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Mineralizations in Mesozoic–Tertiary volcanic and sedimentary units of NE Hungary (with a tour in the Baradla Cave, Aggtelek)

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1. Geological introduction

György Less

This excursion will visit a number of important mineralogical sites in the North Hungarian Range (Fig. 1). This area, according to Haas (2001) "shows a very complicated geological setting. In the north-eastern part of the region, in the Szendrő and Uppony Hills [of Southern Alpine affinity], slightly metamorphosed Paleozoic shales and carbonates crop out. The Bükk Mts. [of Dinaric affinity] are made up of slightly metamorphosed Upper Paleozoic–Jurassic series and a similarly metamorphosed Jurassic sedimentary and magmatic complex, which was overthrusted onto the former series. Both complexes are covered by a marine Paleogene sequence. Nappes of Triassic

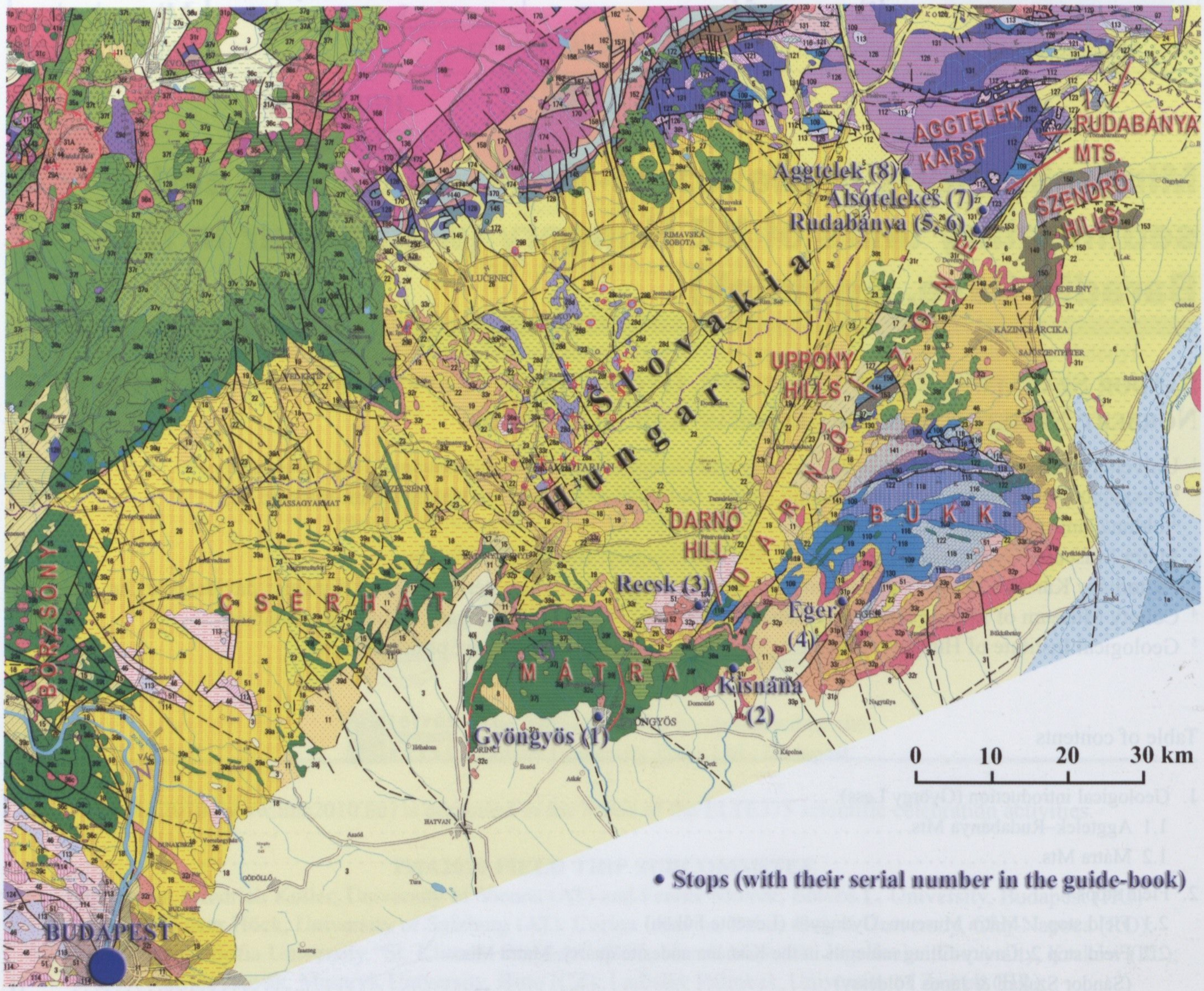

Fig. 1. The North Hungarian Range and the adjacent areas of Slovakia with the main geographical/geological units and stops of Excursion HU6. Geological base map is from Lexa *et al.* (2000).

and Jurassic carbonates make up the Aggtelek and Rudabánya Mts. near the Slovakian border. They are generally considered to be the southernmost members of the Inner West Carpathians. Other parts of the North Hungarian Range are made up mainly of Paleogene and Neogene siliciclastic sequences and Miocene igneous rocks (Börzsöny, Cserhát, Mátra and Tokaj Mts.)." Since the sites of this excursion are situated in the Aggtelek–Rudabánya and Mátra Mts., in this introduction we focus on these two mountains.

1.1 Aggtelek–Rudabánya Mts.

The Aggtelek–Rudabánya Mts., the southernmost element of the Inner West Carpathians, is geologically one of the most complex regions in Hungary (Fig. 2). It can be subdivided into two parts: the Aggtelek Mts. and the Rudabánya Mts. The first one is clearly the continuation of the Slovak Karst Mts. and it is separated from the Rudabánya Mts. by the Trizs–Szőlősardó–Perkupa–Bódvarákó–Hídvégardó–Žarnov line, which is a complicated, generally sinistral strike-slip structure of Oligo-Miocene age (Szentpétery, 1997; Less, 2000). This means that until the Late Oligocene the Rudabánya Mts. were located some tenths of km-s to the S of the Aggtelek Mts., which was relatively intact to the sinistral movements along the Darnó zone (Fig. 1). The Rudabánya Mts. is bordered by the Paleozoic units of the Uppony and Szendrő Mts., which show Southern Alpine and Dinaridic affinity together with the Paleo-Mesozoic sequence of the Bükk Mts. So, the SE margin of the Rudabánya Mts. is once again a sinistral strike-slip fault zone delimiting the entire Inner West Carpathians from the units of South Alpine and Dinaric origin.

By re-establishing the pre-Miocene structures, *i.e.* in pulling virtually back the Rudabánya Mts. to the SW into the

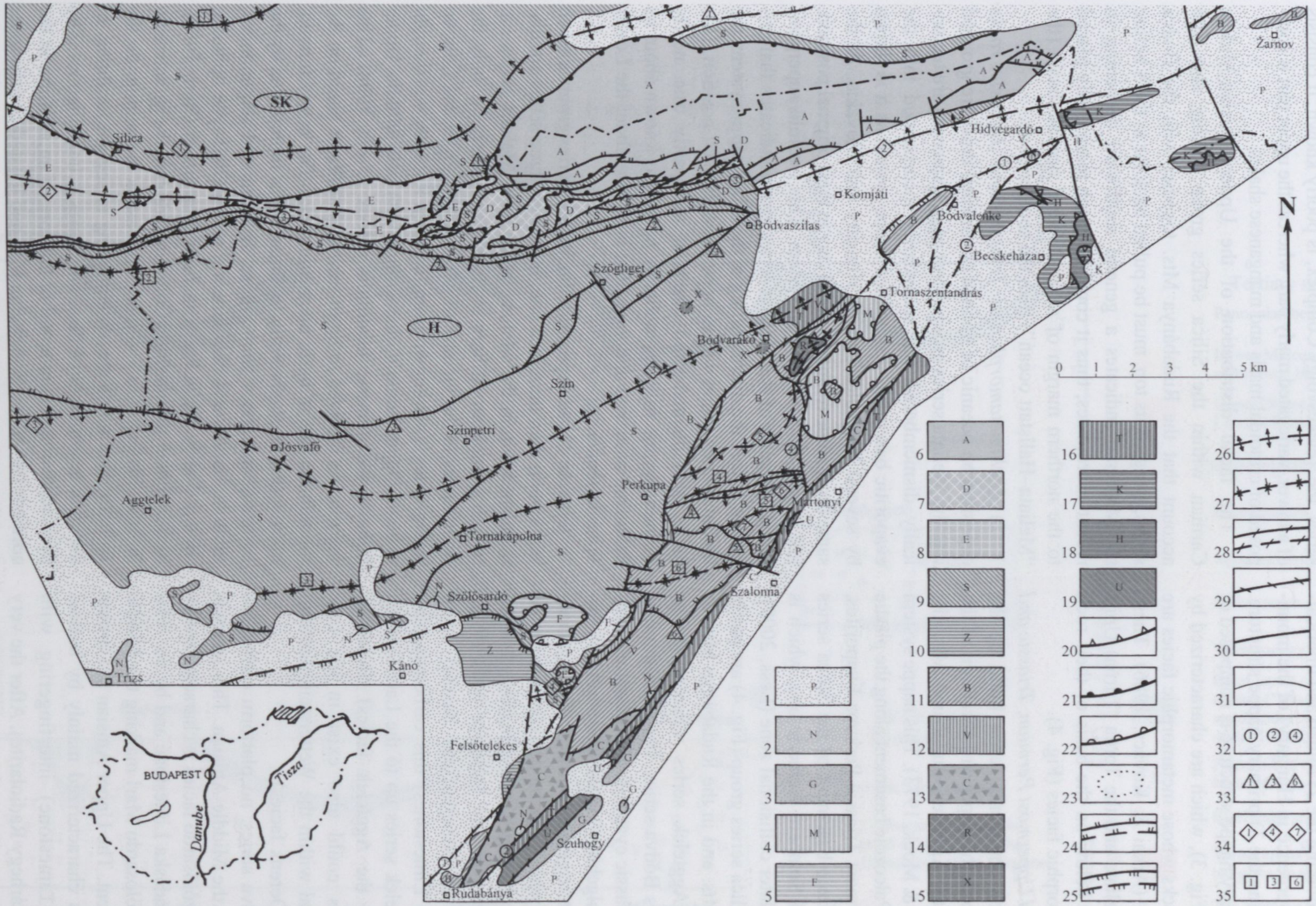

Fig. 2. Tectonic scheme of the Aggtelek–Rudabánya Mts. (Szentpétery & Less, 2006).

1 – Pannonian; 2 – marine Oligocene–Lower Miocene; 3 – continental Lower Miocene. 4–5) Younger (Early Miocene?) secondary nappes (klipps): 4 – Martonyi klipp (Torna series), 5 – Lászi klipp (Bódva series). 6–8) Older (Cretaceous) secondary nappes (klipps): 6 – Alsó-hegy klipp (Aggtelek and Derenk facies), 7 – Derenk klipp (Derenk facies), 8 – Éles-tető klipp (Aggtelek facies). 9–19) Rock sequences in the primary nappe structure: 9–13) Silica series group: 9 – Aggtelek series; 10–13) Bódva series: 10 – Szőlősardó facies, 11 – Bódva facies, 12 – Telekesvölgy series, 13 – Rudabánya-Martonyi ore complex (Lower Triassic to Lower Anisian); 14–15) Meliata series group: 14 – Bódvarákó series, 15 – Tornakápolna series; 16 – Torna series with unknown tectonical underlyer; 17 – Torna series in the Becskeháza nappe; 18 – Hídvégardó series; 19 – Uppony series. Other signs: 20 – primary nappe boundaries, 21 – older secondary nappe boundaries, 22 – younger secondary nappe boundaries, 23 – tectonically reworked ophiolitic blocks, 24 – older reverse faults, outcropped / covered, 25 – younger reverse faults, outcropped / covered, 26 – axis of antiforms/anticlines, 27 – axis of synclines, 28 – sinistral strike-slips, outcropped and covered, 29 – dextral strike-slips, 30 – faults in general, 31 – non-tectonized geological boundaries, 32 – important strike-slips (1 – Rudabánya–Bódvarákó, 2 – Rudabánya–Martonyi, 3 – Ménes Valley, 4 – Martonyi), 33 – important reverse faults (1 – Silická Jablonica, 2 – Szögliget, 3 – Jósvafő, 4 – Szár-hegy, 5 – Szalonna, 6 – Csehi Hill), 34 – important antiforms/anticlines (1 – Torna Valley, 2 – Ménes Valley, 3 – Jósva Valley, 4 – Alsótelekes, 5 – Bódvarákó, 6 – Mész Valley, 7 – Hársas-Konyha Valley), 35 – important synclines (1 – Silica, 2 – Haragistya, 3 – Teresztenye, 4 – Szár-hegy, 5 – Dunna-tető, 6 – Telekes-oldal).

southern continuation of the Aggtelek Mts. and the Slovak Karst, the obtained structure is still very complicated (Fig. 3). From top to bottom, in order of superposition, it consists of the 1) neo-allochtonous klipps of Alsó-hegy (Dolný Vrch), Éles-tető (Ostrý Vrch) and Derenk, covering the 2) folded and imbricated structures (of southern vergence in Hungary) of the mountains that are superpositioning the 3) primary nappe structure.

This reconstructed primary nappe structure is composed of three main tectonic units (Fig. 3), which are characterized by three different groups of rocks whose metamorphic facies are also significantly different (Árkai & Kovács, 1986). These units are the Silica, the Meliata and the Torna (Turňa) Units and they are characterized below on the basis of their rock sequences and their metamorphic facies (Fig. 4).

1) *Non-metamorphosed Uppermost Permian, Triassic and Jurassic rocks* deposited on continental crust build up the Silica series group. They form the upper structural unit of the primary nappe structure of the Aggtelek–Rudabánya Mts., the Silica nappe system (Kozur & Mock, 1973). This nappe system is mostly detached from its Paleozoic basement along the plastic Uppermost Permian/Lowermost Triassic Perkupa Evaporites. We suppose that the Paleozoic basement of the Silica series group could be an external Southern Gemeric one, which is mostly incorporated into a later collisional zone (Less, 2000).

The sequences of the Silica series group (Fig. 4) are partly different in the Aggtelek Mts. and in the Rudabánya Mts. In the former, it is called Aggtelek series whereas in the Rudabánya Mts. its name is Bódva series. Both of them uniformly start with Permo-Triassic evaporite and sandstone beds (corresponding to the "Haselgebirge" in the Eastern Alps), followed by shallow marine, terrigenous but ever more calcareous Lower Triassic units (which can be correlated with the Werfen beds of the Alps), then by shallow marine, Anisian platform carbonates (Gutenstein and Steinalm beds in the Alps). After or without an intraplatform basinal event (Reifling and Schreyeralm Limestones) this carbonate platform survived in the Aggtelek series up to the Late Carnian (Wetterstein Limestone in the Aggtelek facies). However, some intraplatform basins could also exist in the Late Ladinian to Carnian interval within the Wetterstein platform (Derenk Limestone in the Derenk facies).

Meanwhile, in the Bódva series, no platform carbonates can be found upward from the Middle Anisian. This series is also a composite one: the Szőlősardó facies is characterized by the slope deposits of the Nádaska Limestone and by the relatively thick, terrigenous Szőlősardó Marl marking the Middle Carnian, humid "Raibl" event. The Upper Anisian to Carnian of the Bódva facies *s.s.* is characterized mainly by basinal limestones (Bódvalenke Limestone) interfingering with under-CCD radiolarites (Szárhegy Radiolarite). After the very diverse Upper Anisian to Middle Carnian, the Upper Carnian and Norian of the Aggtelek and Bódva series became almost uniform: This interval is represented in both series by the same pelagic Hallstatt and/or Pötschen Limestones.

The Jurassic in the Bódva series has two series (Grill, 1988). One of them, the Telekesoldal Complex, lying upon the Triassic of the Bódva facies *s.s.*, is built up of monotonous black shales then by rhyolitic wildflysch. The Triassic basement of the other series, the Telekesvölgy Complex, is poorly known. It consists of a lower, variegated marly part, whereas the upper part is composed of crinoidal marls and manganese shales.

The facial distribution of the Upper Anisian-Middle Carnian within the Silica series group (taking also into account that the Rudabánya Mts. together with the Bódva series, lying on its top, must be pulled back far to the S before the Miocene) indicates a general southward deepening in recent coordinates, thus it could be much more easily placed to the northern margin of a hypothetical oceanic basin (the "Meliata–Hallstatt ocean") than the southern one.

2) *Anchimetamorphosed Triassic and Jurassic rocks* deposited on oceanic or thinned continental crust are grouped into the Meliata series group. Most of its sequences are tectonically dismembered and secondarily incorporated into the evaporitic basement of the Silica nappe system as it is shown by several boreholes both in Hungary and Slovakia. At the same time, some remnants could stay in their original position, just below the Silica nappe system. This twofold superpositional character of the Meliata series group indicates that primarily, before the overthrusting of the Silica nappe system, the Meliata series group was in uppermost tectonic position. Due to its both dismembered character and partly true, newly formed oceanic nature, practically nothing is known about its Paleozoic basement and very little is known about the Lower Triassic sequences.

Because of bad exposures, the Meliata series group is much less known than the Silica one. However, three series are distinguished within the Meliata group. The Meliata series *s.s.* (which is understood here in its strictest sense, *i.e.* only the occurrences at the vicinity of Meliata, Držkovce and Čoltovo in Slovakia) is not known from Hungary. Recently it is thought to be an Upper Jurassic olistostrome with both Middle–Upper Triassic and Jurassic olistoliths (Mock *et al.*, 1998). This sequence is believed to be of intermediate crust based on the subordinate role of basic magmatic rocks. The newly formed, true oceanic crust of mostly Ladinian age is represented by the Tornakápolna series from whose dismembered serpentinites, gabbros, basalts and radiolarites a real MORB-type ophiolite (Bódva Valley Ophiolite) can be reconstructed (Réti, 1985). Red Ladinian radiolarites (Čoltovo Radiolarite) characteristic for the Meliata (*s.s.*) series and basalts belonging to the Tornakápolna series are interfingering in several localities, so the close relationship of these two series is unambiguous. The Bódvarákó series is exposed in the core of an antiform in the northern part of the Rudabánya Mts. and located clearly under the Silica nappe system represented here by the Bódva series.

3. *Anchi- to epimetamorphosed Triassic rocks* (however, containing relatively high-pressure units at some places, see Árkai & Kovács, 1986) deposited on continental crust and

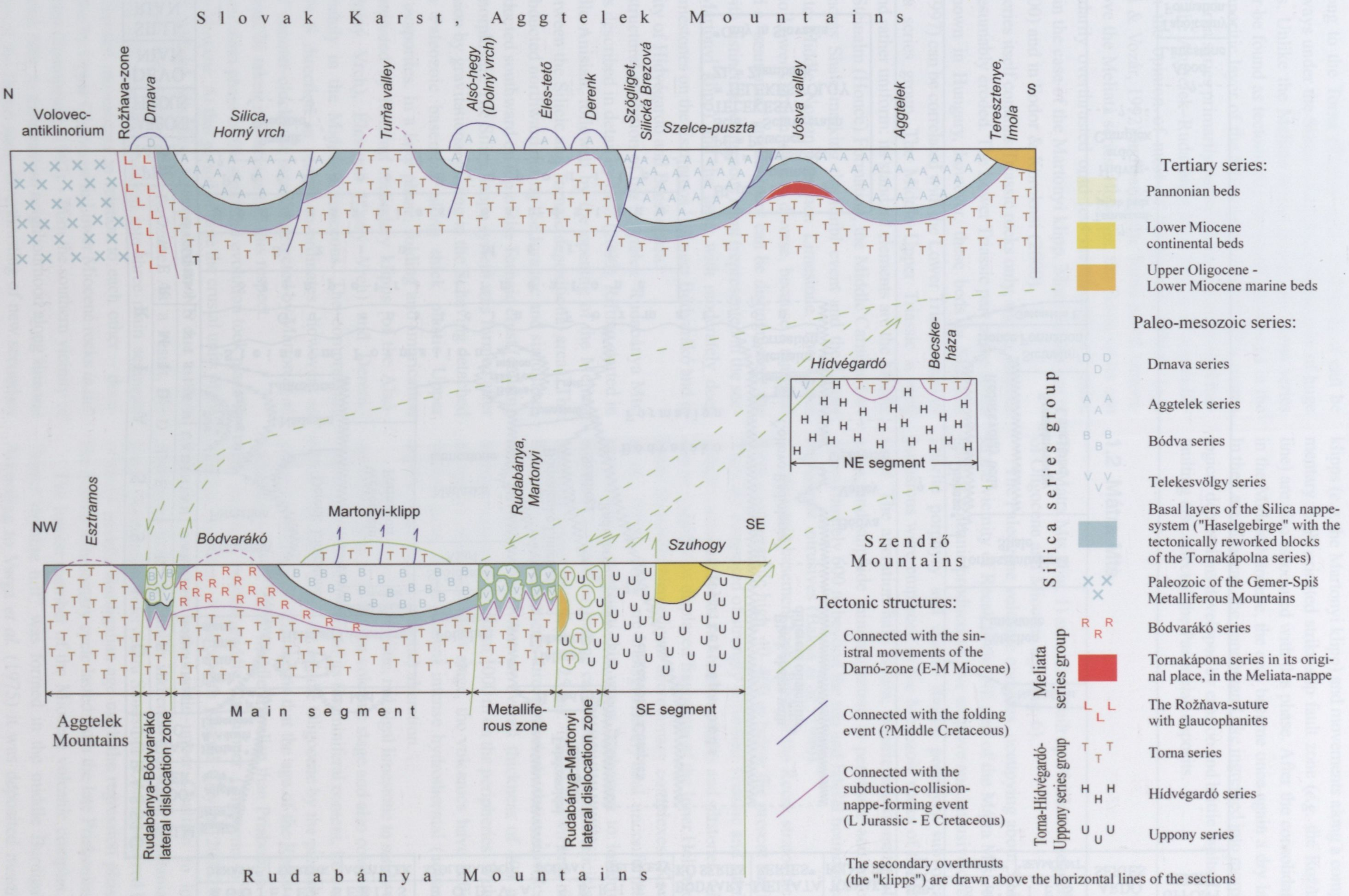

Fig. 3. Schematic geological structure of the Aggtelek–Rudabánya Mts. on principal geological sections, with no scale (Szentpétery & Less, 2006).

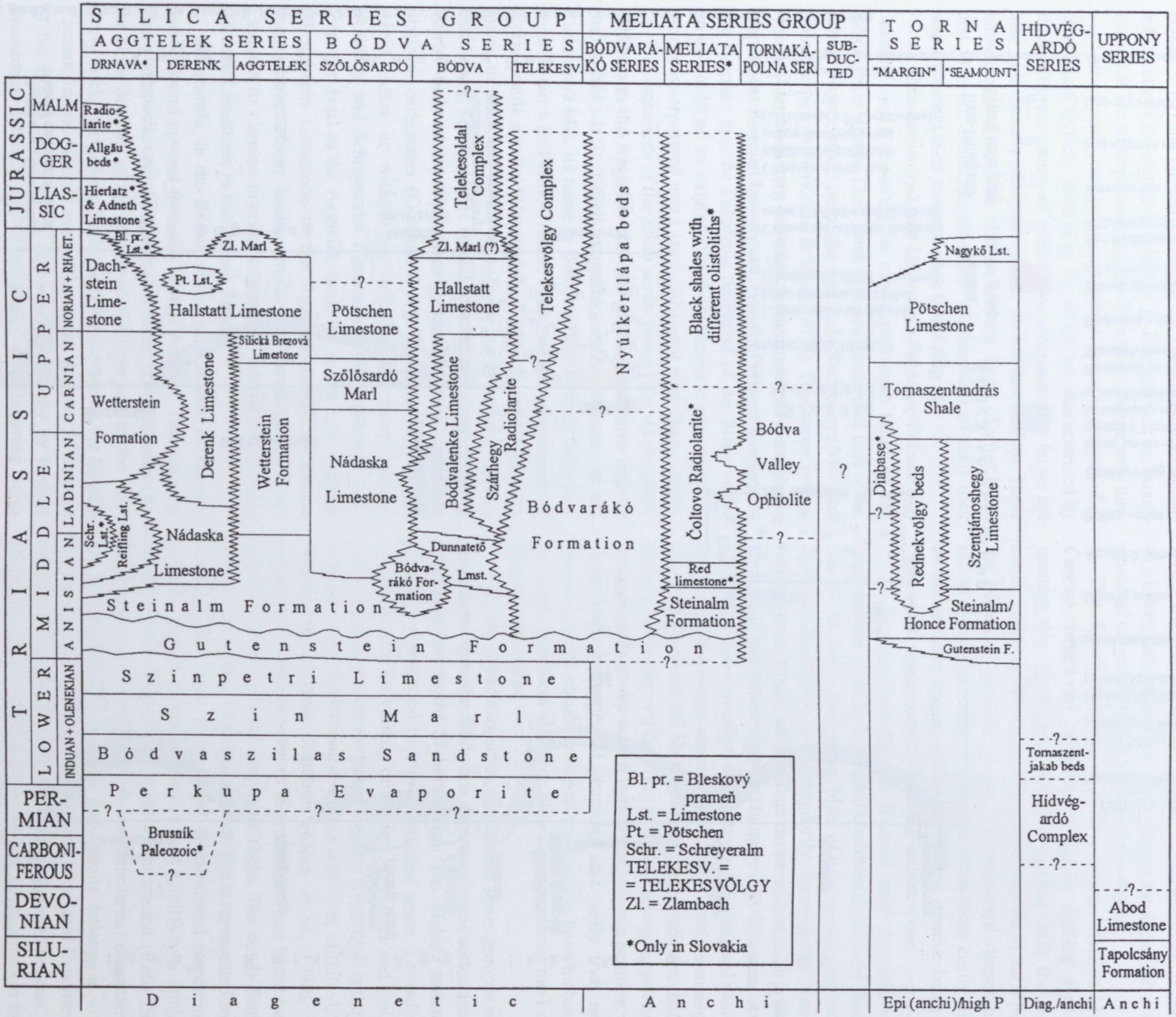

Fig. 4. Stratigraphic sequences of the Aggtelek–Rudabánya Mts. with some adjacent areas of the Slovak Karst (Less, 2000).

they belong to the Torna (Turňa) series. Primarily it can be found always under the Silica series group in the core of huge antiforms. Unlike the Meliata series group, the Torna series can never be found as tectonically dismembered blocks in the basal evaporitic layer of the Silica nappe system. This means that the Torna series primarily forms the lowest known tectonic unit of the Aggtelek–Rudabánya Mts. This is in contradiction with the opinion of most of the Slovak authors (*e.g.* Vozárová & Vozár, 1992) indicating the Torna series tectonically above the Meliata series. However, the Torna series can be secondarily overthrusted onto less metamorphosed units, too, like in the case of the Martonyi klipp. More details see in Less (2000) and in Fodor & Koroknai (2000).

The series itself contains Triassic rocks only, and its Jurassic part is presumably eroded. The Lower Triassic part of the series is not known in Hungary, however, these beds in Slovakia (Mello, 1997) can be correlated with the Lower Triassic units of the Silica series group. The Middle–Upper Triassic is well known and rather uniform: its standard elements are the Middle Anisian Steinalm (Honce) Formation, the Middle Carnian Tornaszentandrás Shale marking the Raibl event and the Upper Carnian to Middle Norian Pötschen Limestone. The Upper Anisian to Lower Carnian is more diverse, because a marginal basin and a "seamount" environment can be distinguished: the former with distinctive terrigenous input (represented in the secondary Martonyi klipp) and the latter with moderately deep basinal limestones on the Esztramos Hill near Bódvarákó and in the vicinity of Hídvégardó and Becskeháza.

The structural evolution of the Aggtelek–Rudabánya Mts. (Fig. 5) is described in detail by Less (2000). Rifting started in the Middle Anisian, followed by the opening of the Meliata ocean between the Silicic and Tornaic depositional areas. The ocean subducted northward during the Jurassic and simultaneously obducted southward on top of the Tornaic crust (causing its metamorphism). The Silica nappe system was formed after the collision by gravitational gliding to the S, having detached from its Paleozoic basement along thick plastic Upper Permian evaporites. In a later phase, folding and imbrication were terminated by forming secondary klipps [of the Alsó-hegy (Dolný Vrch), Éles-tető (Ostrý Vrch) and Derenk] approximately in the Middle Cretaceous. The compression was of N–S direction in recent co-ordinates, however, an about 90° counter-clockwise rotation detected by Márton *et al.* (1988) must be taken into account in this respect.

The last main phase of the structural evolution took place in the Oligo-Miocene. At that period of time the crustal units of the Bükk and Szendrő Mts. have been pushed to NE due to their escape from the Alpine collision zone. As a result, the Rudabánya Mts. was dismembered into three main segments with differential movements in relation to each other – documented also by Upper Oligocene to Lower Miocene rocks in different facies (Szentpétery, 1997) – from the southern vicinity of the Aggtelek Mts. to their eastern neighbourhood along sinistral strike-slips of the Darnó zone. Overthrusting of new secondary klipps (*e.g.* the Martonyi klipp) and movements along a complementary E–W oriented strike-slip fault zone (*e.g.* the Rožňava line) are also associated with this phase. After the consolidation in the Middle Miocene, the area became once again a dry land. In the Late Miocene, the Pannonian Lake ingressed into morphological depressions developed by erosion and brittle faults. Later faulting also affected the Pannonian deposits.

1.2 Mátra Mts.

The Mátra Mts. (Fig. 1) are mainly built up of volcanic sequences of Oligocene and Miocene age (Fig. 6).

The Paleogene volcanic complex, occupying about 30 km^2 in the vicinity of Recsk in the NE part of the Mátra Mts., consists of volcanic products of five eruptive and intrusive cycles. Diorite porphyry and quartz diorite porphyry subvolcanic intrusions were emplaced in the Mesozoic rocks of the basement. The alteration halo (skarn, intense metasomatic alteration, and sulphide mineralization) is pervasive and extends approximately 600 m beyond the top and lateral boundaries of the largest intrusives (Baksa *et al.*, 1980).

Mesozoic basement rocks beneath the Recsk stratovolcano form a topographic high, 40–400 m below the present surface. They are composed of strongly deformed Triassic and Jurassic pelagic carbonate rocks, radiolarites, shales and siltstones, which can be regarded as displaced fragments of the Inner Hellenidic–Inner Dinaridic Neotethyan accretionary complexes (Kovács *et al.*, 2008). They are transgressively and unconformably covered by a relatively thin upper Priabonian to lowermost Rupelian (?) shallow-marine carbonate to pelagic siliciclastic sequence (max. thickness is 25 m). This is known only from boreholes. These sediments directly underlie the stratovolcanic andesite series, which has an overall thickness of 400 m in average, reaching more than 1000 m on the peripheries. With the exception of the youngest stage, the volcanics have suffered various types of subsequent intense hydrothermal (advanced argillic and adularia–sericite) alteration.

Tuffaceous and glauconitic, red algal limestone to sandy marl are intercalated with the last volcanic stage and also cover them. Based on the recent study of its foraminiferal content, Less *et al.* (2008) classified it into the middle Oligocene by the presence of genus *Lepidocyclina*. This means that the age of the Recsk stratovolcano is rather early–middle Rupelian than Priabonian. The next unit is a marine middle and upper Oligocene to early Miocene sequence. It starts with Kiscell Clay of 200–250 m thickness, continues with middle–upper Chattian to lower Aquitanian Szécsény Schlier and ends with upper Aquitanian to lower Burdigalian Pétervására Sandstone. Continental red beds of early–middle Burdigalian age mark the regression phase of the marine sedimentary cycle lasted from the late Priabonian.

The lowest member of the Miocene volcanic complex, the "lower rhyolite tuff" was formed in the middle Burdigalian. According to Varga *et al.* (1975) it was deposited mostly in

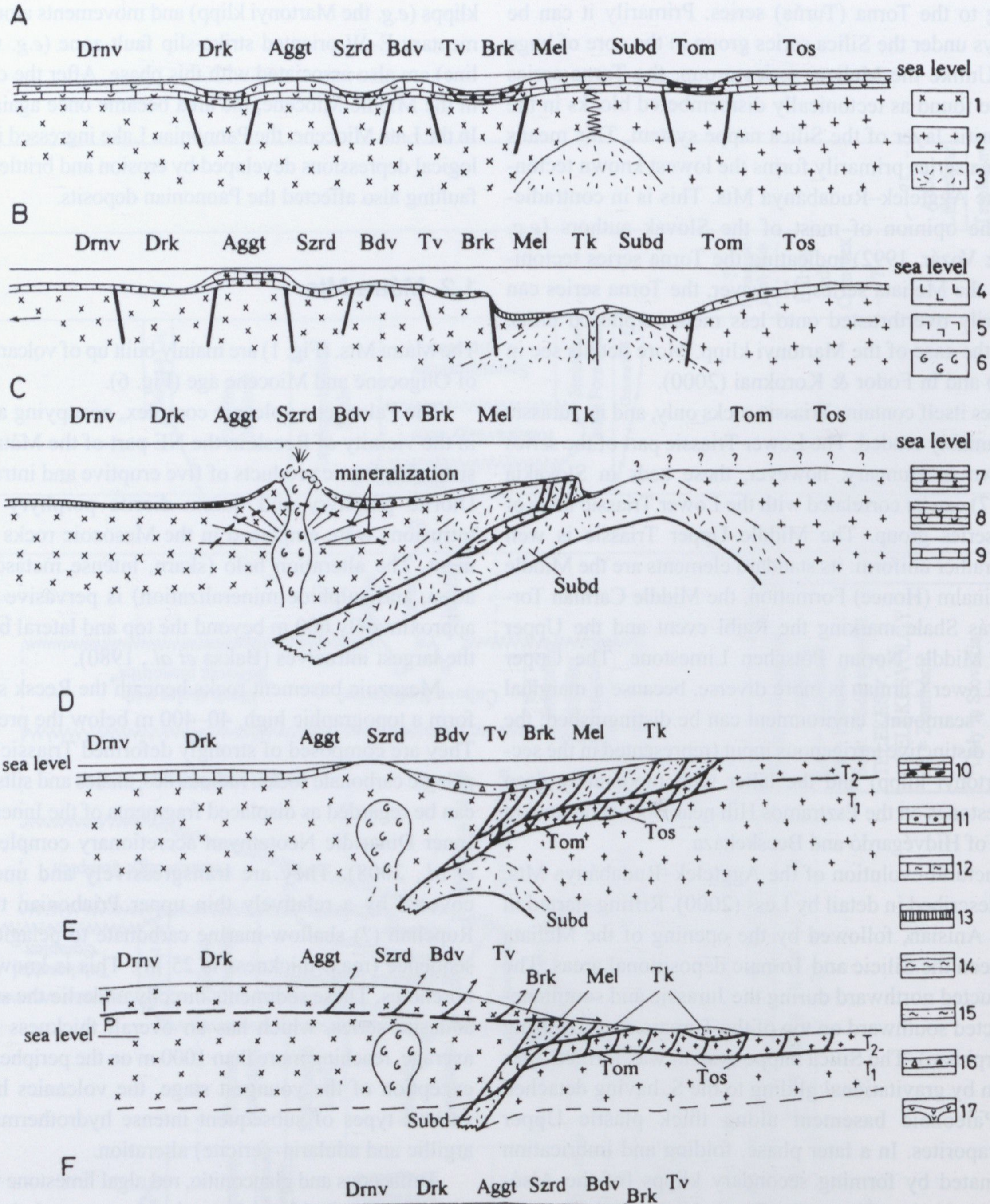

Fig. 5. The process of forming of the primary nappe structure of the Aggtelek–Rudabánya Mts. and Slovak Karst during the Middle Triassic to Middle Cretaceous interval in a series of principal palinspastic profiles with no scale (Less, 2000).

A –The last moment of the pre-rift stage in the Middle Anisian; B –The oceanic stage in the Ladinian; C –The process of subduction and simultaneous obduction in the Middle Jurassic; D –The change of subduction/obduction to collision at the end of the Jurassic; E –The beginning of overthrusting of the Silica nappe system in the Early Cretaceous; F –The primary nappe system before starting the folding phase in the Middle Cretaceous.

Abbreviations for depositional areas (see also Fig. 4): Drnv: Drnava; Drk: Derenk; Aggt: Aggtelek; Szrd: Szőlősardó; Bdv: Bódva; Tv: Telekesvölgy; Brk: Bódvarákó; Mel: Meliata (*s.s.*); Tk: Tornakápolna; Subd: Subducted; Tom: Torna, margin; Tos: Torna, seamount.

1 – Extreme Southern Gemeric crust, 2 – Torna–Hídvégardó–Uppony-type continental crust, 3 – Meliatic oceanic crust; 4 – glaucophanite, 5 – evaporitic basement of the Silica nappe system with tectonically reworked blocks of the Meliata series group, 6 – Mesozoic granitoids, 7 – reefal carbonates, 8 – lagoonal carbonates, 9 – red pelagic limestone, 10 – grey cherty limestone, 11 – limestone of slope facies, 12 – marl, marly limestone, 13 – radiolarite, 14 – black shale, 15 – sandy shale, 16 – olistostrome, 17 – basalt.

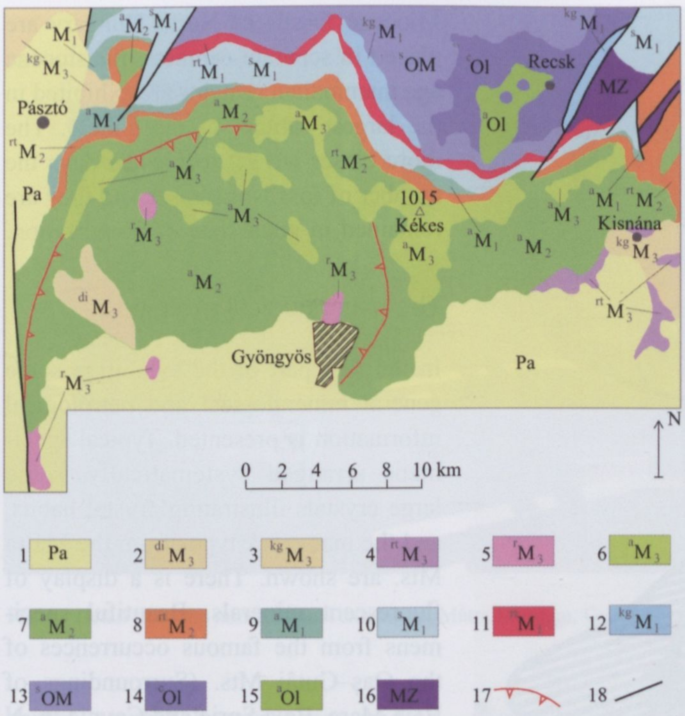

Fig. 6. Schematic geological map of the Mátra Mts. 1:250,000, based on Lexa *et al.* (2000).

1 – Upper Miocene (Pannonian) fluvial and lacustrine sediments, 2 – Upper Miocene diatomite, 3 – Upper Miocene brackish-water conglomerate, 4 – Upper rhyolite tuff (Upper Serravallian), 5 – Upper Serravallian rhyolite, 6 – Middle Serravallian "upper andesite", 7 – Middle Langhian to Lower Serravallian "middle" or "main andesite", 8 – "middle rhyolite tuff" (Lower Langhian), 9 – Upper Burdigalian/Lower Langhian "lower andesite", 10 – Upper Burdigalian sediments, 11 – "lower rhyolite tuff" (Middle Burdigalian), 12 – Lower-middle Burdigalian continental red beds, 13 – Middle Chattian to Lower Burdigalian sediments, 14 – Lower Chattian (Kiscell) clay, 15 – Rupelian (Recsk) andesite, 16 – Mezosoic rocks, 17 – caldera margin, 18 – fault.

dry-land conditions (with widespread ignimbrites) and can well be traced throughout N Hungary. A new transgression started in the late Burdigalian: brown coal deposits and overlying marine sediments are found in the northwestern foreland of the Mátra Mts. From the end of the Burdigalian, the territory was uplifted again and the main stratovolcanic complex of the Matra with altogether about 1000-m thickness started to build up. This complex contains a thinner lower and a thicker middle andesite group subdivided by the horizon of the early Langhian "middle rhyolitic tuff" (in fact of dacitic composition). The "lower andesite" consists of submarine lava flows, pyroclastics, tuffs and agglomerates. The "middle" or "main andesite" (Middle Langhian to Early Serravallian) starts with variable andesitic and dacitic rocks (lavas, tuffs and agglomerates), above which extensive andesite lava flows form the main mass of the Mátra Mts. In the eruption centre, in the Western Mátra (now a remnant of a caldera) subvolcanic and intrusive bodies, like andesite dykes and plugs are also quite common. The "middle andesite" varieties are generally strongly altered, and host epithermal Pb-Zn base metal ore mineralizations (Gyöngyösoroszi mine). The "middle" or "main" andesite is overlain by the "upper andesite" series (Middle Serravallian), which is unaltered and postdates the ore mineralization. The youngest, late Serravallian volcanism is represented by small rhyolitic domes in the caldera. Maar diatreme structures, now represented by diatomite lake sediments, are also linked with the postvolcanic activity The Mátra Mts. have developed into a collapsed caldera at the end of the volcanism in the late Miocene, and later on the whole structure has been tilted southward. A major structural displacement zone separates the Western Mátra (with the collapsed caldera structure) from the Eastern Mátra. The Kisnána quarry, our excursion stop, is part of the Eastern Mátra structure, and belongs to the "upper andesite" series of the Miocene volcanics.

In the late Miocene, a brackish to freshwater lake occupied the Pannonian Basin, isolated from the Paratethys at about the Serravallian/Tortonian boundary and flooded the foothills of the elevated and eroded volcanic land resulting in the formation of thick lignite seams.

Periglacial conditions in the Pleistocene caused destruction and erosion of the volcanic edifice and resulted in thick deluvial rock flows. Alluvial and proluvial Quaternary sediments deposited by the ancient Zagyva and Tarna rivers are of significant thickness.

2. Field stops

2.1 Field stop 1. Mátra Museum, Gyöngyös (Levente Fűköh) History of the Mátra Museum

The Mátra Museum is accommodated in a former mansion of the Orczy family and is surrounded by a two-hectare historic garden in the town of Gyöngyös. This Baroque and Classical style mansion was built during the 18–19th centuries.

While the museum has always been a well-known and well-visited site in Hungary, the mansion building and accompanying garden were in crying need of restoration. The initiative, co-financed by the European Union, was carried out in two phases. The first phase focused on structural improvements and the construction of a glass roof over the courtyard, which now serves as a new welcoming area. The second phase aimed at the construction of the new Pavilion for Natural Science and the revitalisation of the garden that is of significant botanical value. The restoration and construction projects have added to the beauty and experience of the museum, which now has the capacity to accept 80,000 visitors annually.

The Mátra Museum has the second largest natural history collection in Hungary (Fig. 7). The collections are as follows: paleontological, geological, malacological, vertebrate animals, insects, and herbarium. The museum has local history and hunting history collections with relics of the past of Gyöngyös and vicinity as well.

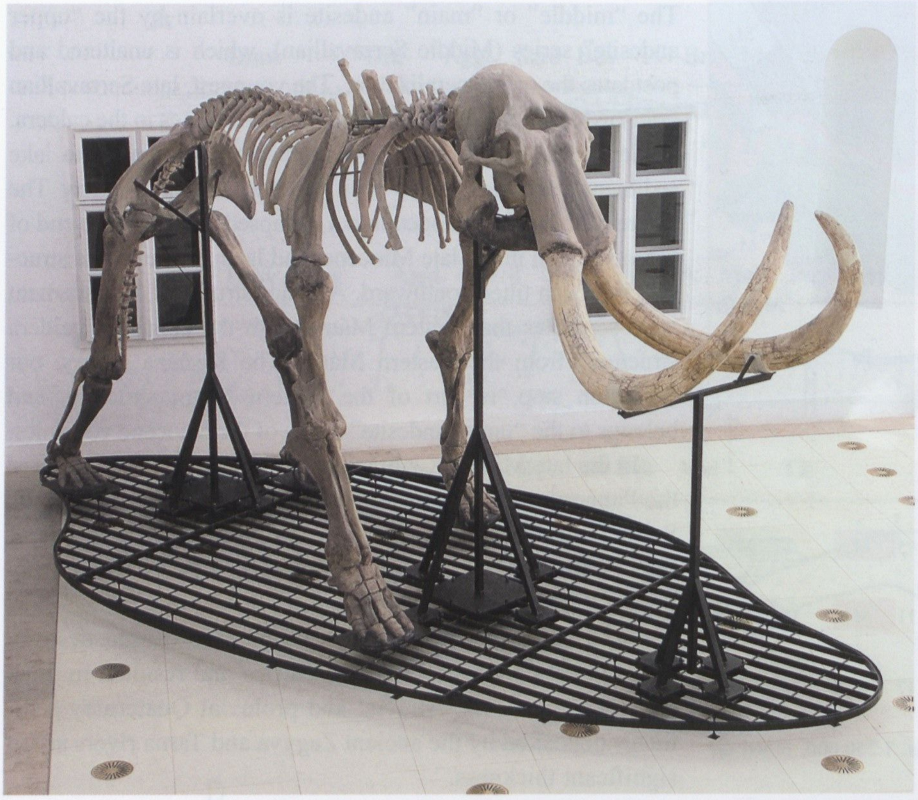

Fig. 7. Skeleton of Mammoth, Mátra Museum, Gyöngyös (photo: L. Fűköh).

Main scientific exhibitions and programs are:

- Holocene malacology in Hungary, biostratigraphy, zoogeography, ecology.
- Taxonomical and faunistical research on terrestrial and freshwater Malacology in the Carpathian Basin, South Europe and Southeast Asia.
- Taxonomical, faunistical and zoogeographical research on Heteroptera in Carpathian Basin
- Taxonomical, faunistical and ecological research on Odonata larva, Ephemeroptera, Cerambicidae in Carpathian Basin
- Osteological examinations on Falconiformes in Europe
- UTM mapping project (Hungary): Gastropods, Odonata (larva), Heteroptera, Cerambicidea
- The studies of the scientists of the museum and their co-workers are published in two regularly issued natural history transactions (*Folia Historico Naturalia Musei Matraensis* and *Malakológiai Tájékoztató* [Malacological Newsletter]).

The palaeontology exhibition

In the glass cabinets of this gallery, characteristic fossils of the Bükk and Mátra Mountains are on display. The first cabinet is dedicated to the memory of Ferenc Legányi, who devoted his life to the collection and research of fossils of this region. His huge work widely contributed to the exploration of the palaeoenvironmental coditions of the Bükk and Mátra Mountains.

The second cabinet displays fossils of the oldest rocks of the Bükk Mountains. These rocks were formed at the end of Palaeozoic Era during the Carboniferous and the Permian periods reflecting marine environment.

The characteristic Mesozoic fossils of the Bükk Mountains and its close vicinity can be seen in the third cabinet. The Bükk Mountains are mainly built up of Triassic limestone, which is relatively poor in fossils. The Cretaceous fossils refer to the diversity of the ancient reef fauna.

Cenozoic (Eocene) fossils are shown in the fourth cabinet. Oligocene and Miocene fossils of North Hungary are placed in separate cabinets. Pleistocene age mammalian remains are exhibited in the largest cabinet of the gallery. The more closer we get to present days the number of fossils increases and they are remained in good state of preservation.

The mineralogical exhibition

In the first part of the exhibition some general mineralogical and petrological information is presented. Typical specimens arranged systematically, some large crystals illustrating crystal habits, and the main rock types from the Mátra Mts. are shown. There is a display of fluorescent minerals. Beautiful specimens from the famous occurrences of the Oaş–Gutâi Mts. (Surroundings of Baia Mare, Baia Sprie and Cavnic in, N Romania) are also exhibited here

The second part of the mineralogy exhibition presents a wide selection about minerals of the Mátra Mts. (Fig. 8). Minerals found in the cavities of Miocene rhyolite and andesite: siderite, aragonite, calcite from the Kisnána Quarry, chalcedony, quartz from Gyöngyössolymos, zeolites (chabazite, stilbite, heulandite, mordenite) from Mátraszentimre. Spectacular microcrystalline quartz varieties (chalcedony, agate) tinted by minute inclusions of coloured minerals (*e.g.* hematite, goethite, cinnabar, celadonite) are also exhibited. There are a few specimens collected from sedimentary formations: gypsum and salammoniac from coal beds, glauconite from sandstone, gypsum from clay deposits, opal from diatomite.

However, specimens from the Gyöngyösoroszi–Mátraszentimre low-sulphidation type Pb-Zn-Cu deposit (central part of the Mátra Mts.), including the major ore minerals: galena, sphalerite, wurtzite, chalcopyrite and the gangue minerals: calcite, quartz, barite, celestite are in the focus of the exhibition (Fig. 9). From the Recsk, Lahóca high-sulphidation epithermal Au-Cu deposit (NE part of the Mátra Mts.) typical specimens of luzonite and enargite are presented. From the deep-seated porphyry copper and skarn ores of the Recsk area

Fig. 8. Detail from the mineralogical exhibition, Mátra Museum, Gyöngyös (photo: L. Fűköh).

garnet, amphibole, pyroxene, epidote, molybdenite, chalcopyrite, pyrite, galena, pyrrhotite, sphalerite, tetrahedrite etc. are exhibited.

2.2 Field stop 2. Cavity-filling minerals in the Kisnána andesite quarry, Mátra Mts. (Sándor Szakáll & János Földessy)

Geology

The Kisnána quarry is found in the Hátsó Tarnóca valley in the Eastern Mátra Mts. (Fig. 10). The quarry produces andesite for aggregates. It is frequently visited by mineral collectors for its great variety of cavity-filling minerals.

Fig. 9. Amethyst from Gyöngyösoroszi, Mátra Museum, Gyöngyös (photo: T. Horváth).

The andesite and intercalated tuffs lie on top of rhyodacite tuffs (average thickness 400 m), known as "middle rhyolite tuff" horizon, Hasznos Formation. The thickness of the andesite sequence at Kisnána is 200 m in the Kisnána-1 borehole for stratigraphic research (Varga *et al.*, 1975). These rocks belong to the basal series of the so-called "middle andesite sequence" (Mátra Andesite Formation), the main series of the Miocene Mátra volcano. Their age is Middle Langhian to Early Serravallian. A 20–50 m thick andesite lava flow unit is quarried, which contains thin tuff intercalations. Scoriaceous flow surfaces can also be observed. The andesite is unaltered, with plagioclase and hypersthene phenocrysts. It also contains secondary biotite and endogene xenoliths.

Cavity-filling mineral paragenesis

The paragenesis of the cavities can be divided into a high- and a low-temperature sequence (Szakáll, 1989). The early

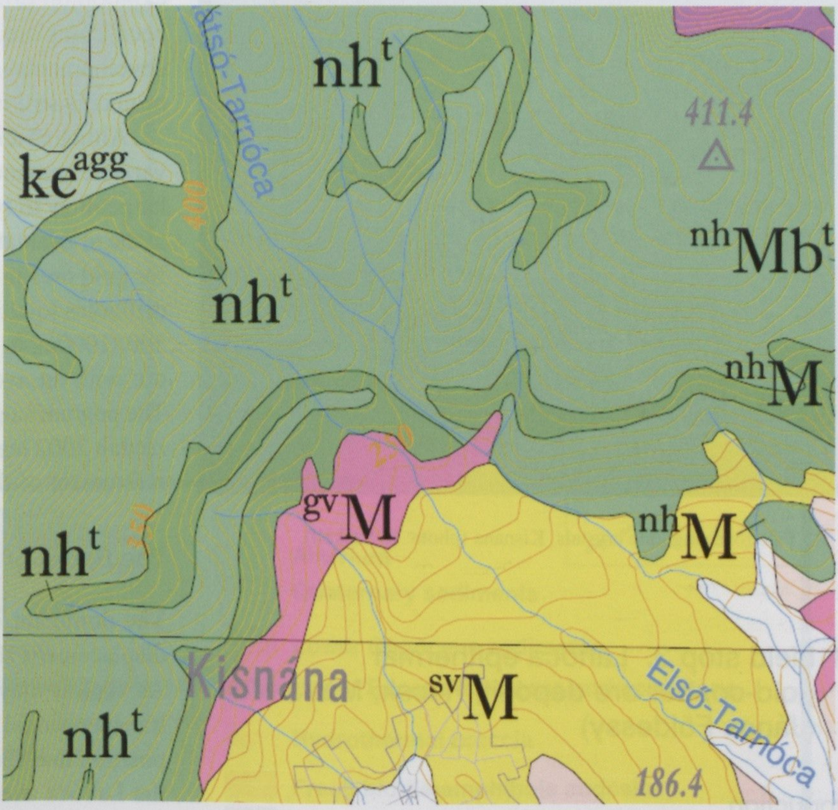

Fig. 10. Local geology map at Kisnána (based on EOFT-100, the digitised 1:100,000 "unified geological map of Hungary", produced by the Geological Institute of Hungary, see http://193.225.4.50/website/fdt100/viewer.htm)

nh^{t} – andesite tuff (Badenian); $^{\text{gv}}\text{M}$ – rhyolithe tuff (Sarmatian); $^{\text{sv}}\text{M}$ – Sajóvölgy Formation; $^{\text{nh}}\text{M}$ – Nagyhársas Andesite Formation (Badenian); ke^{agg} – andesite agglomerate (Pannonian–Sarmatian).

high-temperature stage is characterized by the presence of rock-forming minerals. However, their crystals of 1-2 mm are usually covered by the carbonates of the late, low-temperature stage. The most frequently found species are magnetite octahedra, ilmenite and hematite tablets, apatite needles, sheaf-like aggregates of tridymite, elongated prisms of pyroxenes (not identified at species level yet) and biotite flakes. A next generation is represented by zeolites, including tabular clinoptilolite and prismatic harmotome, and harmotome–phillipsite solid solutions. Carbonates are the most widespread minerals in the vugs: calcite in rhombohedral or spherical forms, colourless and pale pink crystals of 4-5 cm size, aragonite as radial groups of up to 5–10 cm long crystals (Fig. 11), or siderite as spherical gropus and platy rhombohedra. Pyrite is found in fine disseminations and hexahedra of 1-2 mm in size. Sulphates like gypsum and szomolnokite were formed due tot the decomposition of pyrite. A variety of iron and manganese oxides, like goethite, hematite and ranciéite among other yet unidentified Mn oxides were formed by the weathering of Mn-bearing siderite. Usually a white to black layer of smectites covers the carbonate minerals. Opal and montmorillonite inclusions ranging to 1–2 meters in size are also found sometimes.

Fig. 11. Pale rose aragonite crystals, Kisnána (photo: S. Szakáll).

2.3 Field stop 3. Lahóca epithermal gold-copper ore deposit, Recsk, Mátra Mts.

(János Földessy)

Introduction

The Lahóca mine was a small-scale copper producer from 1852 until 1979. Its position is on the northeastern part of the Mátra Mountains, 30-km W from the town of Eger. In 1968, the Recsk Deeps copper deposit was discovered at greater depth by drillholes approximately 1 km west of the Lahóca mine. These two major ore deposits form the most important parts of the Recsk mineralized complex (Fig. 12).

Exploration and mining history

Copper mineralization was discovered in Lahóca in 1852. During 127 years of ore production at Lahóca, twelve individual orebodies were discovered and mined by underground methods. The closed Lahóca mine has had 55,000 m drifts on 44 separate levels. Raises and declines connect 12 open or partially filled stopes within the mine.

In 1937, four deep drillholes were made in and around the Lahóca area to test surface petroleum indications. These holes hit base metal mineralization at several hundred meters depth. Later these have triggered a 4-holes deep drilling programme (1960–1968) to examine these deep ore mineralizations The result was the discovery of the Recsk Deeps porphyry copper system in 1968. The subsequent drilling program at its end consisted of 135 diamond drillholes, which tested the depths down to 1000–1300m. The holes were not cored in the near-surface section during the program.

The development of the Recsk Deeps mine started in 1970 as state-financed investment project. Two 1250 m deep shafts, 7.5 km of connecting drifts and 75,000 m of underground exploration drilling for porphyry and skarn copper ores have been completed. Financial cutbacks have forced halting the developments in 1986. After two decades of maintenance the project is still in the phase of economic re-evaluation.

Although the Lahoca was a copper mine, it also produced variable amounts of gold as by-product. Recognition of its similar geology to typical high-sulphidation epithermal systems led to the re-evaluation of the area for its gold potential. Exploration for gold ores in the Lahóca began in 1994. Fifty-nine diamond drillholes totalling about 9,000 m was completed in an area of 500×1000m, to depths of 100–240 m. 37 million tonnes of gold ore with an average grade of 1.45 g/t Au has been outlined. The pogram stopped due to low gold prices in 1997, and re-vitalized in 2002 leading to re-evaluation of data, new drillings and refinement of the ore deposit model.

The Recsk ore complex

The dominant structural feature is a major NE–SW trending displacement zone known as the Darnó zone (Zelenka, 1975). As such it may represent a transfer structure associated with transpressional tectonics. The lineament may also control the position and direction of the major ore-bearing zones in both the Lahóca and the Recsk Deeps systems.

The pre-volcanic formations consist of gently folded Triassic limestones, quartzites, shales and siltstones. Variations in the Triassic stratigraphy within less altered peripheral parts of the intrusives along a N–S trending shear zone at Recsk indicate that the Paleogene magmatism took place in the axis of an

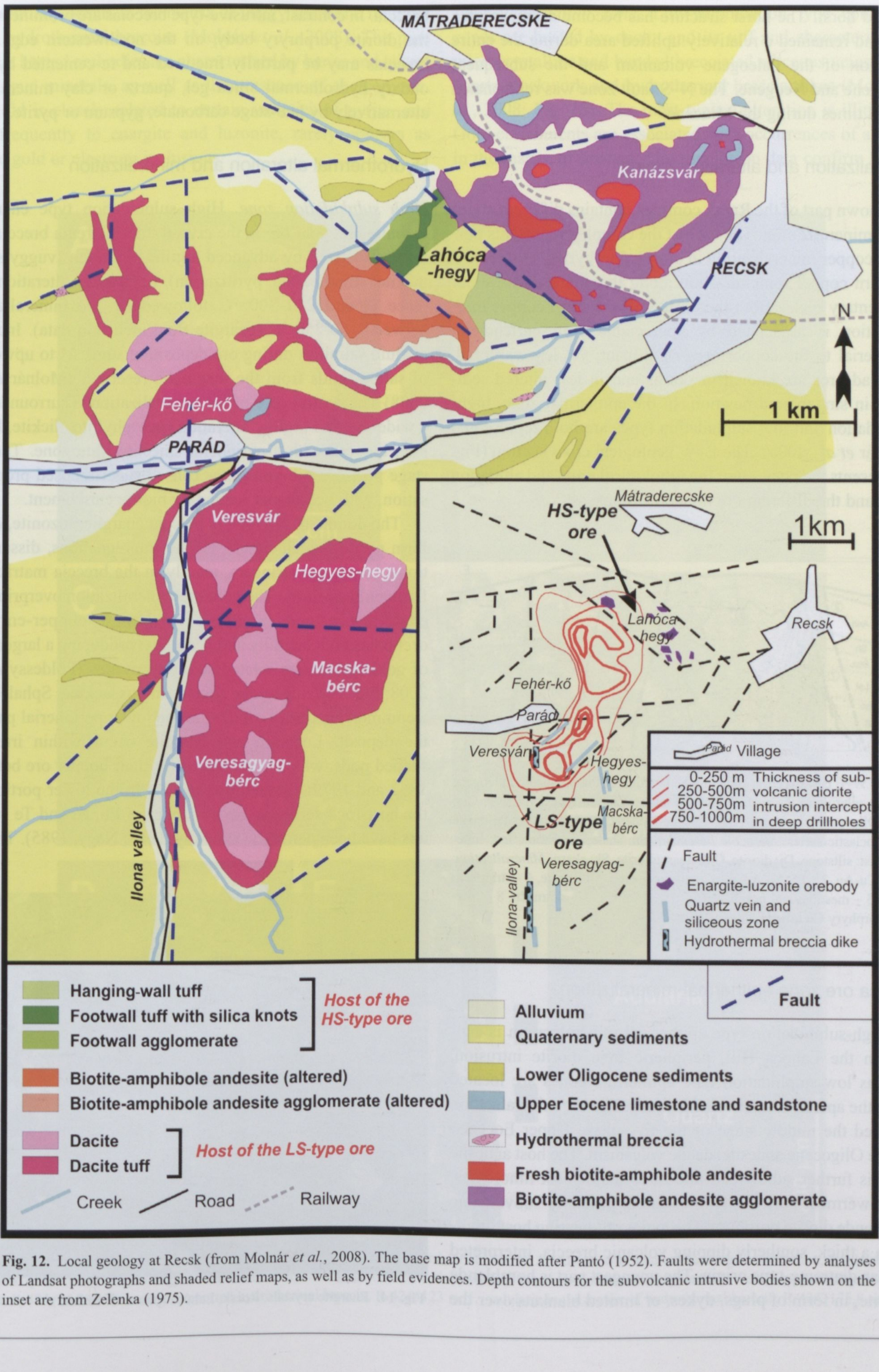

Fig. 12. Local geology at Recsk (from Molnár *et al.*, 2008). The base map is modified after Pantó (1952). Faults were determined by analyses of Landsat photographs and shaded relief maps, as well as by field evidences. Depth contours for the subvolcanic intrusive bodies shown on the inset are from Zelenka (1975).

uplifted horst. The horst structure has become a topographic high and remained a relatively uplifted area during the entire evolution of the Paleogene volcanism and the subsequent Paleogene and Neogene. The N–S fault zone was rejuvenated several times during the Miocene.

Mineralization and alteration zoning

The known part of the Recsk complex contains different styles of ore mineralization. The core of the complex represents porphyry copper mineralization in diorite porphyries, overprinted by skarn copper mineralization along the contact with older sedimentary rocks. Both the porphyry and skarn copper mineralization is associated by appreciable gold enrichment. Peripherial to the copper ores significant, yet less explored, zinc-lead ores are known in skarns and in less altered sediments in stratabound position. In the epithermal zone, high-sulphidation and low-sulphidation types are both represented (Molnár *et al.*, 2008). The E–W geological cross section (Fig. 13) presents the position of the lithological units and alteration zones and the different ore mineralizations.

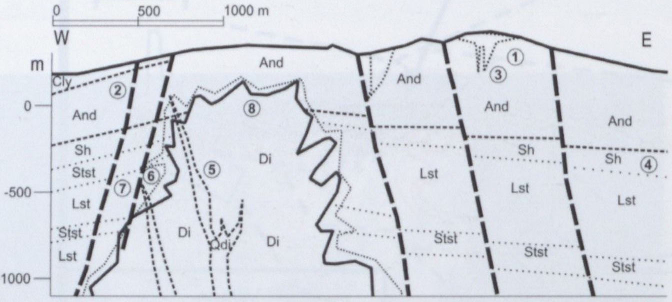

Fig. 13. W–E cross-section showing the position of the Mesozoic/Paleogene interface relative to the surface and the mineralization types. *Tertiary*: Cly: Upper Oligocene claystone, And: Eocene-Upper Oligocene andesite, dacite and pyroclastic series. *Mesozoic basement*: Sh: shale, sandstone, Lst: limestone, Stst: siltstone, Di: diorite, Qdi: quartzdiorite, Sk: skarn. *Mineralization*: 1 – HS Cu-Au, 2 – LS Au-Ag, 3 – Cu–pyrite–enargite–luzonite, 4 – stratiform Zn-Cu, 5 – mesothermal porphyry Cu, 6 – skarn Cu, 7 – skarn Zn, 8 – low-grade porphyry Cu (after Földessy *et al.*, 2004).

Lahóca ore zone epithermal mineralization

The high-sulphidation type epithermal mineralization is centred on the Lahóca Hill, peripheric to a diorite intrusion, whereas low-sulphidation type epithermal zones are located above the apices of a subvolcanic body. The ore mineralization followed the middle stage of the five-phase Upper Eocene–Middle Oligocene andesite–dacite volcanism. The host andesite phase is further subdivided into three major host lithologies. The lowermost part is shallow-seated, probably subvolcanic hornblende diorite porphyry. The major ore-bearing host lithology is a thick, southerly dipping volcanic breccia, interpreted as maar-diatreme-type origin. The youngest part is hornblende andesite, in form of plugs, dykes, or limited blankets over the breccia. In contrast, intrusive-type breccias are prominent near the diorite porphryry body, on the northwestern edge. The breccias may be partially fractured and re-cemented by secondary hydrothermal silica gel, quartz or clay minerals, or alternatively by late-stage carbonate, gypsum or pyrite.

Hydrothermal alteration and mineralization

High sulphidation zone. High sulphidation type enargite–luzonite and gold ore in the crystal tuff–diatrema breccia unit is characterized by advanced argillic alteration (vuggy silica, dickite, silicification, pyritization). Early stage alteration took place around 240–300 °C followed by ore mineralization between 150-250 °C (enargite fluid inclusion data). Increase of fluid salinities during ore deposition suggests to upwelling of saline fluids from the magmatic reservoir (Molnár *et al.*, 2008) The central core of the mineralization is surrounded by a wider halo of argillic alteration (pyrophyllite, dickite, kaolinite, quartz), with a peripheral smectite-illite zone. The late stage post-ore sub-volcanites caused superimposed propylitisation, with occasional secondary biotite enrichment.

The dominant ore type is breccia enargite, luzonite, colloform pyrite, which occurs as fine impregnations, disseminations, bands and stringers, mainly in the breccia matrix, less frequently as clasts. The gold ore mineralization overprints the enargite ore, and extends beyond these copper-enriched orebodies both laterally and vertically, producing a larger zone of gold enrichment related solely to pyrites (Földessy *et al.*, 2008; Fig. 14). Supergene zone is thin or lacking. Sphalerite is a common accessory mineral in the lower peripherial parts of the deposit. Luzonite and enargite occur within irregular shaped pods, which were mined for their copper ore between 1852 and 1979. Tetrahedrite appears in the lower portions of the host-rock series. A large number of Pb, Bi and Te sulfosalts have been detected (Sztrókay, 1943; Nagy, 1985). The ore

Fig. 14. Enargite crystals, Recsk, Lahóca (photo: S. Szakáll).

preferentially occurs in the matrix of vuggy silica and multiple stage hydrothermal breccias (Molnár *et al.*, 2008). The pipe breccia hosted orebodies are characterised by barite and quartz as gangue minerals, as well as the presence of chalcopyrite.

Gold is closely related to certain varieties of pyrite, and less frequently to enargite and luzonite, rarely appears as native gold or electrum inclusions.

Low sulphidation zone. Low-sulphidation type epithermal zones are hosted by dacite and its tuff and characterized by microcrystalline and banded-brecciated siliceous veins, drusy quartz stockwork and hydrothermal breccia dikes (Molnár *et al.*, 2008; Fig. 15). The most typical alteration is illitisation. Gold enrichments are associated with occurrences of adularia in the matrix of breccia. Fluid inclusion data confirm boiling

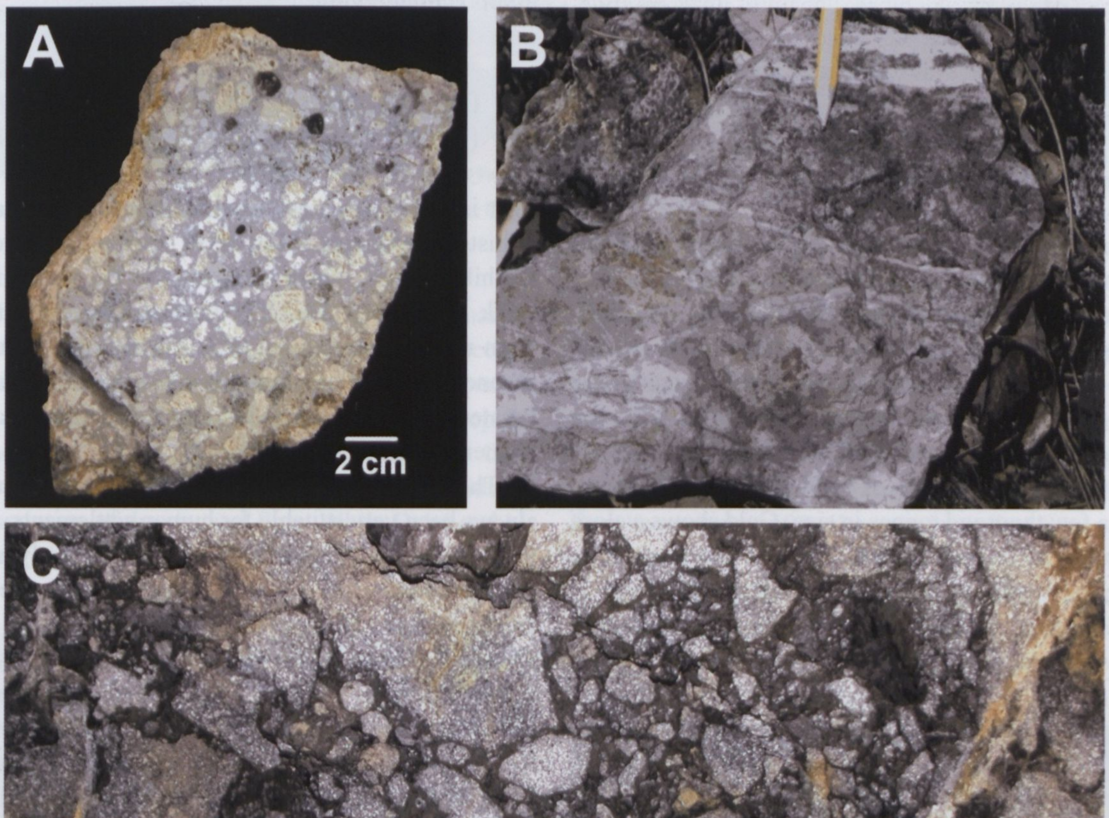

Fig. 15. Rock types and ore-bearing structures, Parád South area (from Molnár *et al.*, 2008). A – dacite with intermediate argillic alteration, B – banded and brecciated quartz vein, Hegyes-hegy, C – monominct hydrothermal breccia with pyrite-rich black, soft matrix, Vaskapu adit, D – clast-supported hydrothermal breccia, R-424, 66.3m, E – matrix-supported hydrothermal breccia, R-424, 123 m, F – adularia in the matrix of hydrothermal breccia, R-424, 175.8 m.

of fluids and 150–300 °C temperature for hydrothermal processes. Age of mineralization is Oligocene (28 Ma, adularia and illite K-Ar data; Molnár *et al.*, 2008). The most characteristic minerals are sericite, with adularia in the central parts of the mineralization. Barite also occurs in silicified pods of tuffs at the highest elevation of the area and is possibly the steam-heated variety. The mineralization is found as disseminations in silicified breccia dykes and veins, which penetrate through the second stage dacite or the third stage andesite. Tetrahedrite and pyrite are the dominant ore minerals. Gold is present as native gold and as various Au and Ag tellurides (Nagy, 1985).

Distribution and character of the gold

In the high-sulphidation part of the system the higher gold values are found mostly in vuggy silica and strongly silicified rocks containing a high sulphide content (Fig. 16). The kaolinite and the smectite zones contain low grade gold, if any. The highest gold values are obtained from the upper contact of the breccia unit with the overlying unaltered andesites, in a zone known by the old miners as the "blue shale" horizon. Historic records mention average grades of 100–180 g/t Au in pyrite-rich pods of a few thousand tonnes in size. Gold shows a close correlation with the overall sulphide content and is strongly associated with enargite, or certain types of pyrite (Földessy *et al.*, 2008). Gold does not correlate with silver, which generally occurs in separate phases such as tetrahedrite.

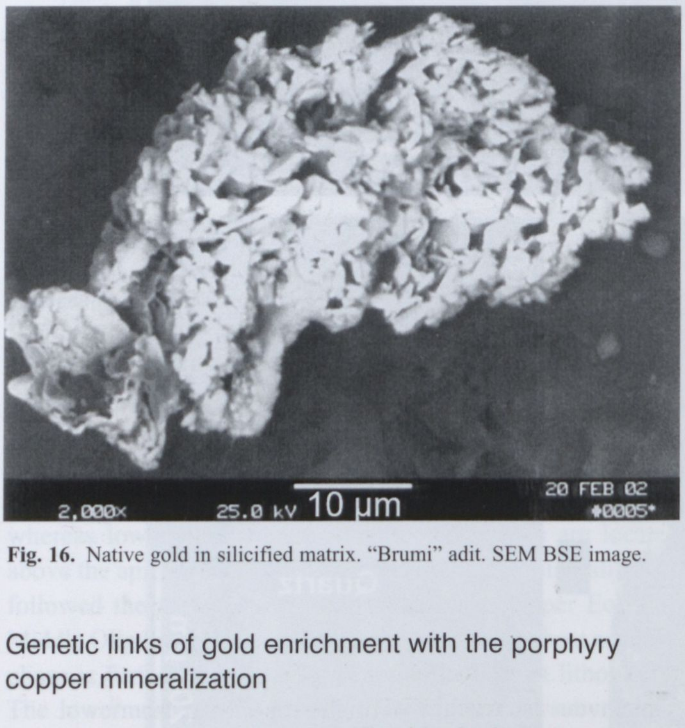

Fig. 16. Native gold in silicified matrix. "Brumi" adit. SEM BSE image.

Genetic links of gold enrichment with the porphyry copper mineralization

Present knowledge indicates that within the large Recsk mineralized system there are a number of isolated epithermally mineralized zones. These may represent structural zones that are linked to a common deeper source. Deeper ore zones are known to the west, to the south and below the "Lejtakna" (inclined adit) mineralized zone. These extensions are apparently not spatially linked to the copper-bearing porphyry, and may occur with any of the younger intrusive phases. It appears that the controlling factor was not the igneous activity itself, but rather the fracturing associated with intrusion. The fracture system that developed during the emplacement and cooling of the sub-volcanic intrusives probably controlled the hydrothermal regime.

2.4 Field stop 4. Eger, historical downtown (based on a compilation by Árpád Dávid)

Eger is one of the most beautiful towns of Hungary with lots of historic buildings. It lies in the valley of the Eger Stream, in the hill country, which extends over the western foot of the Bükk Mountains (Fig. 17). For geologists the name of the town may sound familiar after the Egerian stage, a regional chronostratigraphical unit used in the stratigraphy of the Paratethys area; the stratotype of the Egerian stage is in the former Wind Brickyard at Eger.

The basin of Eger and the hilly region around it have always been very suitable for human settlements, as shown by the many archaeological findings from the early ages of history. The conquering Hungarians occupied the area of Eger at the beginning of the 10th century. Actually the founding of Eger coincides with the church-founding activity of the first king of Hungary, Saint Stephen. He established here one of the ten bishoprics that were organised before 1009. According to the popular etymology of the name of Királyszéke ("King's Seat") Hill, King Saint Stephen watched the building works of the first cathedral of Eger from this point, which in fact one of the best outlook points in the town.

Eger as a cathedral town took up an important place among the Hungarian towns even in the early history of the Hungarian Kingdom. This development was blocked for a short time by the Mongol invasion in 1241, when the town was ransacked and burned down. After the retreat of the Mongols, Lambert, the bishop of Eger, received a permit from King Béla IV for the building a stone fortress. So the nearly destroyed town revived and reached the peak of its medieval development in the 14–15th c. During this period the forests that spread to the limits of the town, were cleared for the most part, and vines were planted in their place.

The reign of King Matthias (1458–1490) saw futher development of Eger. Among others the Bishops' Palace, was rebuilt in Late Gothic style by the order of Bishop Johann Beckensloer. Building activity continued during the bishops Orbán Dóczy, Tamás Bakócz and Ippolito d'Este.

After the disastrous battle against the Turks at Mohács (1526), during the rival dual kingship of Ferdinand I and John I, the town changed hands almost every year and the boundary of the territory occupied by the Ottoman Empire came nearer

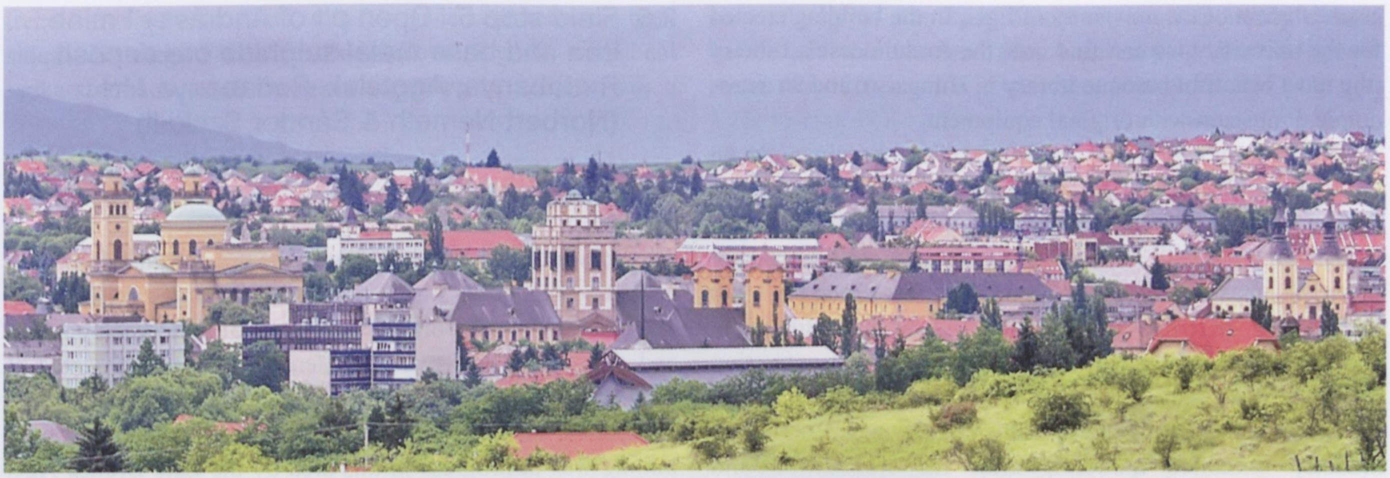

Fig. 17. Panorama of Eger (photo: Á. Dávid).

and nearer. In the autumn of 1552, István Dobó, commander of the castle (Fig. 18) and his handful of soldiers were successful in defending the fortress and northern Hungary from the advance of the Turkish army. One of the most popular Hungarian novels, "Eclipse of the Crescent Moon" by Géza Gárdonyi, translated into numerous languages, provides a romantic description of the siege of Eger. While Dobó and his soldiers managed to defend the fortress in 1552, in 1596 the captain at that time and the foreign mercenaries under his rule handed it over. The graceful minaret, which was built at the end of the 17th century, preserves the memory of the 91-year-long Turkish rule in Eger. 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 seat of a vilayet (a large Turkish administrative division).

Fig. 18. Statue of István Dobó with the castle in the background, Eger (photo: Á. Dávid).

Eger was relieved from Turkish rule in December 1687. Although the reoccupation was preceded by a blockade without heavy bombardment, the town fell into a very poor state. There were only 413 habitable houses within the town walls. Leopold I granted Eger the rights of a free royal borough in 1688, relieving Eger from the ecclesiastic manorial burdens. During the era of Rákóczi's insurrection (1703–1711) the town was the centre of the liberated part of Hungary. Prince Ferenc Rákóczi II stayed several times within the walls of Eger and his general headquarters was here, too. The first Hungarian newspaper, *Mercurius Veridicus* (Veracious Mercury) was issued here in 1705.

The 18th century was the period of development and prosperity in the history of Eger. The bishops of Eger, especially Ferenc Barkóczy and Károly Eszterházy, created that baroque townscape which has been characteristic of Eger since that time. The most spectacular ones among the baroque buildings are the "Lyceum" (central building of Eszterházy Károly College), the Minorite Church (Fig. 19), the Small Provost's palace, the Great Provost's palace (County Library), the County Hall with Henrik Fazola's two wonderful, wrought-iron gates and the Serbian Church. The town population grew suddenly, from 1200 (1688) to more than 17 000 (1787). At this time Eger was the 6th most populated town of Hungary. Viniculture also reached its brightest period in these days. The bishops planned to establish a university in Eger. In 1740 a Faculty of Law was founded, in 1754 Bishop Barkóczy a school of philosophy and in 1769 the first medical school of Hungary was opened. Unfortunately, the Queen hasn't approved the establishment of the university of Eger. In the building erected for the university we can find now the Archdiocese's Library (the most beautiful baroque library in Hungary), and an astronomical museum with original equipment.

The Reform Age (1825–1848) left several lasting marks on the life of Eger, especially on its culture. Archbishop László Pyrker founded a gallery, which he finally donated to the Hungarian National Museum, The Pyrker collection later served as a base for the Museum of Fine Arts opened in 1900 in Budapest. In 1828 Pyrker established the first Hungarian teachers training college in Eger. He ordered the construction of the basilica, built in neo-classical style (architect: József Hild). Unlike other towns in Hungary, the development of industry remained moderate after the Revolution and Independence War (1848–1849) and even after the Austro-Hungarian Compromise of 1867. The character of a school-town was dominant in Eger.

The 20th century brought about several changes in the town life and development but, fortunately, in 1968 the baroque inner city was declared preserved. So it was saved from the deterioration and from the construction of out-of-place, modern buildings, that hit most other towns in Hungary. In 1978 Eger was rewarded with a Hild Medal for its excellent work in protecting local monuments. It was also in appreciation of the town's commitment to protection of its heritage that the Hungarian seat of the ICOMOS (International Council for Monuments and Sites) was located into Eger.

Fig. 19. Minorite Church, Eger (photo: Á. Dávid).

2.5 Field stop 5. Open pit of Andrássy I mine, iron and base metal sulphide ore deposit Rudabánya, Aggtelek–Rudabánya Mts. (Norbert Németh & Sándor Szakáll)

Mining history

The knowledge and exploitation of the ore at Rudabánya goes back to prehistoric times (Hadobás, 2001; Szakáll *et al.*, 2001). Many stone tools and fragments of pottery were found and dated from this era. An interesting stone tool dated at ~8000 BC (early Mesolithic) was recovered near the Rudabánya mine. We can be reasonably certain that copper mining was in progress in this area by the Late Bronze Age. The oxidation–cementation zone of the deposit was mined for native copper. Evidence for this is provided by the remnants of a sizable bronze foundry dating at ~1000–1500 BC, which was excavated at a site near the river Sajó 9 km south of Rudabánya. From the same find many bronze articles were also recovered, including coiled sheets, wires and flat lumps of bronze. Later, during the 10th century, iron production was established in this region. From this era, archeologists have located and excavated more than 70 sites in the vicinity of Rudabánya, including iron smelting furnaces and extensive slagheaps.

The 14th–16th century was the golden age of copper and silver mining of Rudabánya. In 1487 Rudabánya was listed as the founding member of the alliance of the seven "Upper Hungarian Royal Mining Towns". Mining, metallurgy and the related commercial activities could only develop and flourish in relative peace and security. Probably native copper was the main copper ore mined, possibly with some secondary copper minerals (*e.g.* cuprite, malachite, azurite), while silver-rich galena and acanthite were the primary silver ores. Contemporary production data are not available, but the scale of production can be judged from the quantity of slag that remained after the processing of copper and silver ores. The present-day town is partly built on the slag dumps accumulated in this period.

Mining seriously declined then ceased during the Turkish wars (mid-16th to late 17th c.). In the last two centuries (especially since 1880) iron ore was mined in large quantities from extensive open pits. The main ores included "limonite", then later primary siderite and so-called ankerite ore (ankerite and iron-rich dolomite with less siderite). The iron mines were abandoned in 1985, but the long history of mining in Rudabánya is not likely to be finished for ever: the depths of the Earth hide explored but unexploited and further unexplored mineral treasures.

Geology

The Rudabánya Mts. form a 25 km long, NNE–SSW trending range of uplifted Paleozoic and Mesozoic rocks, edged by trenches, which are filled with Neogene sediments on both sides. The range lies in the Darnó Zone (Fig. 1), a regional strike-slip fault zone. Its main identifyable activity was a sinistral slip in the Early Miocene, but it possibly existed before and was renewed after with varying sense of movements (Fig. 20).

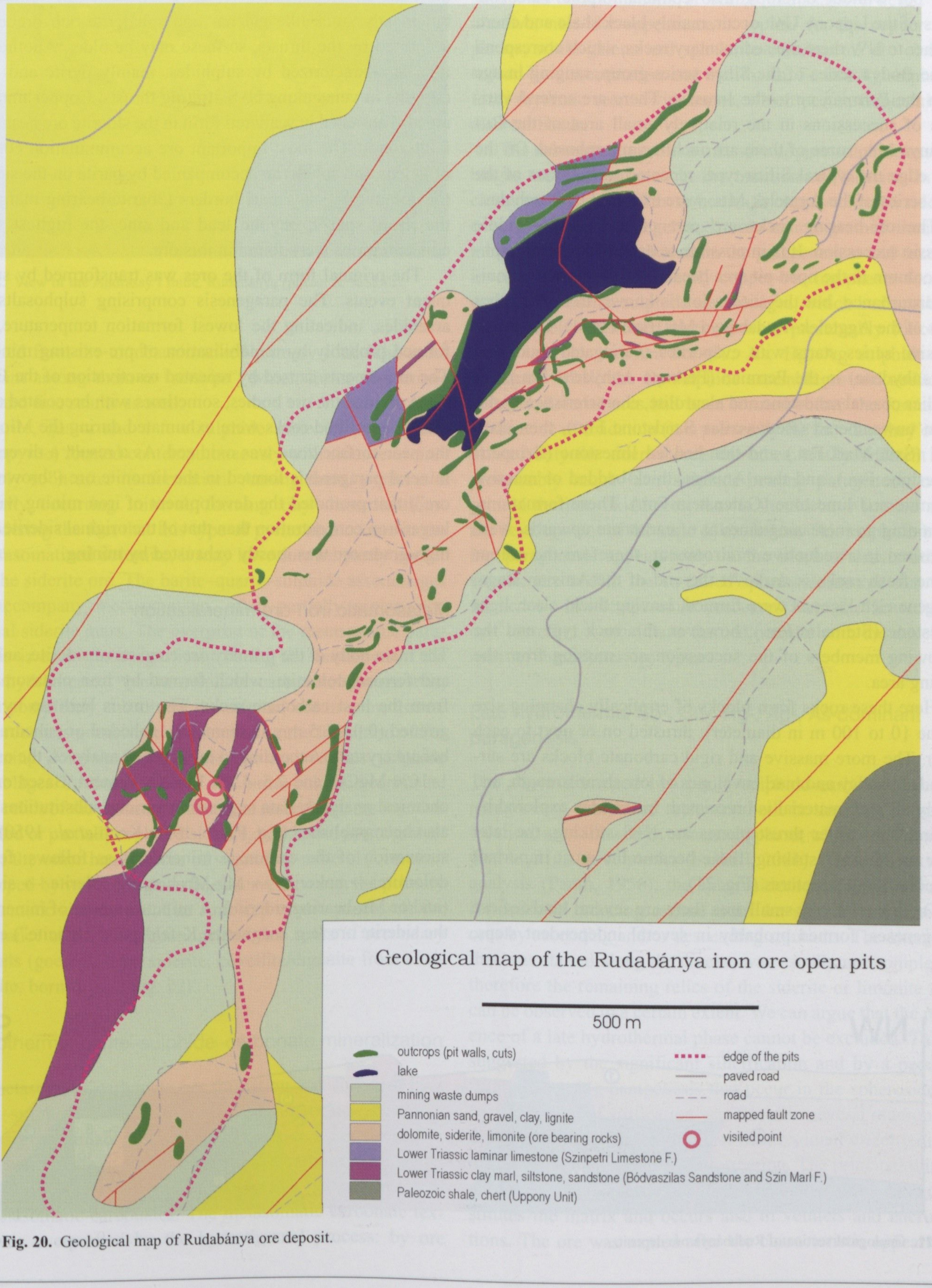

Fig. 20. Geological map of Rudabánya ore deposit.

The rock material assembled along the zone in elongated or imbricated horsts of variable origins. The buried base of the SE edge comprises epimetamorphic Paleozoic rocks of the Szendrő Unit, mainly phyllite. Next to this, partly on the surface but without outcrops, also epimetamorphic Paleozoic rocks of the Uppony Unit occur, mainly black shale and chert. Further to NW there are sedimentary rocks, which correspond to the Bódva series of the Silica series group, ranging in age from the Permian up to the Jurassic. There are several varieties of successions in the relatively small area of the Rudabánya Mts, some of them are anchimetamorphosed. On the NW edge the typical Silica-type, repeated successions of the rock series of the Aggtelek Mts. were explored by boreholes.

The ore-bearing rocks are part of the Lower–Middle Triassic succession. It is impossible to establish a stratigraphical column in the open pit area because of the strong tectonical disturbance, but the succession is known from the other parts of the Aggtelek–Rudabánya Mts. (see Fig. 4). The transgressive series starts with evaporites (variegated mudstone and anhydrite) in the Permian (Perkupa Anhydrite Fm.). On this lies coastal sandstone and aleurolite, characteristically red when unweathered (Bódvaszilas Sandstone Fm.), then slaty marl (Szin Marl Fm.) and thin-bedded limestone (Szinpetri Limestone Fm.), and then Anisian, thick-bedded or massive dolomite and limestone (Gutenstein Fm.). These formations, containing an increasing amount of carbonate upwards, were deposited in a reductive environment, therefore the colour of the fresh rocks is dark. At the end of the Anisian stage, oxygene-rich lagoons were formed, leaving thick, clear, light limestone (Steinalm Fm.); however, this rock type and the following members of the succession are missing from the mining area.

Here these rocks form blocks of erratically changing size (some 10 to 100 m in diameter), thrusted on or next to each other. The more massive and rigid carbonate blocks are surrounded by clay and marl envelopes of low shear strength, and nearly all rock material is brecciated. In the area explored by mining, the earlier thrust planes are N–S striking, the later ones are NE–SW striking; these became the most important ore-controlling structures (Fig. 21).

On this relatively small area there are several kinds of ore parageneses, formed probably in several independent steps. Metasomathic siderite is considered the oldest. According to Pantó (1956) the dissected and imbricated, "marl-enveloped" dolomite bodies served as host rock, in which several mm-sized siderite crystals were grown (called "spar iron ore"). In the marl envelope, however, there are sometimes stratiform but mostly stock-like galena- and sphalerite-rich orebodies, deformed by the thrusts, so these may be older. Another ore type is characterized by sulphides, mainly pyrite and chalcopyrite in veins along N–S striking thrusts. Copper minerals are also enriched in scattered form in the siderite ore near these fault zones. The most important ore accummulation consists of galena and sphalerite accompanied by barite on the siderite (or dolomite) / clay marl borders ("barite-bearing margin of the [iron] spar"); beyond lead and zinc, the highest silver concentrations were found in this ore.

The original form of the ores was transformed by subsequent events. The paragenesis comprising sulphosalts and arsenides, indicating the lowest formation temperature, was formed probably by remobilisation of pre-existing minerals. The movements caused by repeated reactivation of the Darnó Zone divided the ore bodies, sometimes with brecciated material. The uplifted rocks were exhumated during the Miocene, the near-surface zone was oxidized. As a result, a diversified mineral paragenesis formed in the limonite ore ("brown iron ore") that promoted the development of iron mining with its larger iron concentration than that of the original siderite. This high-grade ore was mostly exhausted by mining.

Metasomatic iron ore mineralization

The main body of the primary ore consists of siderite, ankerite and ferroan dolomite, which formed by iron metasomatism from the host carbonate rocks. The ore is built up by fine-grained (0.01–1.5 mm in diameter), anhedral or euhedral carbonate crystals. According to microprobe analyses, the ore has 1–10% $MgCO_3$ and 2.5–4.2% $MnCO_3$ content. Based on wet chemical analyses, data suggesting various substitutions have also been published (*e.g.* Pantó, 1956; Koch *et al.*, 1950). The succession of the carbonate minerals is as follows: ferroan dolomite → ankerite → Mg-Mn-bearing siderite → siderite (and/or Mn-bearing siderite). A minute amount of minerals in the siderite ore (*e.g.* magnetite, K-feldspars, "sericite") can be

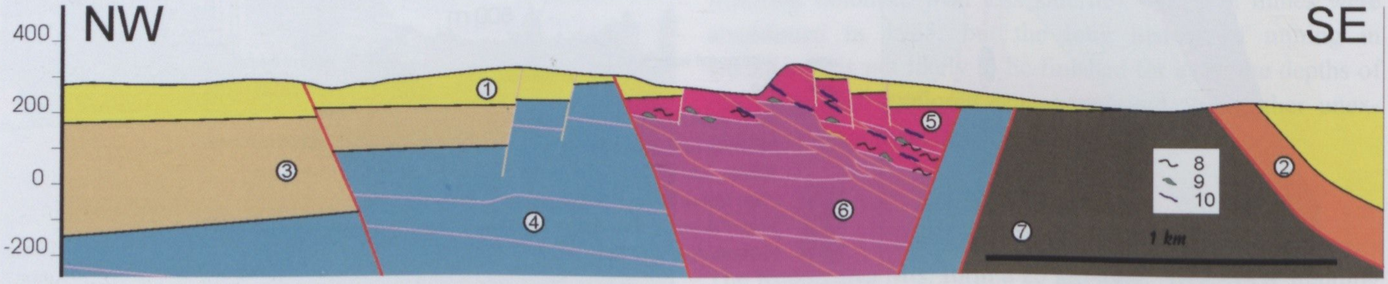

Fig. 21. Geological section of Rudabánya ore deposit.

Fig. 22. View of the Andrássy I mine, Rudabánya (photo: S. Szakáll).

inherited from the unmetasomatized primary rock. The most impotant among them is "sericite", which forms disseminations and fine seams as well.

Barite, quartz and a few sulphide minerals (*e.g.* pyrite, chalcopyrite) formed contemporaneously with siderite or presumably soon after its formation. Among them, pyrite is a generally occurring mineral, forming tiny disseminations. Considering the fact that this type of pyrite also occurs in the unmetasomatized dolomite, it may have formed partly earlier than the siderite ore. The barite–quartz–sulphide assemblages that accompany metasomatism, often partially replace the original siderite mass. The overprint of the metasomatic paragenesis is even more significant during the formation of the next, hydrothermal barite–sulphide–carbonate paragenesis, which completely substitutes the original ore in some zones. This process is primarily characterised by the formation of Fe-containing dolomite–ankerite–siderite and various sulphide assemblages. In the masses of the barite-sulphide-carbonate rocks, relics of the metasomatic mineral assemblage are found as corroded or partially replaced siderite, barite, and pyrite grains.

On the other hand, traces of secondary mineral formation developed by weathering can be observed even in the primary metasomatic siderite ore. The first step of this process is the appearance of film-like coatings and fine spots of secondary minerals (goethite from siderite, covellite/digenite from chalcopyrite, bornite etc.; Fig. 22).

Hydrothermal barite–sulphide–carbonate mineralization

The metasomatic carbonate ore formation was followed by a barite–sulphide–carbonate-bearing paragenesis. The two processes presumably overlapped in time to a certain degree but the main mass of the barite–sulphide–carbonate paragenesis formed after the metasomatism, since it partially replaces the metasomatic carbonates. The metasomatic carbonate texture was overprinted by the hydrothermal process: by ore microscopy one can observe corroded siderite rhombohedra, tabular barite crystals and intensively cracked, eroded pyrite crystals in the sulphide-barite masses.

Sulphides occur in the barite- and carbonate-bearing matrix as disseminations or seams and massive nests. The massive, nest-like appearance is typical for the copper sulphides, while galena and sphalerite enrichments are characterised by dissemination and the Pb, Zn, Fe and Ag sulphides form rhythmic seams with barite, which occurs frequently in discrete bands.

The subsequent nest-like, massive copper sulphide assemblages are also common in the metasomatic siderite. In the closer environment of these bodies, a cream-coloured siderite occurs, which is younger and more coarse-grained than the metasomatic siderite. Based on the paragenetical and textural investigations, the dominantly copper-bearing phases formed earlier. The barite–sulphide assemblages, which had probably been closely connected in time, were presumably followed much later by another Sb, Cu, As, Hg, Ag sulphide-rich sequence. While the Cu sulphide assemblages and abundant galena/sphalerite ores had been formed before the formation of the zone of oxidation (it is proven by the fact that they overprinted only the siderite ore), the other, totally different and presumably much later sulphide-bearing paragenesis overprinted the iron oxide ores, thus it should have formed after the development of the zone of oxidation. This sulphide-bearing paragenesis appears only in the more or less oxidised siderite ore and in the so-called spherosiderite ore that was formed by low-temperature processes from the limonitized ore; therefore it must have formed parallel with the development of these latter ore types.

Late hydrothermal Sb-, Cu-, Hg-, Ag-, As-dominant paragenesis

The above discussed two barite–sulphide–carbonate-bearing parageneses, which are separated both in time and in partly location, are followed by a later ore phase, which is rich in Sb, Cu, As, Hg, Ag sulphides (Szakáll, 2001). Based on textural analysis (Pantó, 1956), the spherosiderite ore was probably formed in a reducing regime from the siderite and limonite ores by ascending and/or descending solutions. The alteration that was started along the cracks, was usually not completed; therefore the remaining relics of the siderite or limonite ores can be observed to a certain extent. We can argue that the presence of a late hydrothermal phase cannot be excluded. This is suggested by the significant silicification and by a peculiar sulphide-bearing paragenesis that occur in the spherosiderite ore. This kind of silification was found in several outcrops of the limonite ore, therefore it can be a regional effect indicating the termination of the ore formation. The principal mineral of the "spherosiderite ore" is of course siderite, which constitutes the matrix and occurs also in veinlets and encrustations. The ore was named after the characteristic appearance of siderite, i.e. radially fibrous, globular or reniform aggregates. The spherosiderite ore formed after the formation of the zone of oxidation.

This mineral assemblage is much more abundant than it was assumed by Pantó (1956) or by Koch (1985). The formation of this paragenesis remobilized different components of the siderite and limonite ores and produced an interesting sulphide and arsenide paragenesis, occasionally accompanied by silicification. The principal members of the paragenesis are Cu sulphides, Cu-Sb sulphides and Cu arsenides. The arsenic-rich zones are specifically distinctive for the brecciated calcite–siderite ore types. The spherosiderite paragenesis is a complicated one: the texture of the earlier (siderite and/ore limonite) ores has partially been preserved as relics or fragments, incorporating minerals from both earlier genetic types (iron-bearing metasomatism and oxidation). The primary ores were overprinted by the late hydrothermal process, resulting in the formation the paragenesis that includes the above mentioned mineral groups. Finally, a secondary paragenesis formed by near-surface oxidation processes. This abundant, extremely varied formation sequences have yielded the mineral diversity of the Rudabánya deposit.

Supergene mineralization (secondary minerals)

During the time that has been lapsed since the Tertiary, the primary zone of the ore deposit has suffered a significant oxidation-type alteration process downwards to 40–60 m depth. In this zone of oxidation-cementation, specific secondary mineral assemblages developed from all earlier ore types:

1) An Fe-Mn oxide-rich, as well as Fe sulphate-rich paragenesis formed from the siderite ore (limonite ore).
2) A paragenesis primarily containing secondary Cu carbonates, Cu sulphates, Cu arsenates developed from the Cu sulphide–barite–carbonate assemblage.
3) A paragenesis abundant in secondary Pb, Zn, and Ag sulphates as well as in carbonates and chlorides formed by the Pb, Zn, Ag sulphide–barite–carbonate ore bodies.
4) The late, Sb, Cu, As, Hg, Ag sulphide-rich stage also produced its own secondary paragenesis, represented mainly by arsenates, oxides and carbonates.
5) Finally, secondary minerals are being formed at the present outcrops. These are discussed at the appropriate sections, taking into consideration the "primary" ore type.

The secondary Fe-, Mn-dominant paragenesis

Iron and manganese, which occur together in the sulphide-depleted metasomatic carbonates, are separated from each other in the zone of oxidation. All iron and manganese oxides occur here separately. Goethite is the most widespread among the secondary iron oxides. According to XRD analyses, it is the principal component of limonite ore. All stages of the alteration process from siderite (ankerite/ferroan dolomite) to goethite can be observed in the zone of oxidation. Hematite and lepidocrocite can also be detected occasionally.

Manganese oxides developed probably at those areas where the Mn-content of the primary siderite was higher. Their appearance is varied; they form earthy disseminations, impregnations, film-like coatings, fine- or coarse-grained crystalline masses. The chemical components of iron and magnesium sulphates that are developing currently in significant masses at the present outcrops are derived from the iron and magnesium content of siderite and limonite ores as well as from the widespread pyrite content of the metasomatic carbonates.

Secondary Cu-dominant paragenesis

This paragenesis was derived first of all from the Cu sulphide–barite–carbonate ore bodies. However, it also should be considered that small nests of Cu sulphides occur frequently in the metasomatic carbonate ore, giving rise to several secondary parageneses with Cu-bearing minerals when the zone of oxidation reached them.

The main process can be described as follows: the primary ore, containing mostly chalcopyrite, bornite, tetrahedrite/tennantite altered in the first phase to chalcocite, digenite, djurleite, bornite and covellite. Further oxidation produced azurite / malachite, antlerite / brochantite, or cuprite / tenorite assemblages. These mineral groups were accompanied by arsenates such as cornubite / conichalcite / olivenite formed by the oxidation of As-rich sulphides (mainly tennantite and domeykite; Figs. 23–25).

Fig. 23. Azurite crystals, Rudabánya (photo: L. Horváth).

Fig. 24. Cuprite crystal, Rudabánya (photo: L. Horváth).

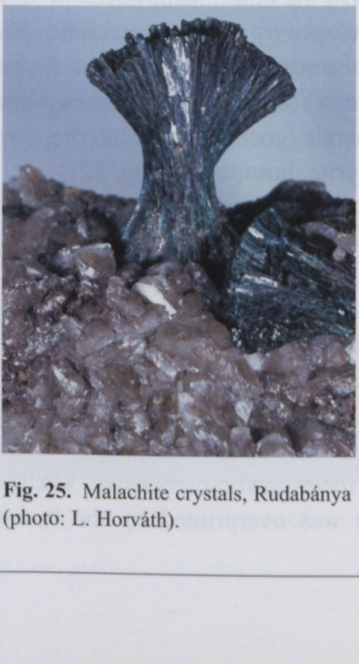

Fig. 25. Malachite crystals, Rudabánya (photo: L. Horváth).

All intermediary stages of these alteration processes can be found. The extent of the alteration depends on the oxidation conditions, the degree of fracturing of the ore (and that of the individual minerals as well) and on the closer environment (the alteration will take place easier in a carbonate environment than in the ore hosted by barite). Since transformation processes could happen several times in both directions, this paragenesis is extremely rich in pseudomorphs.

Secondary Pb-, Zn-dominant paragenesis

Due to the abundance of carbonates, the oxidative alteration of the galena–sphalerite–barite-bearing zones resulted in the formation of cerussite. The first step of alteration of galena sometimes yielded anglesite. The secondary Pb-bearing minerals have been altered first along the cleavage planes or along the grain boundaries. Later, parallel with the development of weathering, the primary sulphides could have completely disappeared and could be replaced by secondary sulphates or carbonates. Carbonatization is pronounced, cerussite and smithsonite are the dominant species, in variable proportion. In the massive, altered, sulphide-bearing regions a yellow-brown, banded texture is indicative for the cerussite and smithsonite precipitation. In the marl-like formations these minerals are not found separately but the occurrence of cinnabar usually indicate their presence. Additional secondary minerals, such as Pb-Sb-bearing sulphosalts, Cu sulphides, cinnabar, malachite as well as bindheimite (developed from fahlore) or goethite, jarosite and gypsum (developed from pyrite) occur only in some nests. The earlier siderite generations altered to goethite.

Secondary Ag-, Hg-, Cu-, Sb-, As-dominant paragenesis

The spherosiderite ore and the adjacent silicified bodies include a peculiar secondary paragenesis, which is mainly composed of late Ag-, Hg-, Cu-, Sb-, and As-rich minerals. Their weathering in the zone of oxidation yielded the occurrence of different arsenate, oxide, silver and copper halogenide, and rare sulpho-halogenide minerals. Whereas the formation of arsenates and oxides can easily be explained, the reason for the abundant appearance of halogenides (and also of sulpho-halogenides) in some outcrops is not so obvious. Widespread formation of halogenides can be explained by the arid conditions that used to exist at the ore deposit, but it can be also associated with evaporites that occur in the vicinity. There is no direct evidence of an arid climate, but halite was found in nearby evaporites. Secondary arsenates can be derived partially from As-bearing tennantite, but several arsenates may have originated by the weathering of domeykite-bearing ores.

2.6 Field stop 6. County Museum of Mining History, Rudabánya

(Sándor Hadobás)

In 1955, the 75th anniversary of the beginning of the modern ore mining was celebrated in Rudabánya. On this occasion the mining and geology experts of the mining company introduced the unique history of the mining at Rudabánya in a temporary exhibition. The iniciative was a great success and stimulated a demand for a constant collection devoted to local and mining history. The wish has been fulfilled soon: the opening ceremony was held on September 3, 1956 on the occasion of Miners' Day. On the basis of this collection In 1965 the newly founded Hungarian Ore and Mineral Mining Museum (from 2006 County Museum of Mining History) moved to the present building with the collection already covering the whole country. The museum is specialized in the historical aspects of metalliferous ore mining in Hungary. The most interesting individual exhibits (Fig. 26) include local finds connected with early mining, such as a reconstructed 10th century iron smelter, wooden mine supports and step-ladders from the 15th century, mining tools and lamps. Large pieces of mining equipment from the more recent past are on show in the courtyard of the museum, and in a simulated mine adit with an original mine portal.

The museum owns a considerable collection of minerals, rocks and fossils. Beyond minerals from the other parts of Hungary, the collection is famous for the specimens from the rich mineral assemblage of the Rudabánya deposit and the large mammal fauna excavated from the

Fig. 26. Detail of the mining history exhibition, County Museum of Mining History, Rudabánya (photo: A. Papp).

Pannonian strata of the "ape colony". The collection has been displayed since 1980 in the separate exhibition building named after Prof. Aladár Földvári (1906–1973), former head of the Department for Geology and Mineral Deposits of the University of Miskolc. From the excellent display of the minerals of the Rudabánya deposit, splendid specimens of azurite, malachite, cuprite and native copper are the most noteworthy. A good selection of minerals and ores are also exhibited from Gyöngyösoroszi, Recsk, Parádsasvár, Úrkút, and other important Hungarian ore deposits (Fig. 27). There are displays of typical specimens from the Alsótelekes gypsum–anhydrite mine, and cave minerals from Tornaszentandrás. A separate exhibition is devoted to the famous Rudabánya fossils. They were found in the Pannonian (Lower Pliocene) cover sediments at the northern edge of the open pit. Among the numerous fossils, skull and other bone fragments were unearthed, which proved to be remnants of ape-like early hominoids, including *Anapithecus* (originally descrbed as *Pliopithecus*) *hernyáki* and *Rudapithecus hungaricus* (some palaoanthropologists classify the latter as *Dryopithecus brancoi*).

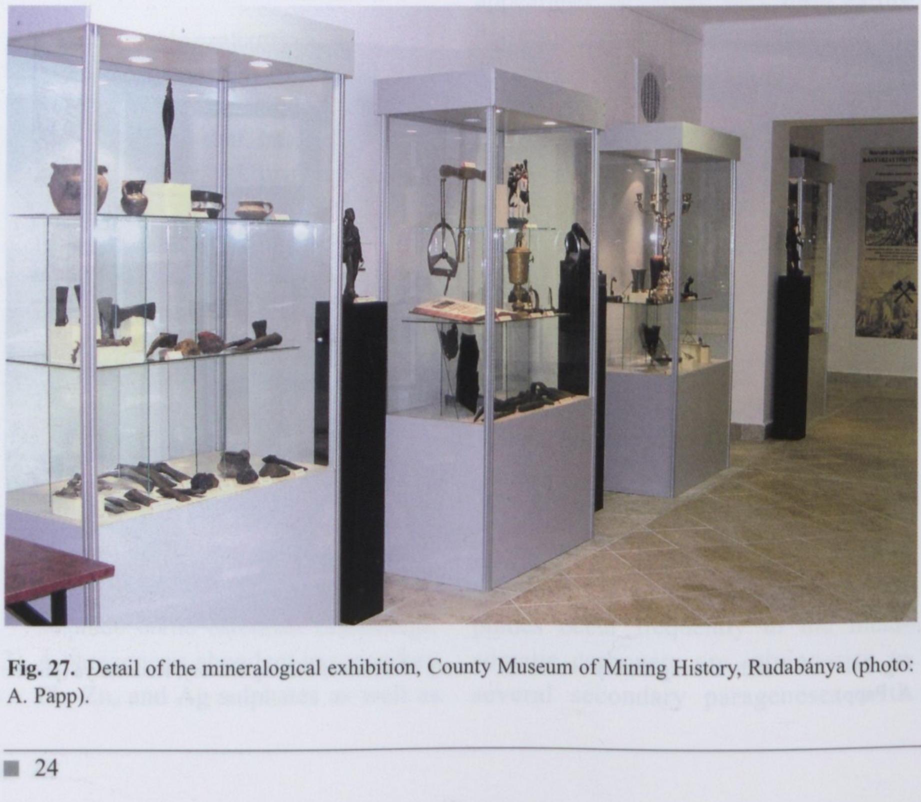

Fig. 27. Detail of the mineralogical exhibition, County Museum of Mining History, Rudabánya (photo: A. Papp).

2.7 Field stop 7. Open pit of the gypsum–anhydrite mine, Alsótelekes, Aggtelek–Rudabánya Mts.

(Norbert Németh)

General geological background

The evaporite complex of the Rudabánya Mts. was discovered by iron ore exploration boreholes in 1950 near Alsótelekes. In 1952, the Perkupa I. borehole explored a stack of anhydrite horstes with imbricated serpentinized volcanic bodies in the Bódva Valley (Mészáros, 1957). Between 1957 and 1985, anhydrite was produced for melioration from the four-level underground mine at Perkupa. In 1968 the At-478 borehole at Alsótelekes (drilled for exploration of the tectonic structure) penetrated a gypsum–anhydrite body with more than 400-m thickness. Since then, 230 exploration boreholes, and extended surface geoelectric surveys had been completed and an open pit was started in 1987. The gypsum–anhydrite–shale–sandstone complex showing a diapiric evaporite tectonics in an area of 0.25 km^2 between the +160 and +205 m levels (Fig. 28). Almost 2 million tons of raw materials were extracted from this opencast mine.

The evaporitic series (Perkupa Anhydrite Formation) is the lowermost known unit of the Silicicum of Upper Permian age (Fülöp, 1994). It is a typical lagoon facies sediment with sabkha-like conditions in the higher and reductive conditions in the deeper parts. There are three textural types of the gypsum layers: brecciated, selenitic (coarse-grained) and laminitic. The lenticular, outwedging strata of the tidal zone contain sand and cm-size, slightly rounded, flat pebbles of anhydrite that was torn up by the waves after its precipitation. On the highest, supratidal parts, lenses of red clay with iron oxides were formed. The strata formed beneath the tidal zone are dark, sometimes bituminous shales, containing calcium sulphates and carbonates with finely scattered pyrite grains. Anhydrite occurs either with shale inclusions or with dolomite interlayering. The frequent alternation of the different rock types shows the undulation of the water level during the sedimentation. The microlayering of the dolomitic anhydrite indicates (probably seasonal) changes in temperature.

In the survey area and in the pit all contacts of the gypsum–anhydrite body are discordant. The direct cover is a continental red clayish sediment with debris and lenticular bodies of limestone breccia and resedimented black or purple clay of the evaporitic complex. The material often contains acicular gypsum crystals and veins. The cover sediment can be classified by its facies and material in the Lower Miocene Zagyvapálfalva Clay Formation, which is widely distributed in North Hungary. On the NW side of the pit, large (10-m size) blocks of dark limestone and light grey Steinalm Limestone are found, not directly on the gypsum but on the continental sediments and on the black shale. There are also separate blocks of black shale, sandstone, dolomite and limestone of unidentified origin enclosed by the gypsum. Black shale is most prevalent on the NW side, in lateral contact not only with the gypsum but also with the

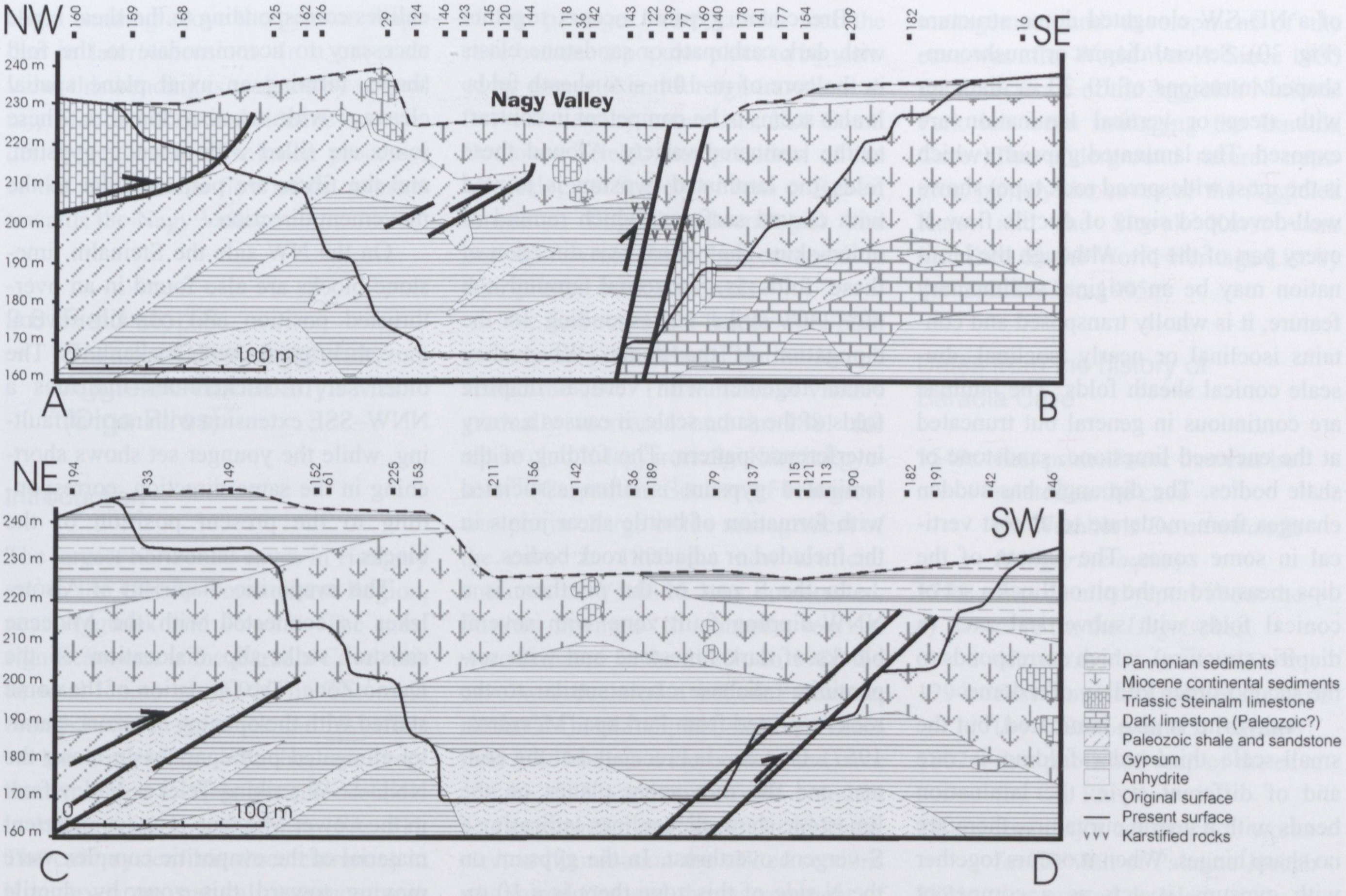

Fig. 28. Geological section of the Alsótelekes open pit (after Zelenka *et al.*, 2005).

continental sediment and between the limestone blocks. Several blocks of black and light grey limestone occur in a NE–SW striking zone on the SE side of the pit. The uppermost beds are Pannonian fine-grained lacustrine and limnic sediments with several lignite layers. The bedding is subhorizontal but seems to be inclined over the highest parts of the gypsum body.

Mineralogy of the Alsótelekes deposit

The gypsum beds contain some accessory minerals, especially dolomite, magnesite, celestite and strontianite in microscopic sizes. Fine lamellae of hematite may give a pale rose colour to gypsum. Fibrous masses of hexahydrite, epsomite and glauberite are found rarely in the fissures. Coarse-grained pale blue aggregates of secondary anhydrite occur in brecciated dolomite and limestone. Massive aggregates (2–4 cm in diameter), rarely dypiramidal crystals (1–2 mm in legth) of native sulphur are closely associated with secondary anhydrite.

The covering sediments, especially clays, often contain epigenetic gypsum, in the form of gypsum roses, up to 10–20 cm in size (Fig. 29). In the fissures of the covering marls colourless to pale violet sprays or solitary needles of aragonite can be found.

Features of the evaporite series observable in the open pit

The gypsum open pit in the Nagy Valley lies some hundred meters away from the Telekes Valley Fault, a master fault of the Darnó Zone. The present open pit expose the western side

Fig. 29. Gypsum rosette, Alsótelekes (photo: S. Szakáll).

of a NE–SW elongated dome structure (Fig. 30). Several diapirs or mushroom-shaped intrusions of 10–20 m diameter with steep or vertical lamination are exposed. The laminated gypsum (which is the most widespread rock type) shows well-developed signs of ductile flow at every part of the pit. Although the lamination may be an original sedimentary feature, it is wholly transposed and contains isoclinal or nearly isoclinal, dm-scale conical sheath folds. The laminae are continuous in general but truncated at the enclosed limestone, sandstone or shale bodies. The dip angle has sudden changes from moderate to almost vertical in some zones. The pattern of the dips measured in the pit outlines a set of conical folds with subvertical axes (a diapiric structure), which corresponds to the second-order folding of a dome.

Anhydrite is also laminated, but the small-scale third-order folding is rare and of different style: the lamination bends with a gentle curvature, there are no sharp hinges. When it occurs together with gypsum, it acts as a competent material. Anhydrite pebbles in the laminated gypsum have in some cases details showing the direction of the tectonic transport.

Brecciated gypsum occurs together with dark carbonate or sandstone clasts in the core of m–10m size sheath folds. It also seems to be competent in contrast to the laminated variety. Around these folds the laminated gypsum is jointed with curved surfaces, which remind of onion-skin. The typical axis direction of these folds is horizontal around the 60°–240° strike corresponding to the elongation of the dome. When they occur together with vertical diapiric folds of the same scale, it causes a wavy interference pattern. The folding of the laminated gypsum is often associated with formation of brittle shear joints in the included or adjacent rock bodies.

In the S part of the pit there is a NNW-dipping fault zone with several blocks of dark limestone and with serpentinite– diabase clasts similar to the rocks reported from Perkupa (Mészáros, 1957). Gypsum is brecciated at the contact and the movement planes on the limestone show slickenlines indicating a S-vergent overthrust. In the gypsum on the N side of this zone there is a 10 m-scale SSE-vergent antiform. In the core of this fold there is brecciated gypsum with several shear joints parallel with the axial plane of the fold and with slickenlines corresponding to the shear sense necessary to accommodate to the fold shape, forming an axial plane spatial cleavage with dm-size domains. These joints are filled with acicular gypsum, and the fibres are perpendicular to the movement direction.

On the NW side the Steinalm limestone blocks are also found in an overthrusted position and contain several movement planes with slickenlines. The older set of slickenlines indicates a NNW–SSE extension with normal faulting, while the younger set shows shortening in the same direction, corresponding to the present position of the blocks.

The evaporitic diapirism at Alsótelekes is connected with the Miocene sinistral strike-slip dislocation of the Darnó Zone. The formation of the dome started with the opening of a zone-parallel elongated pull-apart basin along the NNE–SSW striking Telekes Valley fault in the Lower Miocene. The incompetent material of the evaporitic complex were moving toward this zone by ductile flow under the load of the overlying Mezozoic rocks and produced an anticline by its thickening. The remnants of the Mezozoic cover were uplifted and partly embedded in the evaporites while other blocks slipped aside. As the anhydrite became the outcropping layer on the surface, it was partly transformed into gypsum with karst features on the top. Meanwhile in the basin thick continental debris was accumulated, burying step by step the dome.

In a next phase, maybe still in the Lower Miocene, the basin was inverted and closed by a NNW–SSE transpression. This phase is characterized by SSE-vergent thrusting of the competent blocks with folding of the gypsum, forming an uplifted, imbricated structure. The area took up a geographically high position as younger sediments are missing up to the Pannonian and these lie on an irregular sedimentation surface (Fig. 30).

The Upper Pannonian lignite-bearing formation is unaffected by the evaporite tectonics, though its layers show

Fig. 30. Gypsum-anhydrite pit, Alsótelekes (photo: N. Németh).

slight bending above the gypsum diapir due to later extensions. In a cm-scale view, this bending is realized by several microfaults. This subsidence can be derived either from solution processes or the slow ductile flow of the gypsum towards the Nagy Valley.

2.8 Field stop 8. Baradla Cave, Aggtelek, Aggtelek–Rudabánya Mts. (Olga Piros)

Introduction

The largest horizontal caves in Hungary are in the Gömör–Torna Karst Region, near Aggtelek and Jósvafő. The most significant one is the Baradla Cave with its total length of 23,916 m. The main branch between Aggtelek and Jósvafő is ~6-km long. The branches are very attractive due to their extreme richness in stalactites and stalagmites (Fig. 31). The cave system has three entrances in Hungary: one natural entrance near Aggtelek and two artificial entrances (one is near Jósvafő and the other one between Aggtelek and Jósvafő, near the lake Vörös-tó [Red Lake]). The fourth entrance of the cave is in the Slovak Republic. About 5,600 m of the cave system lies beneath Slovakian territory. This part of the Baradla–Domica Cave Sytem, "jaskyňa Domica" (Domica Cave) is a third show cave on the Slovak side of the state border.

The Aggtelek part of the cave is famous for the Concert Hall. This huge chamber has been used for concerts for decades. This part of the cave offers speleothems in extraordinary colours, blackish stalactites protruding from a red and green coloured ceiling. The Vörös-tó–Jósvafő part has the Giant's Hall. This chamber is used for a musical experience during the tour.

19th century archaeological excavations proved that the entrance section – "Csontház" (Bone house) and "Fekete terem" (Black Hall) – of the cave was known and used by Neolithic Age people. By the 18th century more than 2 km of the passages were known and the cave became a popular place to be visited by domestic and foreign travellers. A few 18th century naturalists, like Count Domokos Teleki, first president of the Mineralogical Society of Jena or Robert Townson, English mineralogist and geologist, wrote about their cave visit in their printed book of travels.

The first stairs and fences were built as early as 1806, when Palatine Joseph visited the cave. The number of visitors gradually increased and in 1881 the alpine club "Magyarországi Kárpát Egyesület" (Carpathian Society of Hungary) was put in charge of the management of the cave. In 1890 the new artificial entrance at Vörös-tó was constructed. Further attempts to enhance tourism were initiated in the 1920s. In 1925 the cave was declared a national treasure, almost 2 km of footpath, steps and more than 100 bridges were built in the cave and in 1928 another artificial entrance was constructed at Jósvafő. In 1935 the electric illumination the visited sections was introduced and the management of the cave was transferred to the "Magyar Turista Egyesület" (Hungarian Tourists' Society). Different organisations, mostly tourist offices were in charge of the management and development of the cave was after World War II. Since 1985 the Directorate of the Aggtelek National Park has been managing the Baradla Cave. The underground natural treasures, namely the caves of the Aggtelek Karst and the Slovak Karst were inscribed on the World Heritage List by the UNESCO in 1995.

Dates from the history of Baradla Cave

1549:	first printed note that can be related to the cave (in Wernher's *De admirandis Hungariae aquis*)
1781:	first detailed report about the cave (in the *Ungrisches Magazin*)
1794:	first (now lost) map of the cave (by J. Sartory and J. Farkas)
1807:	first published map of the cave (by Ch. Raisz)
1806:	first major construction works for the visit of Palatine Joseph
1831:	first printed detailed publication, including a new map (by I. Vass)
1881:	the management of the cave is conferred to an organisation

Fig. 31. The dripstone group named "Tepee", Baradla Cave (Photo: M. Gyuricza).

(“Magyarországi Kárpát Egyesület” – Carpathian Society of Hungary) for the first time
1890: construction of the Vörös-tó entrance
1925: the cave is declared a national treasure
1928: construction of the Jósvafő entrance
1935: electric light in the cave
1985: the Directorate of the Aggtelek National Park is put in charge of the management of the cave
1995: the cave was inscribed in the UNESCO World Heritage List.

Geological buildup

The non-metamorphosed Aggtelek–Rudabánya Mts. in NE Hungary are situated in the NE part of the composite Pelso Unit (Fülöp *et al.*, 1987; Haas, 2001). The carbonate platform (lagoon and reef) facies limestones exposed by the cave forms a 1–3 km wide belt in the karstified Aggtelek Mountains (Figs. 1–2), which strikes NW–SE over a distance of about 7 km between Aggtelek, Jósvafő and Égerszög in NE Hungary. The Aggtelek Karst continues in Slovakia as Slovak Karst (Bystrický, 1964; Mello, 1997).

The Triassic formations building up the Aggtelek Karst belong to the Silica Nappe, the uppermost nappe of the Inner West Carpathians (Kozur & Mock 1973; Mello, 1997).

At the beginning of the Middle Triassic euxinic lagoonal environment came into existence (Gutenstein ramp stage). The Gutenstein Formation is dark-grey to black bituminous, thin- to thick-bedded limestone and dolomite. From the upper part of the Gutenstein Formation (coevally with a relative sea-level fall) Hips (2007) described sponge–microbe mud-mound deposits of Pelsonian age (*Glomospira densa*). Cyanobacteria, calcimicrobes and “*Tubiphytes*” played the main roles in this biocoenosis. The Gutenstein Formation is overlain by the open lagoonal, thick-bedded laminitic, dasycladacean and oncoidal Steinalm Limestone Formation (with a minimum thickness of 170 m) of Pelsonian age.

From the Anisian to Carnian the open lagoonal sedimentation is continuous in the Aggtelek Hills. Some patch-reefs are existed in the area. In the main branch of the Baradla Cave from Jósvafő to Aggtelek natural entrance we can see the continuous sequence from the Gutenstein Formation (Pelsonian) across the Steinalm Formation (lagoonal facies – Pelsonian to Illyrian) to the Wetterstein Limestone (reef and lagoonal facies – Illyrian to Fassanian) (Fig. 32).

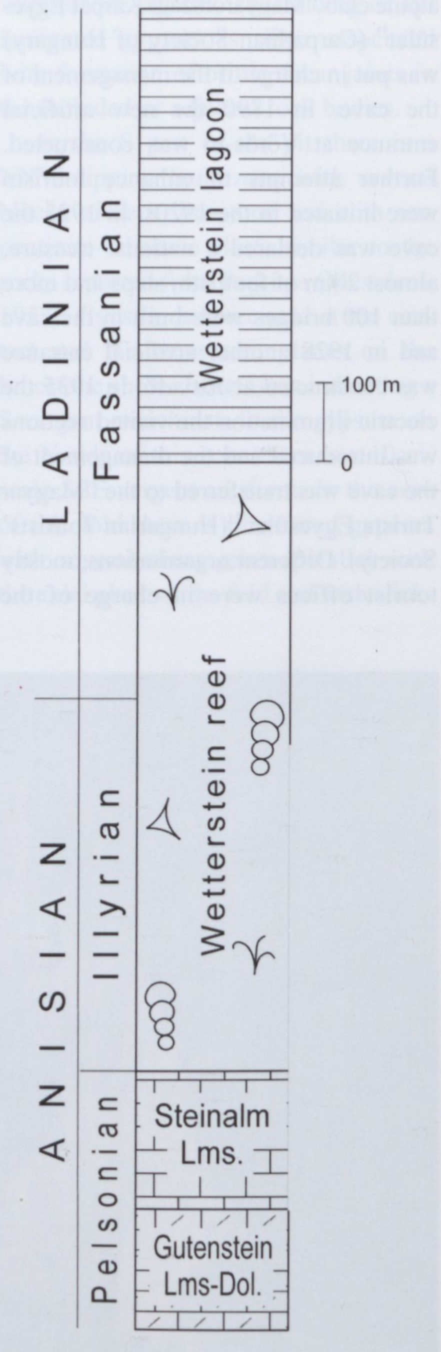

Fig. 32. Columnar section of the Baradla Cave (Velledits *et al.*, in press).

Geological sequence of the Baradla Cave

Gutenstein Formation from the Jósvafő entrance up to the Giants' Hall

First we visit the lower member of the Gutenstein Formation (Fig. 33), represented by dark grey massive mudstones (Hips, 2007). Gradual changes occur in the sedimentary features of the Lower Anisian unit that are attributed to increasing oxygen depletion as a result of density stratification of seawater in the deep ramp areas. Remarkable ecological and sedimentary changes began with the colonisation by sponges and microbes in the Aggtelek facies area, which occurred coevally with a relative sea-level fall. In the upper part of the lower member the appearance of the foraminifer *Glomospira densa* points to late Early Anisian age for these changes.

The upper member is very variable in lithology and facies as compared to the monotonous development of the lower units. Six principal facies types were distinguished and most of them repeatedly occur in the approximately 170 m-thick successions (Hips, 2007). The observed fairly regular recurrence of the facies types suggests cyclic deposition. Each cycle exhibits deepening- and shallowing-upward trend and their stacking pattern suggest a larger-scale shallowing-upward trend. The total absence of dasycladaceans and prevalence of microbes and sponges may have been controlled by extreme environmental conditions, *i.e.* hypersalinity.

We enter into the cave through an artificial entrance near Jósvafő. The upper member of the Gutenstein Formation is exposed from the entrance up to the Giants' Hall.

Steinalm Limestone (lagoonal facies) at the swallow hole in the Giants' Hall

The exposure is situated in the illuminated Jósvafő part of the Baradla Cave, before the swallow hole in the Giants' Hall, on the eastern wall.

The limestone is of splintery fracture, medium grey, sometimes pinkish. It is striped with layers of calcite-filled

Fig. 33. Beds of Gutenstein Limestone ("Dobos cake"), Baradla Cave (Photo: L. Gyalog).

cavities. The exposed rock is well bedded, three types of alternating microfacies can be found within the layers:

1) Loferite (algal mat), biopelmicrosparite with oriented loferitic stripes, Lofer B zone,
2) Biosparite, with rich dasycladacean flora:
   Physoporella pauciforata pauciforata
   Physoporella pauciforata undulata
   Physoporella dissita (Fig. 34)
   Teutloporella peniculiformis,

Fig. 34. *Physoporella dissita*, Baradla Cave (Photo: O. Piros).

3) Brecciated limestone with pinkish matrix containing irregular intraclasts.

The alternation of three types results in a kind of structure similar to the Lofer cyclotheme. In the case of this structure, however, A member is not typical.

Age of this limestone: Middle Triassic, Anisian.

Jenei Limestone Formation at the Dragon's Cave

It begins with pinkish to reddish or greyish micritic limestone with ammonoids at the base (Fig. 35). The "ammonite horizon" (Reifling event; Schlager & Schöllnberger, 1974) yielded two different conodont associations. The association of the lower part indicates the upper part of the Pelsonian (Binodosus Subzone). The upper part of the "ammonite horizon" contains a conodont species of the Trinodosus Zone. Grey plasticlastic limestones with several beds rich in crinoid remnants (Fig. 36)

Fig. 35. Nautiloidea from the "ammonoid horizon", Baradla Cave (Photo: Ö. Vid).

Fig. 36. Crinoid near the "Octopus", Baradla Cave (Photo: L. Gyalog).

are superimposed above the "ammonite horizon" (Piros, 1989). The conodonts clearly refer to the Trinodosus Zone. About 80 m above the "ammonite horizon" a characteristic level of 15-cm thickness follows. It consists of four radiolarite layers, each about 2-cm in thickness, rich in radiolarians and sponge spicules. These are overlain by a tuffite layer followed by a 2-cm thick limestone bed, which is covered again by a thin radiolarite layer. Radiolaria were only recovered from the tuffite/radiolarite level on the top of the Jenei Limestone Fm. The age of the radiolarian assemblage is Illyrian (Velledits *et al.*, submitted).

Wetterstein Limestone Formation (reef facies) from the Octopus to 4400 m

The tuffite/radiolarite level is overlain by crinoidal dominated limestones. Higher up in the section the reef-building organisms become richer and the crinoids disappear. In the lower part of the reef limestone, a lagoonal intercalation can be observed, where *Diplopora annulatissima* appears. This indicates a Late Illyrian age for this part of the reef. *Celyphia? minimima*, found in the upper part of the reef, indicates Anisian age for the reef. *Celyphia zoldana, Colospongia catenulata, Follicatena cautica, Solenolmia manon, Vesicocaulis oenipontanus* have been known up to now only from the Ladinan–Carnian. With the findings from the Baradla Cave section their stratigraphic range must be extended down to the Illyrian (Velledits *el al.*, in press).

Wetterstein Limestone Formation (lagoon facies), Tiger Hall at the Aggtelek part

The key section outcrop is situated in the Aggtelek parts of the Baradla Cave, in the so-called Tiger Hall. On the surface of the medium grey, splintery fractured, thick-bedded limestone, calcareous algae, gastropods and ammonites are visible due to weathering. The texture of the limestone is biosparite, biopelsparite (grainstone). The fossils on the surface of the rock represent the trichophorous and the vesiculipherous types of the dasycladacean *Diplopora annulata annulata*. Dominant is the trichophorous type. Fragments of the dasycladaceans are 6–8 mm in length and 2–3 mm in diameter. The annulation is observable even by the naked eye. Besides the species *Diplopora annulata annulata*, specimens of *Aciculella* sp. can also be found, this form, however, is not observable macroscopically. The chambers of a single ammonite of 3–4 cm diameter are also visible (Fig. 37). Age of the limestone is Ladinian, Fassanian. Based on the textural features and the fossils; the limestone is of lagoonal facies.

Fig. 35. Ammonite, Baradla Cave (Photo: O. Piros).

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Appendix – Itinerary for IMA2010 HU6 Field trip

Wednesday, August 18, 2010 (Day 1)

08.00-09.00 Travel to the town of Gyöngyös
09.30-10.30 Field stop 1: Mátra Musem, Gyöngyös
10.30-11.30 Travel to the village of Kisnána
11.30-12.30 Field stop 2: Cavity-filling minerals in the Kisnána andesite quarry
12.30-13.00 Lunch break at the entrance of quarry
13.00-14.00 Travel to the village of Recsk
14.00-15.00 Field stop 3: Lahóca epithermal gold-copper ore deposit, Recsk
15.00-16.00 Travel to the town of Eger
16.00-17.30 Field stop 4: Eger, historical downtown
17.30-19.30 Dinner with wine tasting
19.30-20.00 Accommodation

Thursday, August 19, 2010 (Day 2)

08.00-09.30 Travel to the town of Rudabánya
09.30-11.30 Field stop 5: Abandoned open pits of the former Rudabánya iron ore mine, metasomatic siderite mineralization with Cu-Pb-Zn-Ag ore
11.30-12.30 Field stop 6: County Museum of Mining History, Rudabánya
12.30-13.00 Lunch break in the museum
13.00-13.30 Travel to the vilage of Alsótelekes
13.30-15.30 Field stop 7: Open pit of the gypsum–anhydrite mine, Alsótelekes
15.30-16.30 Travel to the village of Aggtelek
16.30-17.00 Hotel Cseppkő, accommodation
18.00-19.30 Dinner

Friday, August 20, 2010 (Day 3)

09.00-11.00 Field stop 8: Cave tour in the Baradla Cave, Aggtelek
11.00-15.30 Return to Budapest