*, 2013a, 2013b). The occurrence of barite, pyrite, and further sulphide minerals is also typical for these nodes, while the bulk of the siliciclastic rocks (except for the limonitised parts) is barren (Németh *et al*., 2016).

Copper ore deposit

Copper sulphide (mainly chalcopyrite, bornite, tetrahedrite and tennantite) mineralisation occurs as fine dissemination or patches bound to the siderite with 0.15% Cu content on average (Pantó, 1956). The Cu ore is lithologically controlled, it is hosted predominantly in brecciated carbonate rocks of the fault zones. The copper sulphides are bound to carbonate rocks affected by metasomatism. The grade of the copper enrichment does not depend on the grade of the sideritisation, and it also occurs in the marginal parts of the mining area (Németh *et al.*, 2016).

Copper sulphides and associated minerals overgrow the carbonate grains of the host rock, which occur in veins and in the cement of brecciated rocks. The first significant copper mineralisation (primary copper mineralisation) followed the precipitation of the pyrite and sparry carbonates of dolomite–ankerite composition, also overprinting the products of iron metasomatism (Pantó, 1956).

Ore controls were similar in all of these mineralisation events: fault zones and fractured, brecciated rocks, mainly carbonates. Mineralized host carbonate rocks may previously have been only weakly metasomatized, but Fe-containing, zonal carbonate minerals are always present, even in sandstone hosted occurrences (Németh *et al.*, 2016).

Mineralisation began with the crystallization of tennantite and pyrite forming spherical assemblages, occasionally containing copper and barite as well. After that, bornite formed in major quantity and substituted partly in the previously precipitated minerals. In the following stage, chalcopyrite was formed as a substituent of bornite, fahlore, and pyrite, and also as individual chalcopyrite grains, thus becoming the most frequently occurring copper mineral of the assemblage (Fig. 5.). The crystallization of chalcopyrite and alteration of previous copper minerals indicates an increasing sulphur fugacity and iron content of the system.

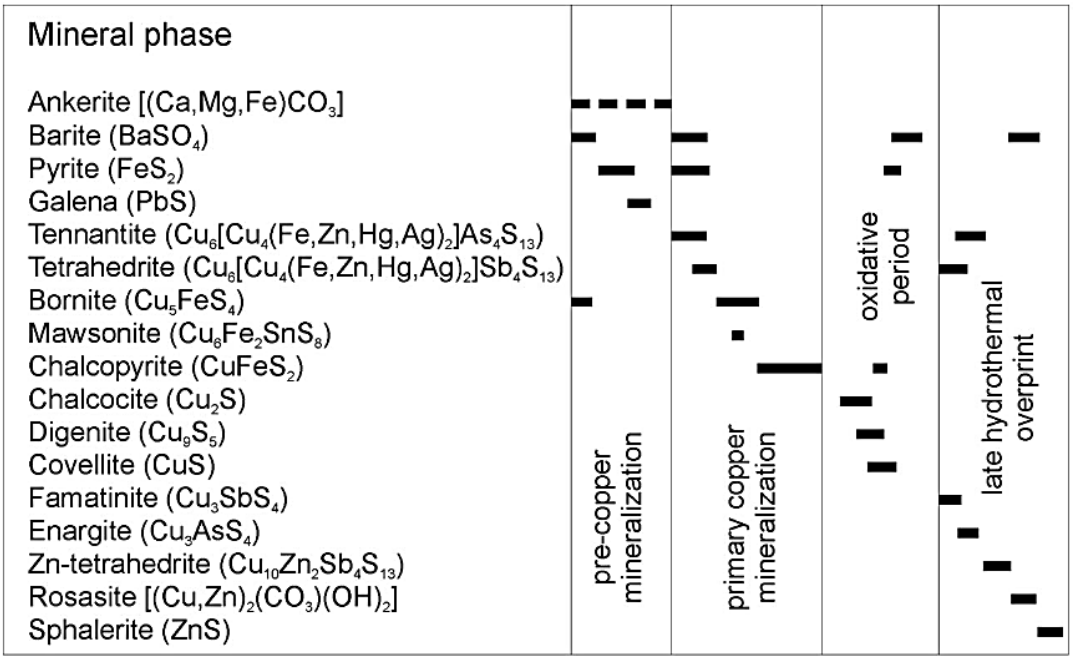

Fig. 5. Evolution chart of the described mineral assemblage related to the copper sulphide mineralisation (Németh *et al.*, 2016).

After chalcopyrite crystallization, the environment became oxidative in certain parts of the deposit, because the oxidation of bornite led to the digenite–covellite–chalcopyrite association, then, chalcopyrite was altered to covellite and pyrite. The latest phases of the mineralisation process are barite and sphalerite, which substitute copper sulphides and copper carbonates as well. So, the oxidation and late-stage hydrothermal mineralisation remobilized the base metals from the altered minerals, and previous mineralisations, producing polymetallic supergene enrichments (Németh *et al.*, 2016).

Zn-Pb ore deposits, and other base metal enrichments

Galena and accessory sphalerite are known from the barite-enriched edge zones of the siderite deposit (Pantó, 1956). The Cu and Pb–Zn sulphides occur separately, which may suggests different genetics. The Pb and Zn is hosted in shale and siltstone, and Csalagovits (1979) even detected silver and manganese enrichment in these siliciclastic rocks, and in carbonates. In some cases, the lead mineralisation consists of alternating barite and sulphide-rich stripes, more frequently, it shows a brecciated structure with cm-scale carbonate, barite and sulphide nodes of large grain size, and cm-scale clasts. In other cases, ore minerals occur in the clasts of a breccia, thus the evolved ore was subsequently fragmented. Galena lenses can also be found in the marl country rock of the carbonate blocks, regarded as clasts previously sheared from the edges of the blocks (Németh et al. 2016).

In some cases, this material occurs in folded layers and was interpreted as a stratiform zinc–lead ore deposit type hosted by the underlying marl (Földessy *et al.* 2010; Németh *et al.* 2013). This ore (and the carbonate-bound type as well) also contains sphalerite beyond galena, and Zn content exceeds Pb by a factor of 4–5 (Németh *et al.* 2016).

Stable isotope studies of the sulphide mineral species of the siderite ore deposit indicated MVT similarity (Hofstra *et al.,* 1999).

The role of underlying evaporite as sulphur source is also possible. The mineralisation was not found in the directly underlying porous sandstone affected by later siderite metasomatism, suggesting rather a lateral synsedimentary exhalative than an ascendent metasomatic origin (Németh *et al.* 2013).

The epigenetic barite and sulphide mineralisation bound to the rim zones of the siderite blocks (Pantó, 1956). Barite, galena and carbonates frequently contain fibrous sulfosalt inclusions; Szakáll (2001), Szakáll & Kovács (1995) described silver containing sulphides and sulfosalts like pyrargyrite, proustite, xanthokon, pyrostilpnite and stephanite. He also observed acanthite and native silver in the galena. Remobilization of primary stratiform ores during later hydrothermal processes is a possible explanation of their genesis (Németh *et al.* 2013).

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7. Tokaj Mountains

General geology and mineral deposits of Tokaj Mountains

Molnár Ferenc in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC Field trip guide, Budapest (ISBN 978-963-08-9294-0)

Geology

The Tokaj Mts. is a part of the Neogene-Quaternary Charpatian Volcanic Belt, which has been formed in relation to subduction of an oceanic slab (remnant of the Penninic Ocean that has been opened during the Jurassic times) between the microcontinents of European and African origin and the European continent itself. Subduction occurred from the north-northeast in the Western Carpathians and from the east in the Eastern Carpathians (Radulescu and Sandulescu, 1973; Royden, 1988; Csontos et al., 1992)

The Tokaj Mts. comprise the southern part of the Slanské-Tokaj Unit, a volcanic range situated in a 1.5 to 3 km deep, north-south trending graben-like structure which is about 150 km long and 15-20 km wide in northeastern Hungary and eastern Slovakia. The Hungarian portion covers approximately 1200 km2 in the Tokaj Mts. and has a moderate topographic relief. The highest peaks are between 700 and 900 m above sea level. The centre of the Tokaj Mts. is located south of Regéc (Fig. 1.).

The graben-like structure of the Tokaj Mts. is filled by Middle-Upper Miocene (Badenian-Sarmatian-Pannonian) volcanic-sedimentary sequence (Fig. 1) and is bordered by the north-northeast trending Hernád Fault and the northwest trending Szamos Fault (Pantó 1968, Gyarmati 1977). The southeast margin of the graben is bordered by the northeast-trending Bodrog Fault. These faults can be related the major strike-slip, left- lateral Zagrab-Zemplén Fault (Mid-Hungarian Fault) of the Pannonian Basin. Within the graben the major faults trend north-south or nearly perpendicular to the Bodrog Fault. The strike-slip movement along the Zagrab-Zemplén Fault caused about 300 km northeastward displacement of crustal units during the Palaeogene – Early Miocene. Paleomagnetic data indicate that during the Miocene an approximately 30° counter- clockwise rotation occurred in some regions of Tokaj Mts. (Balla, 1987; Csontos et al., 1991). The σ1 direction of the regional stress field in the Pannonian area changed from north to the east after the Badenian (Csontos et al., 1991; Csontos et al., 1992). The change in the stress field was caused by the migration of the Carpathian subduction front from west to east. This migration was also accompanied by the change of subduction from oblique in the west to perpendicular in the east. During this tectonic evolution local pull-apart features developed along the regional strike slip faults (Horváth, 1993). Thus, the opening of

the north-south oriented graben of the Tokaj Mts. appears related to pull-apart extension generated by the large-scale strike slip faulting. Thus, the pattern of faults within the graben reflects the change of the regional stress field from north-south to east-west directions. The basement within the eastern part of the graben consist of Pecambrian gneiss and mica schist related to an Assyntian metamorphism (962 Ma), Paleozoic porphyroids (metamorphosed during the Caledonian orogenesis at about 450 Ma), sandstone, conglomerate and shale (metamorphosed during the Saalian Orogeny), and Triassic to Jurassic limestone and dolomite.

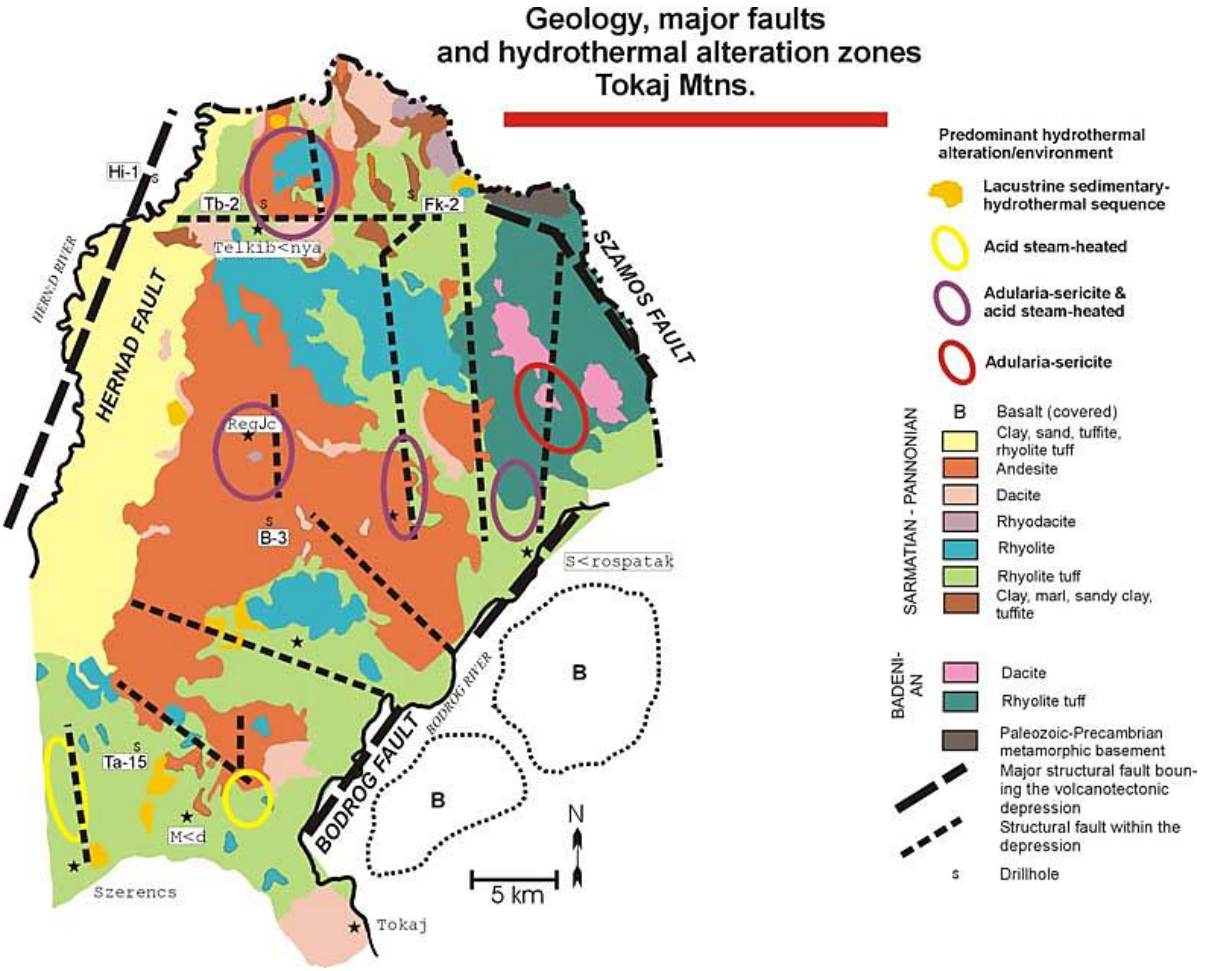


Fig. 1. Geological map of Tokaj Mts. (Modified after Gyarmati et al., 1976).

Along the eastern border of the graben these rocks are exposed north of the Szamos Fault, in the Zemplénikum Unit (Fig.1); west of the fault these rocks occur at 960 m depth in the Füzérkajata-2 (Fk-2) borehole (Ilkey-Perlaky and Pentelényi 1978; Fig.1). Basement rocks have not been penetrated by deep drilling (-1500 m below sea level) in the western and central part of the graben (Hi-1, Tb-2, Ta-15 and B-3 drillholes; Fig.1), but presence xenoliths in volcanic rocks indicate the existence of Palaeozoic shale lithology in the basement (Gyarmati 1977). The basement along the western part of the depression is at least at 1500-2000 m depth (Zentai 1991).

Volcanism started in the Middle Miocene (Badenian) with accumulation of thic rhyodacitic tuff. K-Ar ages for this unit are between 15.2±1.3 and 13.0±0.6 Ma (Pécskay et al., 1986). Ignimbrite, ash flow, and crystal tuff deposits of this volcanic phase are now on the surface only along the northeastern part of the Tokaj Mts. (Fig.1). Along the western boundary of the graben this tuff occurs beneath the approximately 1400m thick younger sedimentary and pyroclastic rocks. The eruptive centres of the Badenian tuff are related to the northwest trending Szamos Fault.

The early eruptive phase was followed by graben subsidence and marine transgression from the northeast. The andesitic and dacitic volcanic rocks succeeding this stage were mostly emplaced in a submarine environment, resulting in various types of peperitic and brecciated rocks intercalated with shallow marine clays, marls and fine sands. These submarine volcanic accumulations are known from drilling in the central part of the Tokaj Mts. at depths below 800 m (B-3 drilling, Fig.1). Small and shallow subvolcanic andesitic-dacitic intrusions were also associated with the Badenian volcanic activity and these intrusions now crop out in the northeastern part of the Tokaj Mts. or are known from the deepest parts of the Telkibánya (Tb)-2, Füzérkajata (Fk)-2 and Tállya (Ta)-15 drillings (Fig.1). At the end of the Badenian, volcanic activity temporarily ceased and uplift of various segments of the basement resulted in the regression of the Badenian sea. Deposition of shallow marine-brackish water clay, marl, sand and reworked volcanic material was restricted to small basins in some parts of the Tokaj Mts. The Sarmatian-Pannonian volcanic phase consisted of successive deposition of acidic and intermediate rocks and basaltic volcanism in the final stage. According to Mátyás (1974), the general evolution of the Sarmatian-Pannonian volcanism in different parts of the Tokaj Mts. was initiated by eruptions resulting in rhyolitic tuff sequences up to 600 m thick, accumulating under partly subaqueous, partly subaerial conditions. In the volcanic centres these tuffs are associated with small rhyolite domes. The products of this volcanic stage crop out in the northern part of Tokaj Mts., as well as in the east and south Tokaj Mts. in an area around Sárospatak, Erdőbénye, Mád and Szerencs (Fig. 1.).

The Lower Sarmatian acidic volcanic stage was followed by or at some places it was contemporaneous with andesitic-dacitic eruptions producing aerially extensive lava flows and locally tuff accumulations. Centers of this volcanic stage form caldera-like depressions and circular structures in the vicinity of Telkibánya, Regéc and Mád, as well as cones in the central parts of the Tokaj Mts. (Fig.1). The andesitic products of these eruptive events can be divided into two units (Gyarmati, 1977). The thick-bedded andesite lava flows of the lower unit are often intercalated with andesite pyroclastic beds. Most typically the lava flows of the lower

andesite unit have a weathered appearance, but propylitic alteration is also typical in areas proximal to volcanic centers. The subvolcanic- intrusive bodies of the lower andesite are located in the caldera-like structures and are characterised by propylitic and adularia-sericite alteration (Telkibánya, Mád, Regéc, Fig.1). The caldera-like depressions are also associated with andesitic cones (Telkibánya, Regéc) or extrusions of rhyolite and dacite (all centers). The K-Ar ages of rocks from these centers cluster between 12.5 and 11.5 Ma (Pécskay et al., 1986).

During the major stages of the Sarmatian andesitic volcanism some areas of the Tokaj Mts. were still covered by a shallow sea. Therefore, tuffaceous accumulations are often well bedded and intercalated with clastic-pelitic sedimentary rocks deposited in brackish water. Synchronously with or succeeding the accumulation of the lower andesite units, rhyolitic dome-flow centres formed independently between Telkibánya and Sárospatak, as well as in the vicinity of Erdőbénye and Mád (Fig.1). The most typical K-Ar ages of these rocks are between 10 and 12 Ma (Pécskay et al., 1986).

The late stage of volcanic activity was characterised by either pyroxene andesite lavas or local dacite-rhyolite products. The andesitic lava flows occurring at higher elevations in the western and central part of the Tokaj Mts. form the upper andesite unit, and they are correlated with the emplacement of andesitic dikes (Telkibánya, Mád). Dacitic extrusions and intrusions occur sporadically in the area of the Tokaj Mts; the most important occurrence is at Tokaj (Fig. 1.). K-Ar ages of rocks deposited during the late, Pannonian stages of volcanic activity are mostly between 10 and 11 Ma (Pécskay et al., 1986).

The olivine basalt of the final stage of volcanism in the Tokaj Mts. (9.4 ±0.5 Ma; Pécskay et al., 1986) is not exposed; it is covered by Pannonian and younger sediments and is known only from drillings in the vicinity of Sárospatak along the eastern boundary of the Tokaj Mts. (Fig.1).

The Sarmatian-Pannonian volcanic cycle shows a more differentiated character compared with the Badenian stage (Gyarmati, 1977). Both volcanic cycles started with acidic products and evolved to and intermediate-basic composition.

However, the full rhyolite-rhyodacite-dacite-acidic pyroxene/amphibole andesite–pyroxene andesite series developed only during the Sarmatian-Pannonian cycle. According to Gyarmati (1977), Póka (1988) and Szabó et al (1992), the petrochemical characteristics of these volcanic rocks have calc-alkaline signature with transitional character between island-arc and active continental-margin magmatic series. However, the rocks show much diversity, with high-K character (K_2O>2.5 wt%) for rhyolite and some dacite and medium K-character (0.75-2.5 wt% K_2O) for andesite and dacite. Mátyás (1974) suggested that the temporal variation in

the composition of volcanic rocks originated from different levels of secondary magma chambers.

Szabó et al. (1992) concluded that the bimodal character of volcanism indicates the existence of different magma chambers for different rock types, or a different degree of contamination in the same magma chamber. The initial 87Sr/86Sr (0.7060-0.7135), 134Nd/144Nd (0.51221-0.51255) and Pb-isotopic ratios presented by Salters et al. (1988) and Downes et al. (1995) indicate a strongly contaminated character of the volcanic rocks in the Tokaj Mts. The isotopic characteristics most probably resulted from the contamination of metasedimentary or acid meta-igneous upper crust in a mantle-derived melt which composition was already modified by the subducted slab.

Mineral deposits

Both Badenian and Sarmatian-Pannonian volcanic cycles of the Tokaj Mts. were associated by intense hydrothermal activity. In general, both volcanic cycles generated low-sulfidation type epithermal systems in which metallic and non-metallic mineral deposits were formed depending on the palaeodepth of hydrothermal processes, as well as proximal or distal setting in relation to the major conduits of hot fluids. Because of the different depths of erosion, different levels of epithermal environments are exposed. In addition to the mineral deposits of hydrothermal origin, volcanic rocks, especially perlite, and their non-hydrothermal alteration products (e.g. zeolite) have important economic values in the Tokaj Mts. Resources and reserves of non-metallic mineral deposits are listed in the Table 1.

Type of raw material	**Resource (1000 t)**	**Reserve (1000 t)**
Kaolin	8200	3100
Illite	1700	800
Bentonite	7700	5400
Silica	10765	5100
Diatomite	5000	1700
Alunite	200	50
Potassium	700	200
Zeolitic tuff	26900	17500
Perlite	30500	15100

Table 1. Resources and reserves of the Tokaj Mts.

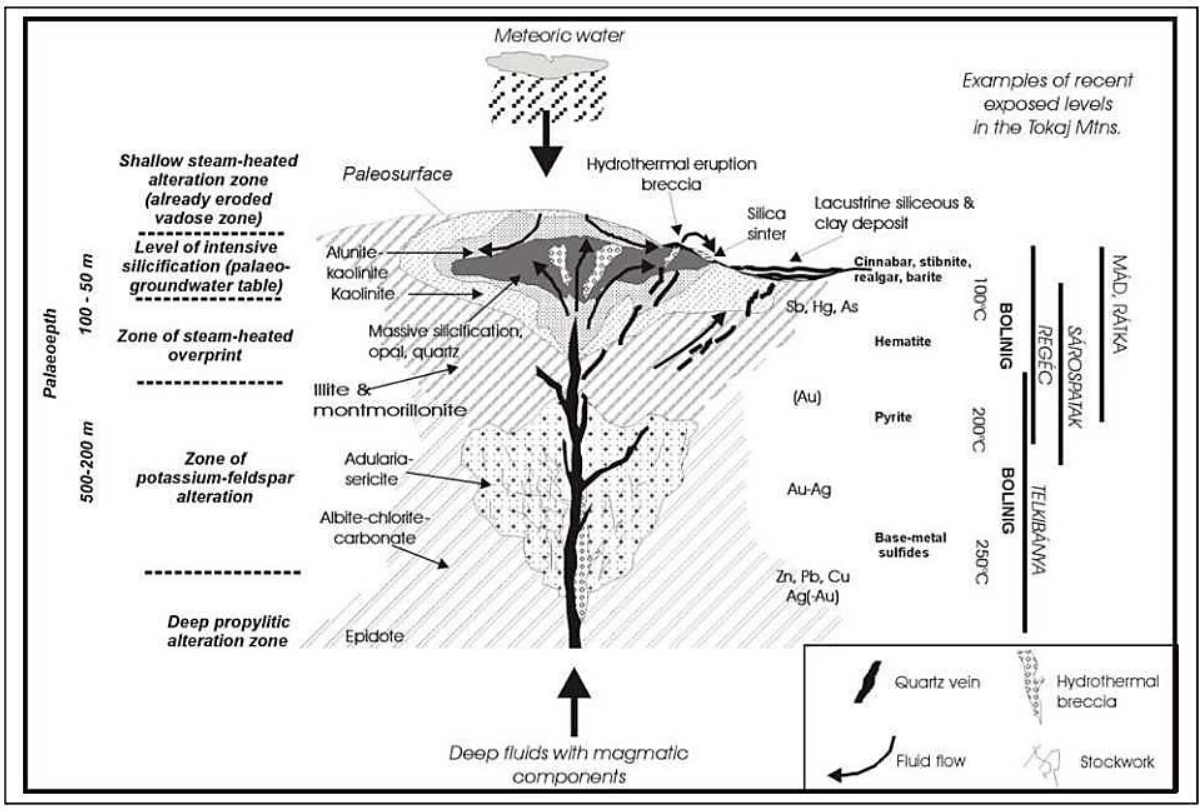
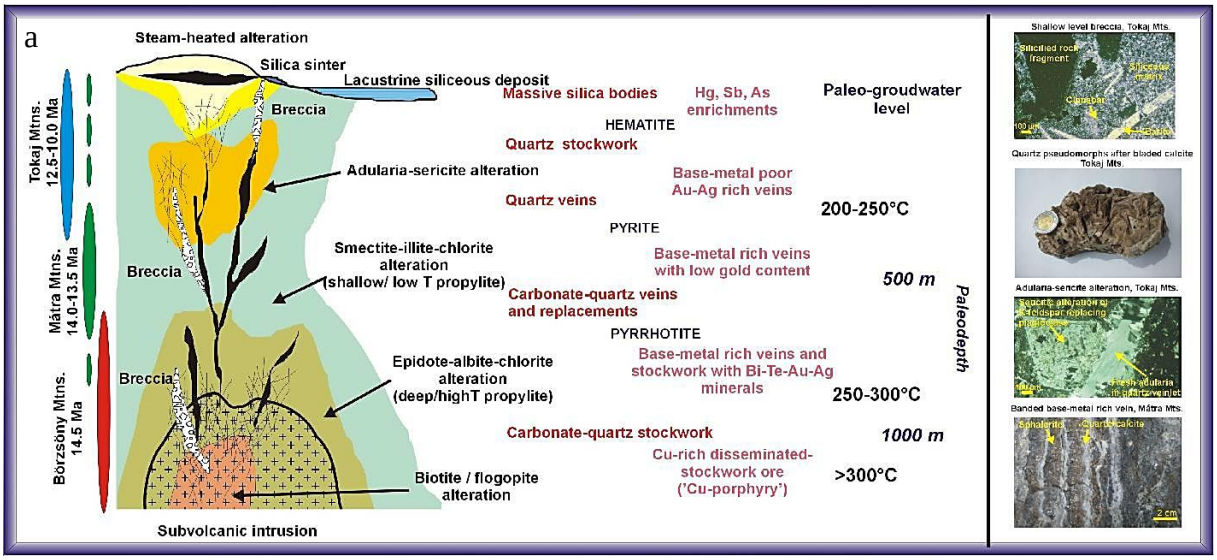


Fig. 2. Model for hydrothermal systems and occurrences of metallic and non- metallic mineral deposits in the Tokaj Mts. (Molnár et al., 1999).

The location of the most strongly mineralized zones is controlled by the major faults and volcanic centers; most commonly their orientation is elongated in a north-south direction. The alteration zones at Telkibánya, Regéc, Komlóska, and north of Sárospatak and around Mád are characterized by strong potassium anomalies. Chemical analyses of altered rocks from these areas contain above 5-8 wt% K2O (Széky-Fux, 1970; Gyarmati, 1977). These hydrothermal zones with quartz veins surrounded by adularia-sericite alteration (resulting in potassium anomalies) were the sites of the medieval gold and silver mining at Telkibánya and north of Sárospatak (Fig.1). In similar zones at Komlóska and around Regéc, exploratory pits associated with the old mining activity can be found. In the last 100 years the alunite-kaolinite alteration zones (the very shallow steam-heated acid alteration part of low sulphidation type epithermal systems) in the Mád area and north of Sárospatak, as well as the strongly argillized (bentonitic) host rocks to veins at Komlóska, have been the primary targets of clay exploration and exploitation. The small basins and their lacustrine environments formed at the late stages of volcanism in several parts of the Tokaj Mts. and they host illite (Füzérradvány) as well as diatomite, bentonite, kaolinite and silica accumulations (Erdőbénye, Mád). These lacustrine environments were also fed by hot springs and accumulation of raw materials can be interpreted

as a result of combined distal hydrothermal and sedimentary processes. A generalized model for the hydrothermal systems of the Tokaj Mts. with the occurrences of various mineral deposits is shown on the Fig.2. This model was established on the basis of detailed geological, mineralogical, geochemical, fluid inclusion and K-Ar studies (Molnár et al., 1999).



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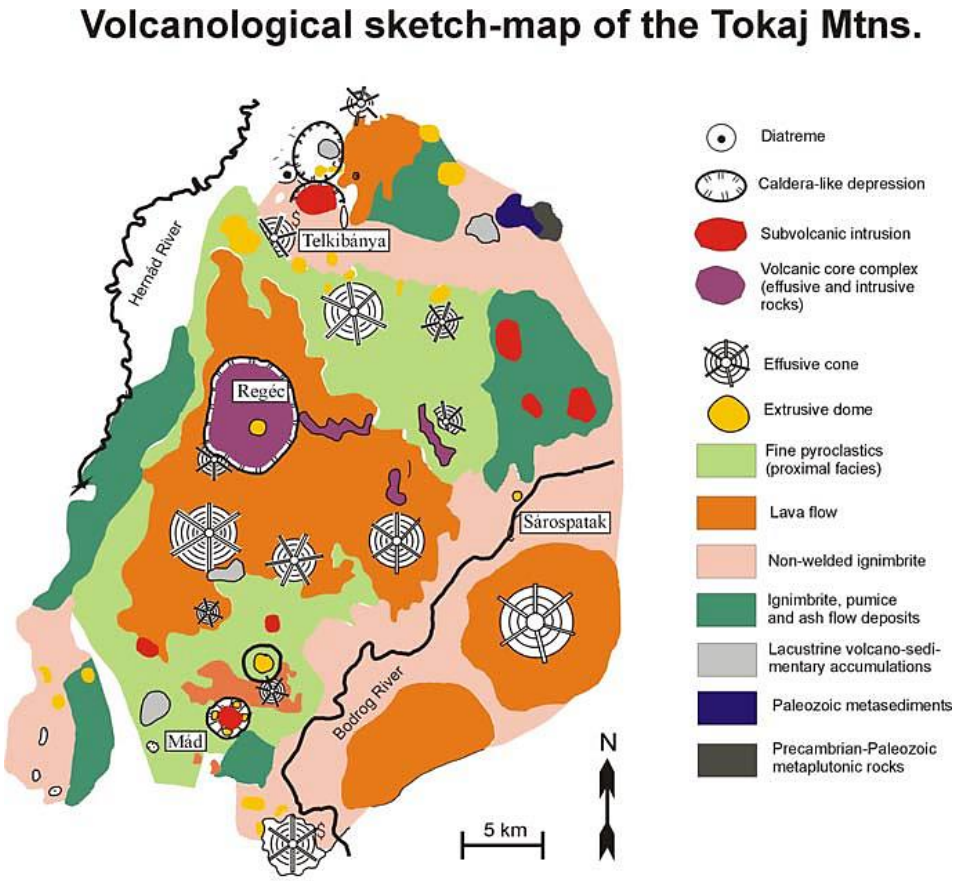

Fig. 3. a, Proposed model for hydrothermal mineralization of the Neogene volcanic belt in Hungary b, Volcanological sketch map of the Tokaj Mtns. Compiled by T. Zelenka and P. Gyarmati (1977).

7.1. The perlite quarry of Pálháza, Tokaj Mts.

Benedek Gál in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

General geology

The Miocene volcanism of the Tokaj Mts. took place in two major stages. The older (Badenian) volcanic stage produced ignimbrite and felsic tuff eruptions along with andesitic to dacitic lava flows and andesitic-dacitic subvolcanic bodies intruded intro the earlier volcanic and sedimentary rocks. The initial stages of the Sarmatian-Pannonian volcanic cycle of the Tokaj Mts. started in partly subaqueous and partly subaerial conditions. This second phase was characterized by accumulations of felsic tuff often intercalated with shallow marine clay and marl. In the central and northern part of the Tokaj Mts., initial felsic pyroclastic deposition was followed by formation of subaerial andesitic stratovolcanic structures (Telkibánya and Regéc). Synchronously with andesitic volcanism, rhyolite dome-flow complexes were formed in the Mád area as well as southeast of Telkibánya.

The quarry near Pálháza village is located in this northern rhyolite field of the Tokaj Mts. The quarry on the northern slope of the Gyöngykő Hill exposes a perlitic part of a rhyolite intrusive and extrusive dome-flow complex which penetrated the lower Sarmatian shallow marine clay and marl units (Fig. 4.). Perlite occurs as marginal facies of lava flows on the slopes of a cryptodome with dip angle of bedding varying from subhorizontal to fairly steep angles. The size, the geometry and the contact relationship between the host mud and the coherent igneous bodies indicate a multiple injection and pulsatory magma supply that formed the cryptodome and dome complex exposed here.

Geochemistry

In general, petrochemistry of the well differentiated Sarmatian-Pannonian volcanic series show medium to high calk-alkaline character with up to 5 wt % potassium content for rhyolites. SiO2 content of the rhyolitic samples from the Tokaj Mts. ranges between 70 and 77.5 wt%. No significant difference can be detected in the major element and also the trace element concentrations of the perlites and the fresh rhyolites except the H2O and the Cl content of the perlites are remarkably higher (H2O=3.9 and 4.7 wt%; Cl=676-740 μg/g) then that of the fresh rhyolites (H2O> 1.4 wt% and Cl> 460 μg/g) (Németh et al. 2006). Boron-content of the examined whole rock samples is between 20-68 μg/g, falling in the range typical for subduction related volcanics. Geochemical data including major oxides and trace elements and the

radiometric ages determined on the perlitic samples reflect the high homogeneity of the whole volcanic body.

K-Ar ages are in accordance with biostratigraphic data which shows that perlite at Pálháza is slightly older than perlite from the adjacent areas in the Carpathians (13.6 Ma at Pálháza, 12.5-11.6 Ma in other areas e.g. Avas/Oas, Kárpátalja/Transcarpathia and Slansky Vrchy, according to Németh et al. 2006).

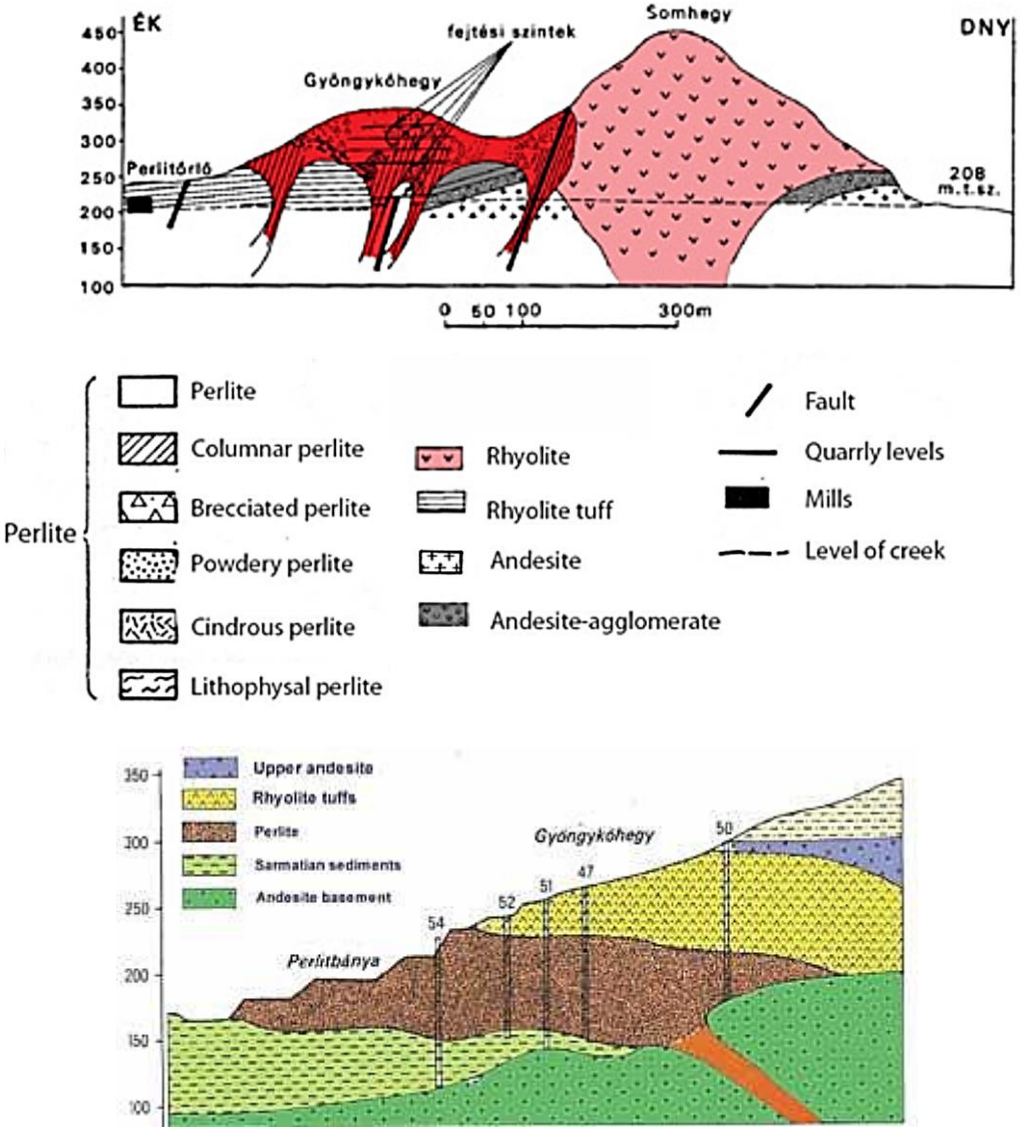

Fig. 4. Simplistic cross section of the perlite mine and its vicinity near Pálháza (after Véghné 1967).

Volcanic facies

The quarry exposes in a 3D view at least 200 m thick succession of complex rhyolitic cryptodomes and endogeneous lava domes, partially intruded into wet, unconsolidated marine sediments. The individual coherent magmatic bodies are slightly concave upward and they are up to 50 m wide and 25 m thick. The columnar jointing is well developed in the inner core of

the individual lensoid coherent lava facies. Many of the margins of the coherent rhyolite are glassy and strongly perlitic in texture. Columnar jointing forms a slightly radial joint pattern and platy fracture zones perpendicular to the main jointing. The more intact rhyolitic coherent units are commonly flow banded and having alternating cm-wide black and grey zones. The coherent bodies have only occasional vesicular texture, and the vesicles exclusively located in the outer margin of the individual coherent igneous bodies. The coherent magmatic rocks are very glassy in general, and porphyritic, aphanitic in texture.

The interior of the coherent silicic magmatic bodies are commonly false vitriclastic in texture with small dm-size relicts of original perlitic, black glassy zones. Along the dome margins, thin darker colored, variably devitrified obsidian perlite can be identified that are commonly flow banded and shows also false vitriclastic texture.

The contact relationship with the underlying marine sediments records shallow marine (from few tens to few hundred meters depth) depositional environment and suggest subaqueous emplacement of the igneous masses.

Fragmented volcanic rocks form a complex architecture enclosing most of the coherent rhyolitic rock units in the quarry. The matrix supported, angular, glassy commonly flow banded rhyolitic clast rich, massive volcaniclastic breccias are interpreted to be hyaloclastite associated with the emplacement of the silicic igneous units at Pálháza. The general increase of jig-saw fit hyaloclastitic breccia near the rhyolitic, rhyodacitic coherent zones indicates that the hyaloclastite is in situ and no significant remobilisation of clasts took place through gravity flows.

Besides fragmented volcanoclastic units the coherent rhyolite domes are also surrounded by few meters thick breccia zones on the contacts with shallow marine muddy sediments. Proportion of the marine sediments increases dramatically, especially on the base of the exposed volcanic successions. These reaction rims of the rhyolitic lava and the soft in-situ marine sediments are considered as a peperitic facies of the volcanic build-ups. The identification of peperitic margin along the Pálháza rhyolite complex attest its predominantly shallow subsurface intrusive origin, where rhyolitic magma initially intruded unconsolidated and wet fine grained sediments. Unlike it is common in the case of mafic lavas peperites here are not much fluidal (globular) but display a rather blocky nature which is interpreted to be the result of the progressive cooling of the magma during intrusion, and also from the breakdown of fluidization when the limited supply of fine glassy matrix in the host hyaloclastite was exhausted similarly to the processes well described in mafic intrusions into coarse grained sediments. Increasing magma viscosity as temperature decreased (and overall lower intrusion

temperature compared to mafic magmas), combined with pulsatory intrusion, were inferred to be evidently important in the production of the blocky peperite. Muddy sedimentary dikes of various thicknesses also penetrate into the jig-saw breccia zones of the coherent rhyolitic bodies.

Industrial use

What makes perlite an important raw material is its water content. Compared to other volcanic felsic glassy materal (pumice, obsidian) it contains a relatively large amount of water even up to 2-7 wt%. Most of the known perlite occurrences are young volcanic areas because of easy devitrification of the material. Average composition of perlite used for industrial purposes is:

SiO_2: 73%, Al_2O_3: 13%, Alcalines: 7%,Water: 2-7% FeO: 1-2%,

MgO: 1% CaO: 1.5% TiO_2: <0.3% P_2O_5: <0.03%

Perlite after fine-crushing is heated in furnaces. During this process water content of the rock evaporates while the rock expands resulting in a very porous material with tube-like microscopical pore spaces, resistant to moisture, heat, pests and weathering. Volume increase during the processing can be as high as 1:20. Depending on the properties and quality of the material, expanded perlite can be widely used in different applications. Thermal and noise insulations, filters, absorbents are the main fields of use of high quality perlite. Large amount is used as admixture to concrete and other constructional material. Agricultural use is also significant.

Although perlite in Hungary occurs in the Mátra and Tokaj mountains as well, exploitation only takes place in the latter. Mining of perlite near Pálháza began in 1957 and continued without disruption up until now. Today perlite from Pálháza adds 6% to the world's and 30% of Europe's perlite consumption.

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7.2. Diatomite at Ligetmajor, Erdőbénye, Tokaj Mts.

Zsófia Poros in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

The diatomite of Erdőbénye is one of the 13 significant non-metallic raw materials of the Tokaj Mts. Exploitation started in 1937 (Mátyás, 1987), today known reserves are approximately 4-5 million tons of diatomite. Diatomite is accompanied by another raw material here, called bentonite, which is a halmyrolytic product of volcanic tuffs.

Geological setting and sequence

In the Tokaj Mts. little pull-apart basins were formed due to strike-slip movements in Badenian times. Diatomite beds were formed in such a lacustrine basin filled up by limnic and volcanic sediments. Large amounts of SiO2 in the water, due to the volcanism, are propitious for reproduction of diatomes.

Diatomite beds at Erdőbénye are parts of a 100-110 metre thick freshwater sedimentary sequence (Fig. 5.). The basement of the basin is andesite which is covered by an allochthonous and autochthonous pumiceous-vitric tuff. Alteration of the tuff shows lateral zonation: no significant alteration can be observed in the nearshore region which resulted in porous, non-argillic rocks without siliceous cementation. Sediments in the "offshore" region are rather characterised by fine-grained sediments with significant alteration resulted by interaction with hydrothermal fluids. Both rock types are overlain by four cycles each with diatomite beds. The cycles start with pumice-dominated sandstone followed by diatomite beds which are overlain by limnoquartzite. In the diatomite beds there may be also intercalations of pumice-sand and opal-limnoquartzite. Within all four cycles, grain size decreases upward (Mátyás in Végh, 1967).

Basin-evolution (Mátyás in Végh, 1967):

1st phase: "transgression" (lake-level rise): clastic sediments 2nd phase: "stagnant" water level: fine-grained diatomite

3rd phase: "regression" (lake-level fall): coarse-grained diatomite

4th phase: geomorphological "differentiation": formation of several, smaller basins 5th phase: cessation of limnic environment

Age

The age of the diatomite is Sarmatian (~13-12 Ma) based on biostratigraphy. Predominant diatome species are: Melosira and Navicula (Hajós, 1959).

Mineral composition

Diatomite at Erdőbénye consists of small (~10 1m) frustules of freshwater diatoms and small amounts of clay and limonite with organic contaminations at some places (Hajós, 1959). In the case of 1st class diatomite SiO2- content is higher than 80 %, Al2O3 is about 4%, Fe2O3-contamination is up to 1 %, TiO2 is 0.8 % (Mátyás in Végh, 1967). As secondary mineral phase hydroquartzite can be observed along cracks.

Consumption

These small boat-shaped diatoms have economic significance as filter aid and as insulating material– because of their significant microporosity – and as abrasives. Nowadays more and more they are used in environmental industries and in the agriculture, as well.

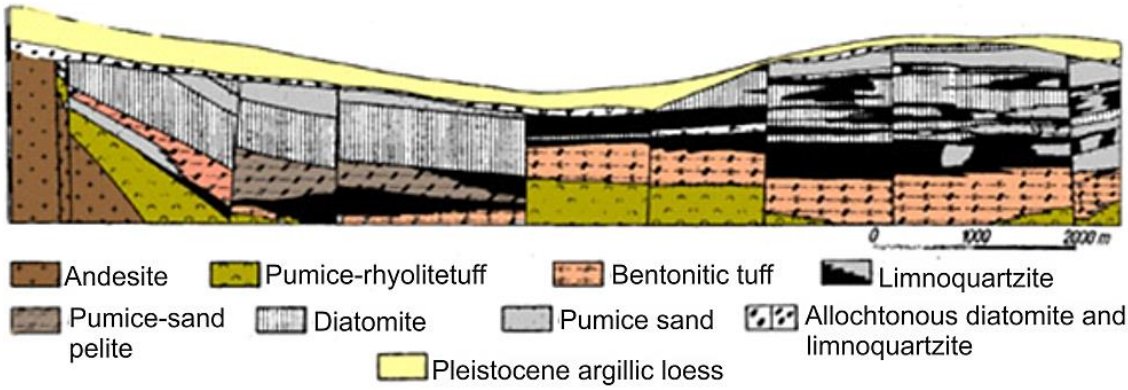

Fig. 5. Geological section of the diatomite deposits at Erdőbénye (Mátyás in Végh 1967).

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7.3. The Au-Ag deposit at Telkibánya

Ferenc Molnár in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

Local geology

The Sarmatian volcanism in the Telkibánya area started by deposition of rhyolitic tuffs overlain by and partly intercalated with shallow marine and fluvioclastic sedimentary rocks. The eruption center of the rhyolite tuff is located in the southwestern part of this area (Horváth et al., 1989; Fig. 6.). The tuff is covered by 30-40 m thick sandstone- conglomerate fluvioclastic sequence in the eastern part of the deposit (Figs. 7. and 8.). The conglomerate consists of well rounded pebbles of metamorphic rocks, as large as 10 cm. Some pebbles from the rhyolite tuff also occur.

Andesite, dacite and rhyolite were subsequently emplaced as lavas, domes and dikes. These are the main rocks that crop out in the mineralized area (Fig. 6.). Based on evaluation of satellite images, remnants of two andesite calderas 5-7 km in diameter and andesite cones were recognized NNE of Telkibánya (Horváth et al., 1989; Horváth and Zelenka, 1997; Fig. 6.). The Tb-2 drillhole revealed that the southern caldera, which hosts the majority of mineralization, contains an approximately 700 m thick sequence of andesite lavas. K/Ar ages for the fresh andesite are between 11.8±1.0 and 13.1±1.2 Ma (Pécskay and Molnár, 2002). Within the calderas, rhyolite domes and lava flows, as well as rhyodacite flows were also emplaced. Some of these acidic rocks are intensely altered. A subvolcanic body corresponding to the intrusive facies of the lower andesite unit was emplaced in the central part of the southern caldera. Intrusive breccias were found along its contacts with both Upper Badenian clays and Sarmatian clays and rhyolite tuff (Horváth and Zelenka, 1997). The area of positive gravity anomalies coincides with the location of this andesitic body (Fig. 7.). Subsequently faults with NNW-SSE, NE-SW and E- W strikes developed. Younger, post-mineral domes (11.2±0.7 Ma; Pécskay and Molnár, 2002) formed in the middle of the northern caldera and south of the southern caldera (Fig. 7.).

The latest stage of volcanic activity in the region is represented by unaltered upper pyroxene andesite lava flows covering the higher elevations south of Telkibánya (Gyarmati, 1977). The K/Ar age of this rock is 10.7 Ma (Pécskay et al., 1986). The 0.5 to 10 m thick unaltered pyroxene andesite dikes occurring in the strongly mineralised southern caldera (Fig. 7.) have K/Ar ages between 10.6±1.4 and 10.9±0.5 Ma (Pécskay and Molnár, 2002), suggesting that the emplacement of these late dikes was genetically related to the volcanism producing the upper andesitic lava flows.

Wall rock alteration

In the Telkibánya area, precious- and base-metal mineralization formed in association with both the Badenian and the Sarmatian volcanic stages. The older phase was recognized only in the Tb-2 borehole (Fig. 6.) at depths between 900 and 1050 m. There, stockwork mineralization occurs in mm-cm thick veinlets hosted by the Badenian volcanic rocks, and it is characterized by a sphalerite-galena-pyrite-chalcopyrite- arsenopyrite assemblage (Széky-Fux, 1970; Molnár, 1993; Horváth and Zelenka; 1997). The host rocks underwent various alteration processes from the albite-chlorite-epidote- carbonate bearing propilitization to adularia-sericite alteration.

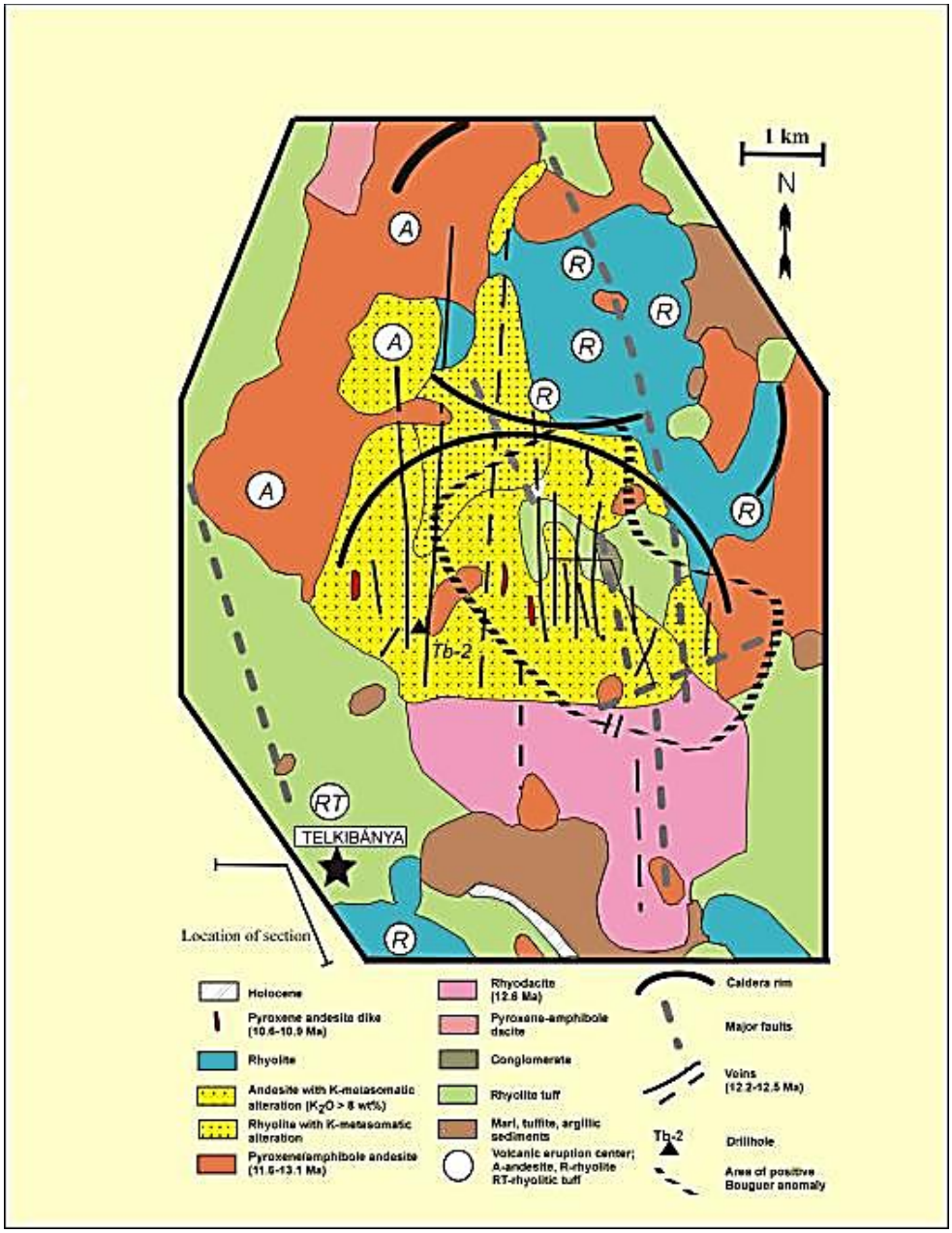

Fig. 6. Geological map of the Telkibánya ore deposit from Széky-Fux (1970), Gyarmati (1977), Molnár (1993) and Horváth and Zelenka (1997).

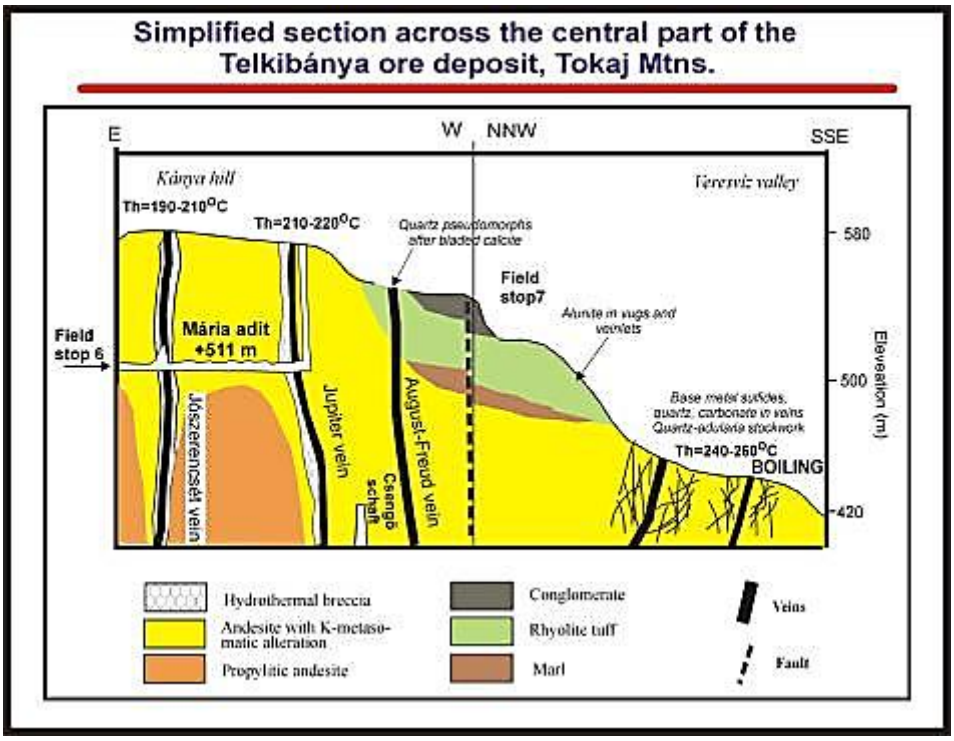

Fig. 7. Generalized section across the eastern part of the Telkibánya ore deposit. Location of the section is shown in Fig. 6. Data from Széky-Fux (1970), Horváth and Zelenka (1997) and Molnár (1997). Th – modes of homogenization temperatures in fluid inclusions from vein quartz.

The near-surface mineralization is hosted by the Sarmatian volcanic rocks. The deposit is located mostly in the southern caldera structure, where the major host rock is the strongly altered subvolcanic andesite (Fig. 6.). In the vicinity of veins, especially in the near-surface zones, the altered andesite contain 8-14 wt% K2O (Széky-Fux, 1970). The high potassium content of the rock resulted from the replacement of plagioclase by K- feldspar, and the occurrence of adularia in the dense network of thin (0.1-1 mm) veinlets, as well as in the silicified groundmass (Molnár, 1993; Molnár, 1994b).

Hydrothermal K-feldspar that replaces plagioclase was subsequently altered to illite while adularia in veinlets is fresh. This suggests that replacement of plagioclase by K- feldspar and its successive alteration preceeded the fracturing of the host rock and precipitation of adularia in the veinlets. The mafic phenocrysts of the strongly altered rock are replaced by quartz aggregates and chlorite. Pervasive dissemination of pyrite crystals with sizes of 0.1-1mm is also common. According to Széky-Fux (1970), the adularia-sericite alteration is funnel-shaped and pinches out in the deeper zones of the mineralization (Fig. 7.). Propylitic alteration envelopes the adularia bearing zones and this type of alteration predominates along the deeper zones of veins. Plagioclase is altered to albite or calcite, and mafic minerals are replaced by chlorite. Disseminated pyrite is common and epidote is also present and in the deeper parts of

the propylitic zone. In comparison to the fresh andesite and propylite, the Na2O, CaO, MgO and FeO content is very low, whereas the Fe2O3 content has increased to 4-7 wt.% in the alteration zones with adularia. The K-rich rocks are also enriched with respect to As, Zn and Ni (100-130 ppm) as well as Ba (up to 0.08 wt.%; geochemical data are from Széky-Fux, 1970).

The rhyodacite and rhyolite in the eastern and southern parts of the mineralization (Fig. 14) are also characterised by intense potassic alteration and silicification. K-feldspar replaces phenocrysts and groundmass. Mafic minerals are replaced by chlorite. Argillic alteration with illite, carbonate alteration, and pyrite dissemination is also typical (Kozák, 1994).

Rhyolitic tuff in the eastern part of the deposit (Figs. 6. and 7.) contains strongly altered zones characterized by the complete dissolution of pumiceous fragments. Within these vugs euhedral (platy and rhombohedral) alunite crystals up to 1 cm are present (Molnár, 1993). Alunite also occurs as disseminations in the porous groundmass of the rock as well as in comb-textured aggregates filling fractures. The groundmass of the rock shows silicification in the form of fine-grained quartz aggregates and weak dissemination of xenomorphic pyrite with a small amount of kaolinite.

The conglomerate overlying the rhyolitic tuff in the eastern part of the mineralization (Figs. 6. and 7.) shows intense silicification. Kozák (1994) reported the occurrence of adularia in the fractures of this rock.

Characteristics of the veins

The majority of vertical-subvertical veins at Telkibánya trend north subparallel to major faults of the area; a few trend NE (Fig. 6.). The E-W trending faults cross cut mineralized veins. (Széky-Fux, 1970). The major veins extend to 3 km strike length and their width varies from 0.1 to 1 meter. Hydrothermal and tectonic breccia zones (3-5 m width) commonly occur along the contacts of the veins. In the upper zones of the deposit the hydrothermal breccias are strongly silicified and have very fine-grained rock-flour matrix with disseminated pyrite. The matrix of the breccia veins is less silicified and forms a softer, argillised mass in the deeper zones. Wall rock fragments in the breccias are semiangular-round with variable size, up to 5 cm. Angular fragments of the silicified fine-grained matrix are also present suggesting repeated brecciation. The hydrothermal breccias grade into fractured country rock that have undergone adularia-sericite alteration.

In the vein outcrops, quartz and lesser amounts of chalcedony, opal, kaolinite and smectite are common. Five major textural varieties of vein quartz can be distinguished (Molnár, 1993; Fig. 8.). At some places quartz pseudomorphs after bladed calcite also occur. Euhedral

quartz crystals are widespread in the 1-10 cm size gas cavities of altered rhyolite, and in vugs of brecciated zones in altered andesite and rhyodacite. This type of quartz shows perfect euhedral-prismatic and scepter habit. Opal (opal A and opal CT; Molnár and Szakáll, 1994) and chalcedony predominate in the northern termination of veins. Coarse aggregates of rhombohedral and scalenohedral calcite occur in the deeper zones of the veins where it is associated with quartz and sulfides (Fig. 7.). Calcite is also common in stockwork mineralization found in the Tb-2 drillhole (see location on Fig. 6.) between 430 to 500 m depth below the surface (Horváth and Zelenka, 1994).

The sulfide paragenesis is simple. With the exception of pyrite, base-metal sulfides appear in small pockets in the deeper parts (below 450 m elevation) of the veins. In this base-metal rich ore, chalcopyrite, galena, freibergite and acanthite are partially replaced by a later sphalerite-pyrite association, which is followed by the precipitation of a second generation of acanthite, Ag-bearing sulfosalts and pyrite. This late Ag-rich paragenesis also contains 5-10 μm large grains of native gold. A late stage "gel-like" pyrite often overgrows the earlier pyrite and this late Fe-sulfide contains up to 3-4 wt% arsenic plus antimony (Molnár, 1993). Sphalerite is always characterised by growth zonation with alternating thick yellow and dark brown zones. Bulk chemical analyses (Széky-Fux, 1970) and XRD analyses (Molnár, 1993) indicate that the sphalerite contains 3.3 to 7.8 wt% Fe.

Base-metal content is very low in the upper zones of veins. Pyrite is the major sulfide mineral with very irregular distribution in the siliceous and hydrothermal breccia veins. Native gold occurs sporadically as fine disseminations in quartz. The silver content of gold grains is higly variable up to 45 wt% (Szakáll and Kovács, 1994). Enrichment of gold and silver (Au up to 7 ppm; Ag up to 320 ppm) occur in 10-15 m wide chimney-like structures in the pyrite-rich zones of the quartz veins (Horváth and Zelenka, 1997). Base- metal rich pockets of the deeper zones have Au concentrations up to 20 ppm and silver concentrations up to 600 ppm (Széky-Fux, 1970). Siliceous hydrothermal breccia veins contain 100-750 ppm Ag; the Au-content is usually below 1 ppm. Breccias with argillic (smectite, illite) matrix and the clay rich selvages along them contain 0.4-6.4 ppm Au and 10-630 ppm Ag. The quartz and quartz-carbonate stockwork (Tb-2 drillhole, 430-450 m; Veresviz valley, Fig. 8.) contain 0.6-2.0 ppm Au and 1-14.8 ppm Ag (Horváth and Zelenka, 1994).

Precious metal production from the Telkibánya mine is not known due to the lack of documentation from the Medieval Ages. Dumps near the medieval mills contain 29 546 tons of fine-grained mud with 0.1 to 0.7 ppm Au and 3-168 ppm Ag (Horváth and Zelenka, 1997).

These data suggest that the Medieval miners used efficient crushing and washing methods for processing of ores, leaving largely uneconomic waste material.

The most typical secondary minerals in the oxidation zone (above 380 m elevation) are limonite, goethite, Mn-oxides, jarosite-plumbojarosite, gypsum, anglesite, melanterite, halotrichite and alunogen (Széky-Fux, 1970; Szakáll et al., 1994a; Molnár and Szakáll, 1994). Chlorargyrite, Ag-Hg-chloride and Pb-chloride are also reported (Szakáll et al., 1994b).

Age of the mineralization

K/Ar ages of fresh rocks range from 10.6±1.4 to 13.5±1.5 Ma. The K/Ar ages of adularia lie in a narrow time interval between 12.2±0.7 and 12.4±0.5 Ma. The data from intensively altered rock samples with very high K content show slightly younger ages from 12.0±0.5 to 12.4±0.8 Ma but considering the standard deviation of the K/Ar data they are indistinguishable from the ages determined on hydrothermal minerals. Data for alunites are 12.49±0.51 and 12.27±0.57 Ma indicating that alunite alteration is coeval with hydrothermal mineralization at Telkibánya (Pécskay and Molnár, 2002).

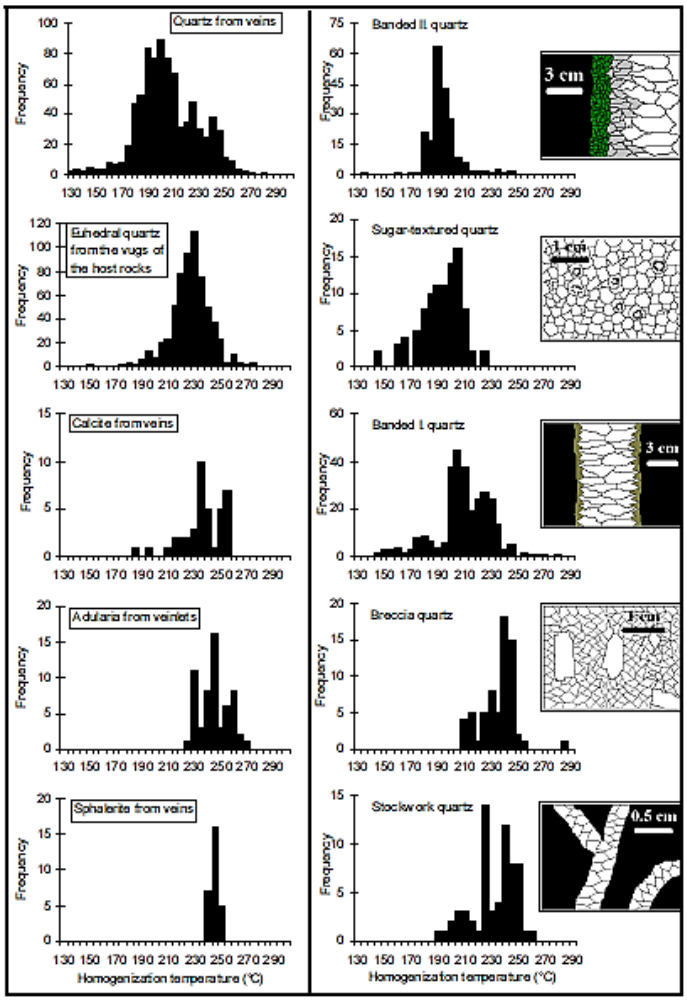

Fig. 8.: Homogenization temperature of fluid inclusions from various minerals and texture varieties of quartz from the Telkibánya ore deposit, Tokaj Mts.

Fluid inclusion data

Homogenization temperatures for sphalerite, adularia and calcite range from 200 to 270°C with most typical values between 230 and 260°C (Fig. 16). Data for vein filling quartz are polymodally distributed between 130 and 270°C. Homogenization temperatures correlate with the texture of vein filling quartz (Fig. 8.). In contrast, frequency distribution of homogenization temperatures from euhedral quartz in vugs of host rocks shows a well defined peak at 230 °C. Coexisting

liquid-rich and vapor-rich fluid inclusions occur in vein quartz samples with homogenization temperatures above 200°C as well as in euhedral quartz crystals. This suggests that boiling conditions existed during the hydrothermal activity (Molnár and Zelenka, 1995).

The ice melting temperatures in fluid inclusions correspond to salinities less than 5 NaCl equiv. wt% (Fig. 9.). The variation of ice melting temperature with the homogenization temperature suggests that both boiling with gas loss and dilution with marginal steam heated waters affected hydrothermal fluids during mineralization. Locally dilution with ground water also occurred.

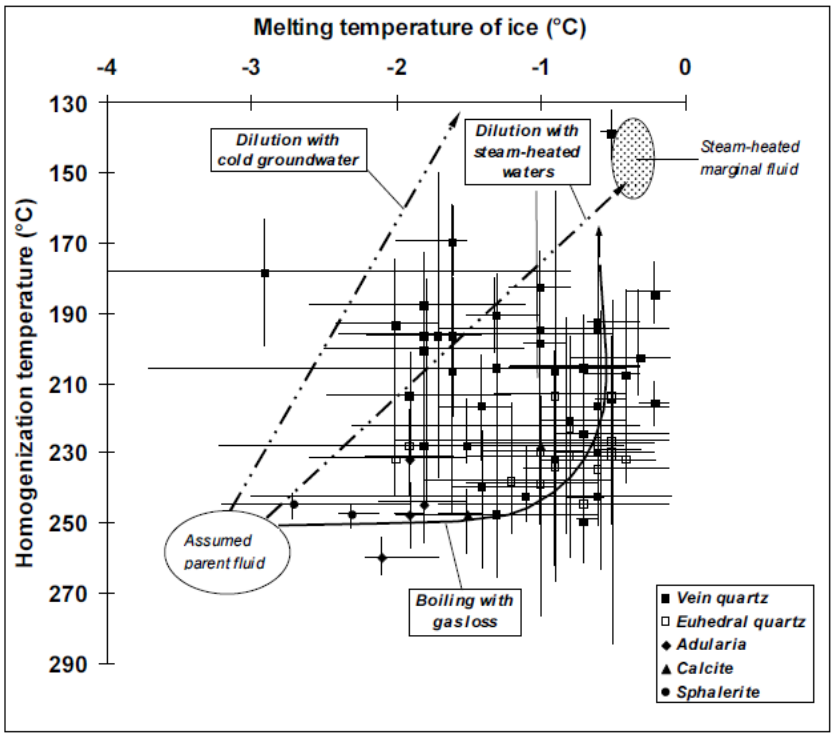

Fig. 9. Homogenization temperatures vs. ice melting temperatures diagram for fluid inclusions, Telkibánya (modified from Molnár and Zelenka, 1995).

Data points correspond to average values of samples. Error bars indicate the range of data. Field of steam-heated marginal fluids (ca. 150 °C, Tm ice~ 0.5°C) is from Hedenquist et al. (1992). Distributin of data points may be explained by gass loss during boiling and by dilution with steam-heated waters. Expected trend for dilution with cold ground water is also indicated.

The degassing of fluids during boiling is also indicated by the characteristics of the adularia-sericite alteration in the Telkibánya ore deposit. The precipitation of adularia after sericitic alteration of earlier K-feldspar indicates an increase of pH during stockwork- type fracturing of the altered host rock (Molnár, 1994). This shift of pH to neutral-alkaline conditions

can be explained by the partitioning of acidic gases, such as CO2, into the vapor phase during boiling related to a pressure drop resulting from the development of open fractures (Browne and Ellis, 1970). The precipitation of calcite in the same temperature range as adularia (Fig. 9.) and the occurrence of bladed calcite (pseudomorphosed by quartz) in some veins (Fig. 8.) are also consistent with the occurrence of boiling (Brown and Ellis, 1970; Simmons and Christiensen, 1994).

Boiling curves fitted to the fluid inclusion data indicate that the paleowater table was at 775 to 900 m elevation (Fig. 10.). Thus, the minimum amount of erosion ranges from 200 to 500 m. The spread of homogenization temperature data suggests that the water table may have shifted during mineralization (Simmons, 1991) as is indicated by the occurrence of alunitic alteration just above an adularia-bearing horizon (Fig. 7.). In general, Figure 10. shows very similar patterns to the depth-temperature profiles of geothermal fields such as Broadlands, New Zealand (Hedenquist, 1990) and Otake-Hatchobaru, Japan (Taguchi and Nakamura, 1991).

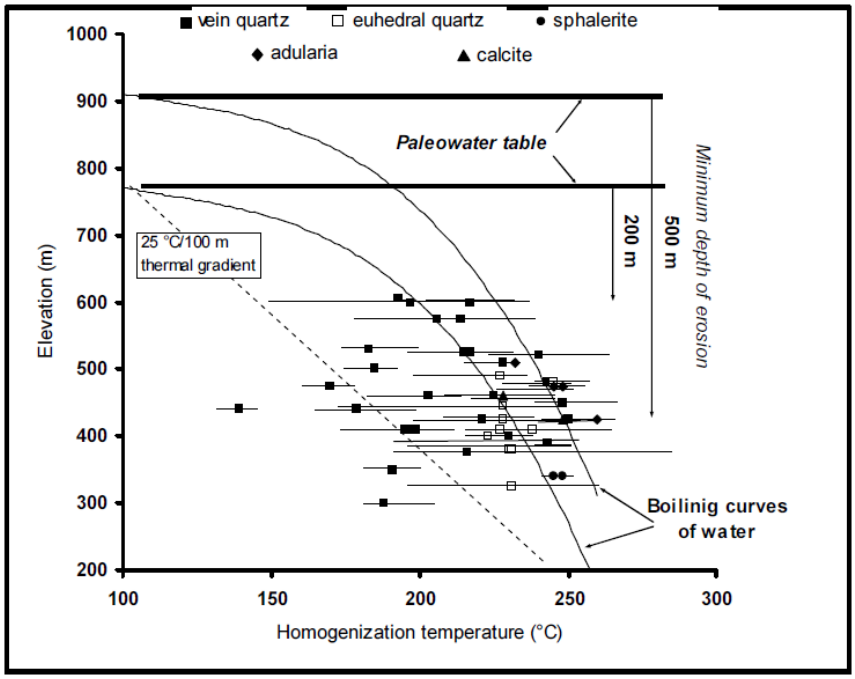

Fig. 10. Average homogenization temperatures from various minerals at different levels of the Telkibánya ore deposit.

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7.4. The abandoned quarry at Vizsoly, Tokaj Mts.

Gabriella B. Kiss in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

The quarry can be found in the southern part of the village of Vizsoly and now it is a protected outcrop (as it is the type locality of the Vizsoly Rhyolite Tuff Formation) as well as a geological demonstration site.

The rhyolite tuff, which can be seen here, is a result of the last phase of the Miocene volcanism in the Tokaj Mts. The radiometric age data reveals that this rock formed in the Sarmatian-Pannonian (11 Ma). The most probable origination place of the volcanics is the area of Boldogkőváralja (Gyalog, 2002).

The found rhyolite tuff was produced by a pyroclast flow and contains not only lithoclasts, but also pumice as well, which is quite fresh; traces of hydrothermal alteration cannot be observed. As no features typical to high temperature can be observed, it can be concluded, that the suit of this quarry represents a distal facies of an ignimbrite.

The tuff unit is characterized by gas blowdown structures, which can be observed easily on the wall of the quarry. The gas blew away the fine grains and/or lighter clasts, while coarser grains and/or heavier clasts became rounded and left in the pipe. There are two theories about the source of the gas. The first theory suggests that the pyroclastite deposited on wet ground, thus the generated steam left the rock through these structures. According to the second theory, the pyroclast flow slid on a gas pillow and after the deposition, this trapped gas formed these observable structures.

The rhyolite tuff, which was mined in the quarry of Vizsoly, was used in the past centuries by the local people mainly for house building purposes (isolation, plaster…).

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7.5. Clay and siliceous deposits in a hot-spring feeded lacustrine basin near Mád (Kerektölgyes Quarry), Tokaj Mts.

Ferenc Molnár in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

The sedimentary sequences of the lacustrine basin west of Mád outcrop cover an approximately 8 km2 area. The original size of the basin is not known because it is bordered by normal faults to the west and south. The strongly tectonised sequence of the basin was reconstructed by Mátyás (1966) on the basis of more than 460 shallow drillholes and observations in open pits.

The footwall of the limnic sequence of the basin is composed by a pyroxene andesite lava flow connected to the intermediate volcanic activity between the fourth and fifth rhyolitic tuff horizon of the area. At the concordant contact with the footwall the mixing of andesite and rhyolitic tuff (fourth explosive phase) is common whereas the upper parts of the lava beds show shallow subaqueous accumulation with hyaloclastite breccia and bentonitic alteration (Mátyás, 1966).

In addition to the regional bentonitic alteration, the pyroxene andesite lava flows contain transsecting alteration zones, also with montmorillonite. These were formed around thin siliceous veinlets ocurring below the thickest parts of the silica deposits.

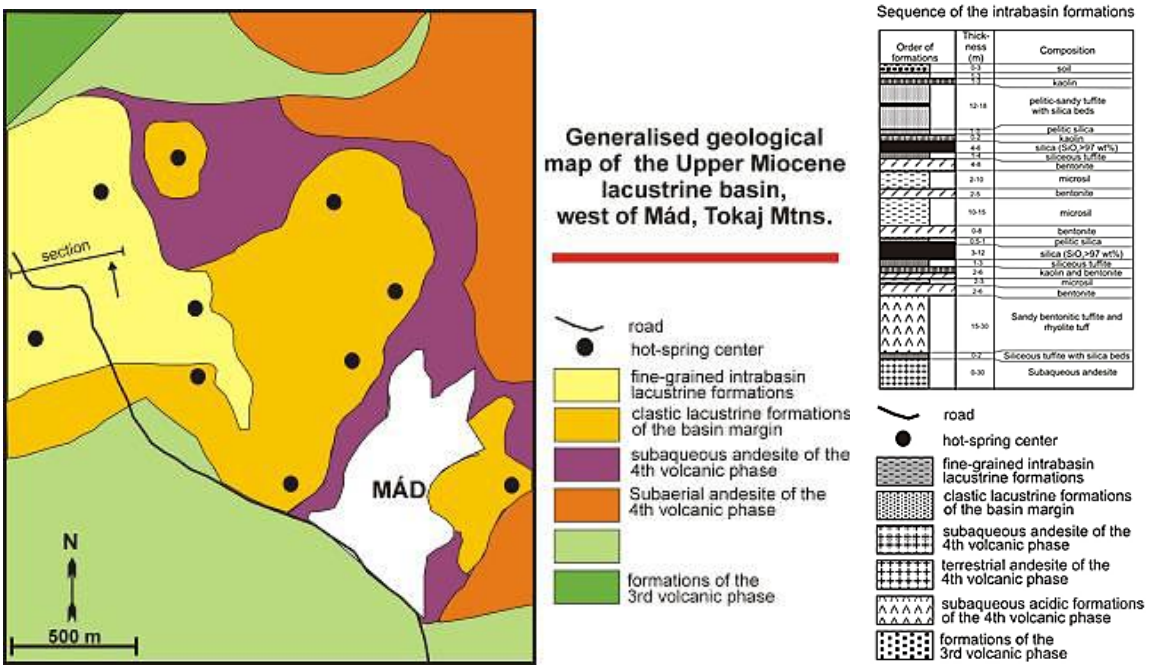
In the lacustrine sequence, three major consolidated siliceous layers occur. These layers appear in a cyclic sedimentery series in which the periodicity of sedimentation resulted from the relative intensity of accumulation of terrigeneous, pyroclastic and chemically precipitated materials. The occurrence of tuffite, tuff sand and local conglomerate units indicates the periods of the predominantly pyroclastic and terrigeneous source of basin filling. These sediments predominate at the base of each cycle. However, the composition of clasts and pebbles in conglomerate indicates a variation in the direction of transport. In the hanging wall of the lowermost siliceous layer the conglomerate contains andesite pebbles from the erosion of the footwall andesite, while conglomerate above the middle siliceous layer contains only well rounded rhyolite pebbles (Mátyás, 1966). The grain size of clasts increases from the west to the east, suggesting an origin of the terrigeneous material from the east. Angular pumice fragments are present in each sequence proving the contemporaneity of the basin filling with the fifth eruptive phase in the area.

The grain size of sediments gradually decreases, not only horizontally (to the west) but also vertically in each cycle. Thus, the upper horizons of sedimentary cycles are characterised

by pelitic sediments which show intensive kaolinitic and bentonitic alteration around the hydrothermal centers. The localities of feeder zones within the basin (Fig. 11.) are marked by this horizontal zonation of clay minerals (kaolinite close to the feeder zones fringed by a montmorillonite halo) as well as by the thickness of silica layers. Close to the centers the thickness of siliceous deposits is up to 10-12 meters, while on the margins their thickness is not more than a few meters, or they totally pinch out. The siliceous layers are laterally intercalated with pelitic sediments in which the silica content gradually decreases away from the siliceous bed.

In addition to the feeder zones within the basin, Mátyás (1979) also outlined subaerial hydrothermal centers around the depression. These centers now form small hills with strongly silicified and brecciated rocks.

The siliceous layers show bedding in which the individual layers have very variable thickness from a few centimeters up to 1-2 meters. The thick siliceous layers also contain interbedded argillic material and rhyolitic tuff whithout silification. This field evidence indicates that the silica was precipitated as very fine mud directly from the warm water and the siliceous beds were not forming by the silicification of a fine-grained sediment.



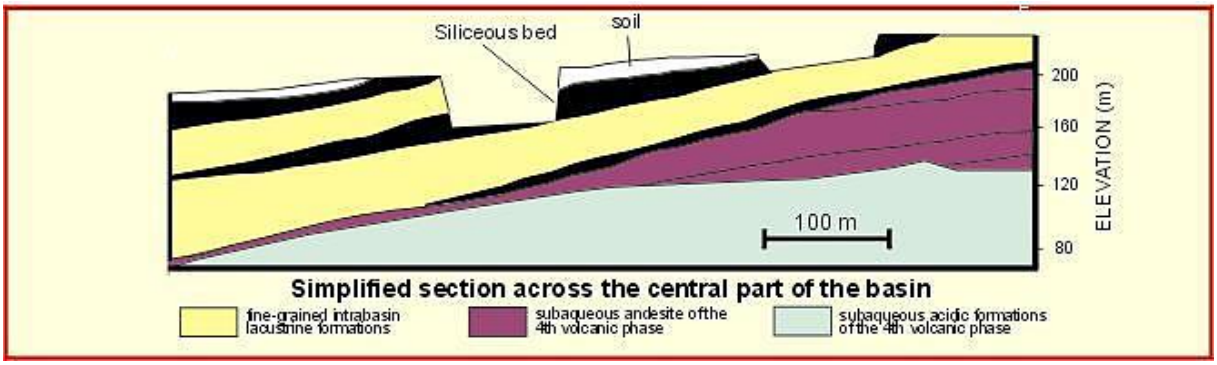


Fig. 11. Geological map, simplified section and sequence of rock types in the hydrothermal field West to Mád. Conplied on the basis of Mátyás (1979).

The colour of the individual beds shows high variation, from white to grey, green, red and black as well. The variation of the colours from layer to layer is related to the presence of minor mineral particles. Red layers contain fine hematite, while framboids of pyrite and marcasite are present in the black layers. These sulfides occasionally follow the distribution of organic material. The siliceous beds are generally characterised by anomalously high concentrations of Sb (up to nx100 ppm), and less anomalous As and Hg, as well as some Ag anomalies (Vetõ, 1969; Szakáll, 1990; 1991). Stibnite, stibikonite from the oxidation of stibnite and realgar occur in very uneven distribution in the siliceous beds.

The boundary between the layers is often irregular and the footwall contains the impressions of the hanging wall bed. These impressions were probably formed during the diagenetic compaction of the semi-consolidated silica mud.

Some layers show brecciated texture with variously coloured angular siliceous fragments cemented by the silica material. These breccia bodies sometimes transect the bedding, however, they may also be restricted to one horizon. The brecciation may be related to slumping of the semi-consolidated silica sediment; thus, brecciation may be interpreted as proof of syntectonic deposition of the siliceous material.

Some layers also show cellular structures similar to the lower parts of thick silica sinters (E. Izawa pers. commun. 1998). Thus, it cannot be ruled out that these structures are the remnants of algae mats having formed during a temporary subaerial period. The distortion of the columnar-lamellar structures may have resulted from recrystallization and compaction due to diagenesis. Alternatively, these cavities could also be related to accumulation of gases in the semi-consolidated silica mud during the decay of accumulated plant remnants.

The siliceous layers often contain petrified wood and reeds as well as various fossils indicative of a shallow water or swamp environment. Most typical plant fossils are Gliptostrobus, Osmunda, Taxodium, Populus and Salix species. Prints of Quercus

mediterranea, Quercus kubinyii and Acer decipiens leaves transported into the basin from the surrounding areas are also common. The occurrence of non-thermal conditions during the accumulation of the silicieous beds is reflected by the presence of tourtoise and fish fossils.

Within the sedimentary sequences there are unconsolidated beds (‘microsil’) which are composed of uncemented quartz plates 5-20 μm size and very little argillic material. The occurrence of plant remnants is also typical. The ‘microsil’ contains 93 wt % SiO2 while the silica content of the massive siliceous layers is above 98 wt%.

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7.6. Steam-heated alteration zone in a shallow epithermal system ont he Király Hill at Mád, Tokaj Mts.: geology, mineralogy and genesis

Ferenc Molnár in Molnár, F., 2014, Epithermal system and ore potential of NE Hungary, 5th ISGC, Budapest (ISBN 978-963-08-9294-0)

General geology

The exploitation of kaolinite, bentonite, zeolite and pure silica deposits started before World War II in the area around Mád, in the southern part of the Tokaj Mts. State owned mining was most active between the 1950s and 1970s; recently private enterprises has been exploited these raw materials. The formation of clay deposits is related to steam-heated alteration zones of low sulphidation type epithermal systems near Király, Bomboly, and Diós hills about 2 km northeast of Mád (Fig. 12a). Bentonite together with pure silica which were deposited in local fresh-water basins fed by silica rich palaeo-hot springs (distal environments of hydrothermal systems) also form important deposits 1.5 km west of Mád (see Fig. 1. in the chapter about general geology of the Tokaj Mts.).

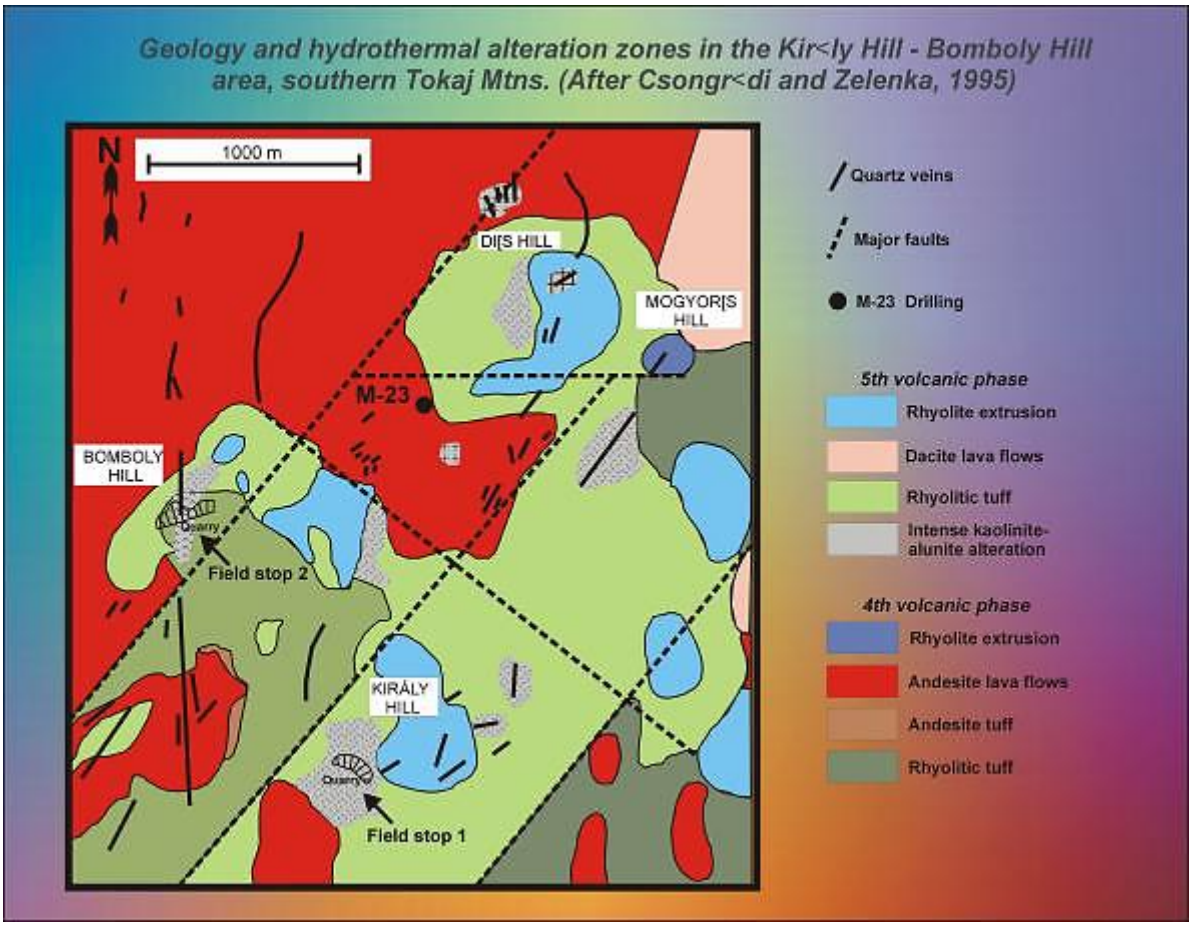
The products of the Badenian volcanic cycle of the Tokaj Mts. are not exposed in the area around Mád. The 1200 m deep Tállya-15 (Ta-15) drillhole (see its location on Fig. 1. in the chapter about general geology of the Tokaj Mts.) reached the Badenian rocks (14.2 Ma K-Ar age; Pécskay and Molnár, 2000) at 900 m depth below the present surface. The Mád-23 drillhole in the center of the mineralized area northeast of Mád (Fig. 9a) found only Sarmatian-Pannonian volcanic and sedimentary rocks (11.5-12.2 Ma K-Ar age, Pécskay et al., 1986) to a depth of 712 m.

According to Zelenka (1964) and Mátyás (1974), the major part of the Sarmatian-Pannonian volcanic sequence is composed of five rhyolitic tuff units (Fig. 12b). Each unit reflects the variation of local, subaerial or subaqueous conditions of accumulation and they are intercalated with shallow marine clay and marl beds. The pyroclastic units are predominantly pumiceous glass tuff and lapilli bearing pumiceous tuff with subordinate crystal tuff as well as ignimbrite. The explosive tuff accumulations are associated with extrusive domes and pumiceous lava flows. The glassy matrix of the rhyolite tuff of the second unit underwent subaqueous-diagenetic alteration during and after its deposition. The glassy matrix of the upper part of this unit was altered to clinoptilolite and K-feldspar, whereas the lower, slightly more basic and crystal-rich layers were altered to Na- bentonite (Nemecz and Varjú, 1963).

In the mineralized area northeast of Mád, the rhyolitic tuff and associated domes of the fourth explosive phase can be found on the surface (Fig. 12.). This phase was followed by

andesitic volcanic activity producing lava, tuff and agglomerate beds deposited in shallow water and terrestrial environments. Deposition of the layered pumiceous rhyolite glass tuff of the fifth volcanic phase together with subsequent rhyolite domes and dacitic eruptions (9.8-10.8 Ma K-Ar age; Pécskay et al., 1986) represents the last stages of volcanism in this area. Rhyolite domes now form the Király Hill, Bomboly Hill, Diós Hill (Fig. 12a).

The major faults have NE-SW, N-S and E-W directions. The N-S and NE-SW trending faults were active during hydrothermal activity, as indicated by the predominant strike of siliceous veins (Fig. 12.a). The E-W trending faults were also active after the volcanic-hydrothermal stages, resulting in block tectonism of the volcanic and sedimentary sequences. The mineralized zones and quartz veins of this area occur in various host rocks including rhyolite and rhyolitic tuff as well as andesitic rocks. K-Ar ages of alunite from the rhyolite of Mogyorós Hill (Fig. 12a) are 11.7 Ma, whereas alunite from the layered rhyolite tuff of Király Hill has an age of 10.9 Ma (Pécskay and Molnár, 2000). These data suggest protected hydrothermal activity in this area and are in the range of K-Ar ages for volcanic rocks.



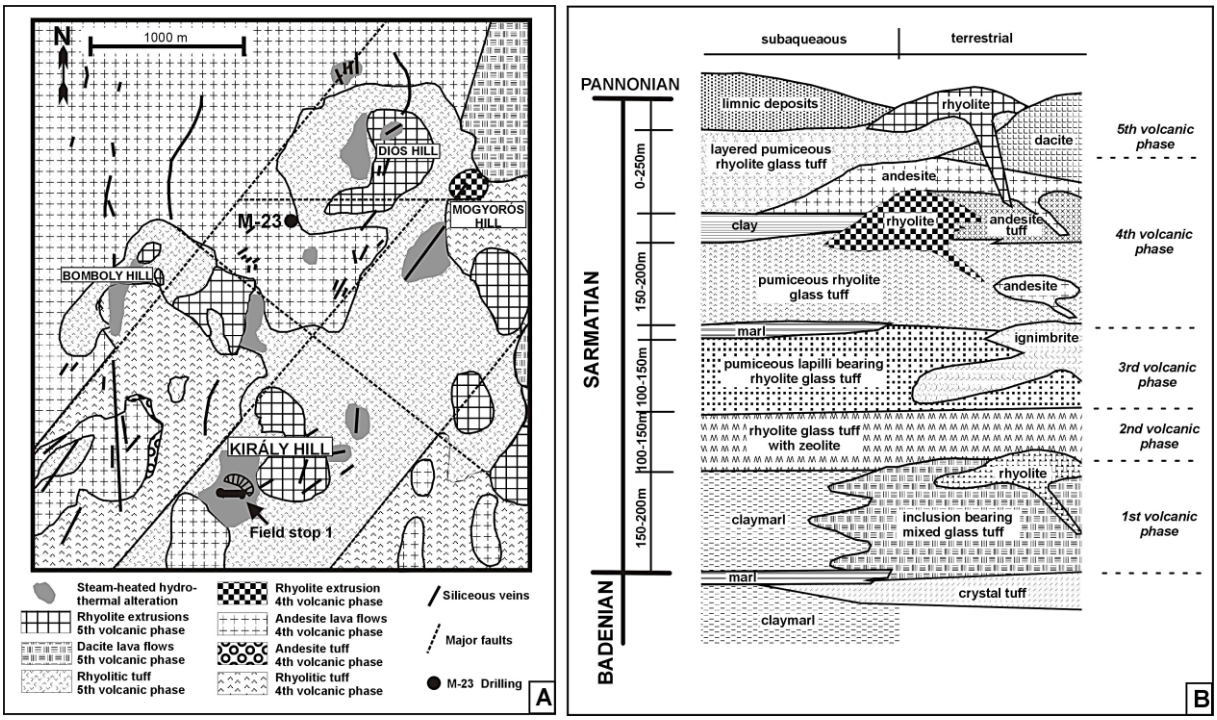


Fig. 12. Geology northeast of Mád, Tokaj Mts. A – Uncovered geological map with zones of the most intense hydrothermal alteration (modified after Csongrádi and Zelenka, 1995). B – The volcanic-sedimentary sequence in the southern part of the Tokaj Mts. (Zelenka, 1964).

Mineralization of the Király Hill at Mád

A horizontal zonation of the steam-heated alteration at shallow depths (along and above the palaeogroundwater-table) can be seen in the quarry of the Király Hill. Here the most intensively silicified zones in the fourth and fifth rhyolitic tuff units formed along a tectonic contact with the fifth stage rhyolite (Fig. 13.) The silicification is most intensively developed in the porous rhyolitic tuff; rhyolite is altered only just along the fault. The silicified zone of the fifth tuff unit exposed in the quarry laterally changes into a kaolinite zone with decrease in the SiO2 content (from about 95-98 wt% to about 80 wt %) and increase of the Al2O3 content (from 2-3 wt% to 10-11 wt%). The average sulfate content increases to about 3 wt %, but locally can be as high as 15-20 wt % (chemical data from Mátyás, 1966 and Varjú, 1974). Sulfate-rich zones also have 3-5 wt% K2O, suggesting that the enrichment of sulphur is associated with the presence of alunite. Nemecz (1973) reported dickite in addition to kaolinite in the kaolinite-alunite zone. The kaolinite bearing zone is fringed by illite-montmorillonite alteration. According to Nemecz (1973), the illite- montmorillonite has an interlayered structure with ordered pattern of illite and montmorillonite layers (this type of clay mineral was described as ‘allevardite’ and ‘rectorite’ in the older literature). The outermost part of this alteration zone contains only montmorillonite.

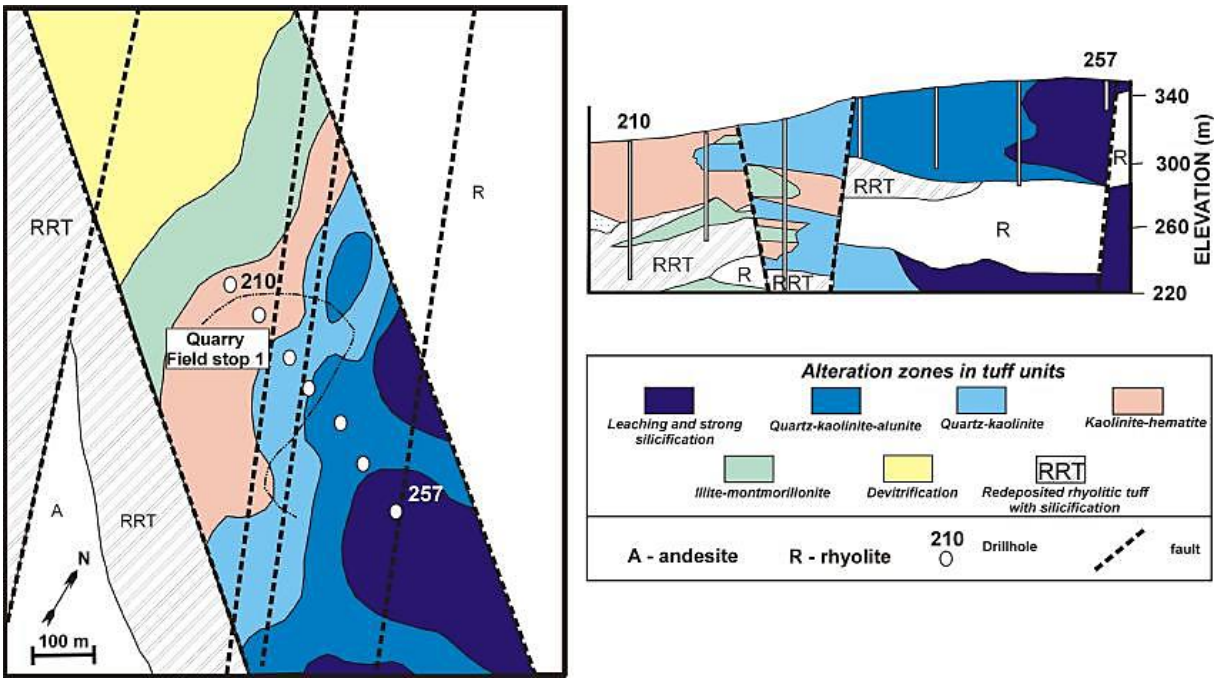


Fig. 13. Hydrothermal alteration on the Király Hill at Mád (Compiled after Mátyás, 1973 and Nemecz, 1973)

No sulfide minerals were found in the alteration zones. The major Fe-bearing minerals are the hematite and other Fe-oxyhydroxides. The presence of hematitic patches and disseminations are typical in the marginal parts of the kaolinite-rich alteration zone (Mátyás, 1973; Fig. 13.).

In the strongly silicified zone the original texture of the rhyolitic tuff is totally masked by hydrothermal alteration. As the intensity of silicification decreases towards the kaolinite-alunite zone, the rock becomes highly porous due to hydrothermal leaching. The resulting cavities are mostly found in pumiceous fragments and formed the preferred sites for precipitation of alunite. Alunite is mostly pure K-alunite (minor Na-content may occur in some growth zones; Bajnóczi et al., 2002) and forms aggregates of fine-grained individual crystals (0.1-1 mm) with rhombohedral or platy habit. The 10.8 Ma K/Ar age reported in Pécskay and Molnár (2000) was determined on cavity-filling alunite from this locality. Minor quartz, chalcedony and opal are associated with alunite. Very fine alunite is also present in the kaolinitic-siliceous groundmass of the rock. In the illite-montmorillonite zone the color of the tuff changes from white to grey/greyish-green. The cavities formed by acidic leaching are less abundant and filled with illite-montmorillonite or montmorillonite.

Steam-heated alteration with alunite forms in a near-surface portion of a low- sulfidation type epithermal environment, where H2S exsolved through deep boiling is absorbed into steam-heated water and underwent oxidation to form H2SO4 (Schoen at al., 1974; Henley and Ellis, 1983). At the paleowater table, massive silicification occurs in a porous unit, probably as a

result of mixing of three different fluids: (1) acidic fluids descending and mobilizing silica from the acid-leached zone; (2) ascending near-neutral, also silica rich hydrothermal fluids and (3) cooler aquifer fluids (Schoen et al., 1974; Sillitoe, 1993). The horizontal zonation with less acidic character of alteration moving apart from the silicified and kaolinite-alunite bearing zones suggests lateral flow of fluids along the palaeowater table at Király Hill.

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