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The Brehov volcanogenic and stratabound base metal and gold deposit (Eastern Slovakia): Position and genetic relations in the Internal Carpathian–Alpine Cenozoic metallogenetic belt

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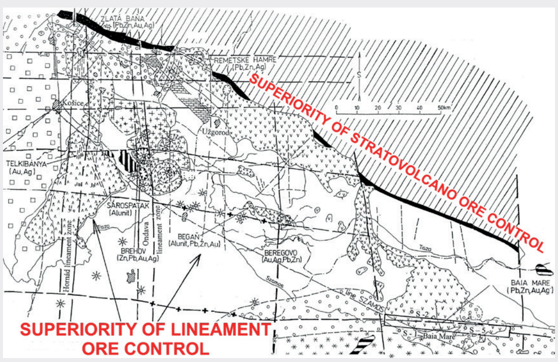
Abstract: The Brehov ore deposit, near the village of Brehov, is located in the East Slovakian Basin 15 km southeast of the Trebišov town. A progressive development of Middle Badenian to Middle Sarmatian sedimentation and volcanism in the Brehov hydrothermally mineralized area is manifested in the article. The volcanogenic, stratabound, polymetallic (Zn, Pb, Cu) and gold sulphide deposit within the Brehov–Sirník interpreted resurgent caldera occurs in the volcanosedimentary sequence. Mineralization in the deposit, consisting of the fine-grained aggregate of sulphides, is interpreted to be of shallow water origin. It is placed mostly in the rhyodacite volcaniclastics and partly in calcareous claystone, altered and brecciated. Three types of ores – the stringer (keiko), yellow and black ore – were distinguished near the Brehov village on the basis of ore composition, being formed by successive mineralization stages. The stringer ore, consisting of the sulphide minerals, dominates in the quartz-dioritic (siliceous) rocks. The yellow ore is represented primarily by pyrite, but contains also minor chalcopyrite and quartz. The black ore is an intimate mixture of sphalerite, galena, sometimes barite and minor pyrite and chalcopyrite. Tetrahedrite and marcasite occur sporadically. The ore in all cases is fine-grained. The ore bodies are almost everywhere enclosed by clay, composed of montmorillonite, sericite and chlorite. The ore bearing fluids were probably colloids of hydrothermal origin. Textures are considered to indicate that the colloids replaced the country rocks, rather than merely filled open spaces in the rhyodacite pyroclastics and epiclastics. Despite the precious metals (mostly gold) are economically important commodity in many Kuroko type deposits, in the Brehov ore deposit they occur in volumetrically minor amounts. Visible gold is present as inclusions of native gold in major sulphide minerals, whereas silver occurs in Ag-sulphides and sulphosalts, e.g. tetrahedrite and ferberite.

The location of important Neogene magmatic, as well as metallogenetic structures in the "Boundary Zone" between the Western and Eastern Carpathians, in the Brehov–Zemplín area, is controlled by the orthogonal deep penetrative regional faults – lineaments. They are interpreted as the surface expression of deep-crustal and mantle rooted trans-lithospheric structures, which have been periodically reactivated as pure-shear regional faults during individual orogenic cycles, forming discontinuities long several tens, hundreds, or even thousands of kilometers.

In regions of subduction-related magmatism, the Kuroko type volcanogenic stratabound sulphide and gold ore deposits, like Brehov in Eastern Slovakia, may be generated along these lineaments, because the discontinuities allow the ascent of relatively evolved magmas and fluids from the deep-crustal magma reservoirs. However, the lineament intersections can focus this activity under appropriate lithospheric stress conditions only where a magma supplies exist – as was demonstrated in the case of the Brehov ore deposit, represented by an extended quartz diorite-porphyry stock body related sills and dikes (like in Cenozoic rifted back arc basin between Western and Eastern Carpathians).

The Brehov ore deposit occurs in the crossing of the Ondava submeridional lineament zone with the Komárovce–Brehov subequatorial lineament, which developed in weakened zone of Mesozoic Meliata suture zone after Neo-Tethys Ocean. The resurgent elevation of the Brehov–Sirník caldera is developed on this crossing.

Graphical abstract



Highlights

- The Brehov deposit mineralization is interpreted as Kuroko genetic type
- Role in magma and fluid transport is attributed to regional trans-crustal discontinuities (lineaments) of subequatorial and submeridional course, and especially their crossings

1 Introduction

In the beginning of the 1980s, the "Border Zone" segment between Western and Eastern Carpathians (Figs. 1 and 2) was considered to be an insignificant metallogenetic unit of the Internal Carpathian–Alpine Cenozoic metallogenetic belt. The discovery of the Kuroko type submarine volcanogenic Zn-Pb-Cu sulphide and gold deposit Brehov had started a new exploration period, which continued until the 1998, after the Brehov type ore prices have decreased.

In the Brehov submarine ore structure (Fig. 7), following stages of evolution have been recognized:

1. Origin of the Brehov–Sirník caldera as a result of the Middle Badenian acidic-rhyodacite explosive volcanism and its filling with rhyodacite type volcanosedimentary complex.
2. Denudation and emplacement of a quartz-diorite porphyry intrusion (15.4 ± 0.4; 15.1 ± 0.1 Ma; Lang et al., 1994), with development of the Kuroko type semimassive, matrix- breccia Zn-Pb-Cu-Au-Ag mineralization in the volcanosedimentary complex (main concordant-stratabound part of the deposit), as well as in the form of veinlets and disseminations in subvolcanic quartz-diorite bodies (discordant part of the deposit). Simultaneously with the intrusion of magmatic bodies, as a consequence of this intrusion, the uplift of resurgent horst ore structure took place.
3. Origin of the fresh and strongly argillized lava flows and extrusive bodies of pyroxene andesite near the villages of Brehov, Sirník and Hraň of ages 14.7 ± 1.1 and 14.1 ± 0.5 Ma for andesite extrusive body from the Veľký Vrch hill (272.2 m a.s.l.) near the village of Brehov (Lang et al., 1994).
4. Silicified and adularized rhyodacite extrusive bodies and lava flows developed directly in the Brehov ore deposit (11.8 ± 0.2 Ma, l.c.). Formation of volcanic exhalation mineralization.

Based on our observations and experiences with the Carpathian Neogene metallogenetic belt, its volcanic rock structures and ore deposits are principally connected with the deeply seated tectonic zones (lineaments). These trans-crustal discontinuities, and in particular their intersections, may provide high-permeability channels for ascent of deeply derived magmas and fluids. Optimum conditions for magma penetration were provided when these structures formed at regional extension or transtension (Mayo, 1958; Kutina, 1980; O'Driscoll, 1981, 1985, 1986; Richards, 2000; Richards et al., 2001).

When tracing the course of lineaments, the earlier ophiolites (suture zones) may represent an essential tool for the location of the younger lineaments, because they are related with the zones of earlier continental breakup and even after collision and closure of oceanic spaces they still represent trans-crustal discontinuities, which can be essential for the Cenozoic magmatic and metallogenetic processes.

In the Internal Carpathian-Alpine Cenozoic metallogenetic belt the discontinuous bodies of Mesozoic ophiolites (ca 150 Ma) exclusively follow the subequatorial lineament zones. The Alpine-Himalayan Mesozoic ophiolite belt (ca 150 Ma) was ascertained by Ishiwatari (1985) and Dilek and Furnes (2014).

In the "Border Zone" metallogenetic segment between W. Carpathians and E. Carpathians, besides the Brehov–Zemplín Neogene ore sector, there is well known a group of ore fields with partly subaerial and partly submarine nature. They include the Zlatá Baňa ore sector, the Begaň–Beregovo–Kvasovo ore sector and submarine influences are known also from the Telkibánya, mostly subaerial ore sector. The above mentioned Neogene ore sectors possess a number of characteristics that are, in part, typical for Kuroko type deposits and in part resemble volcanogenic epithermal base and gold deposits.

The Cenozoic magmatism and metallogeny in the area between towns of Banská Štiavnica (Slovakia) and Baia Mare (Romania) are preferably conditioned by subequatorial and complementary submeridional lineaments. Other – so-called "normal faults", which reach a depth of 10–40 kilometers from the surface, have only secondary, or very small influence for Cenozoic magmatism and metallogeny in the Internal Carpathian–Alpine Cenozoic metallogenetic belt.

Remark: In this article, the hierarchy and terminology of metallogenetic units is used after Popescu and Neascu (2010).

2 Regional geological setting, description of principal lineaments

The Brehov–Zemplín metallogenetic sector is located in Eastern Slovakia, 46–54 kilometers south-east from the town of Košice. The Brehov ore deposit is a part of the Internal Carpathian–Alpine Cenozoic metallogenetic belt (Fig. 1; sensu Heinrich & Neubauer, 2002; slight modified by Bacsó, 2014), which consists of six regional segments:

1. The Western Alps – Brusson segment;
2. The Eastern Alps – Hohe Tauern segment;
3. The Western Carpathians segment;
4. The "Border Zone" segment between Western and Eastern Carpathians;
5. The Eastern Carpathians segment;
6. The Apuseni Mountains segment.

Concerning the Brehov ore deposit, three segments of above listed metallogenetic belt are important: The Western Carpathians segment; the "Border Zone" segment between W. Carpathians and E. Carpathians; and the Eastern Carpathians segment (Figs 1, 2 and 3).

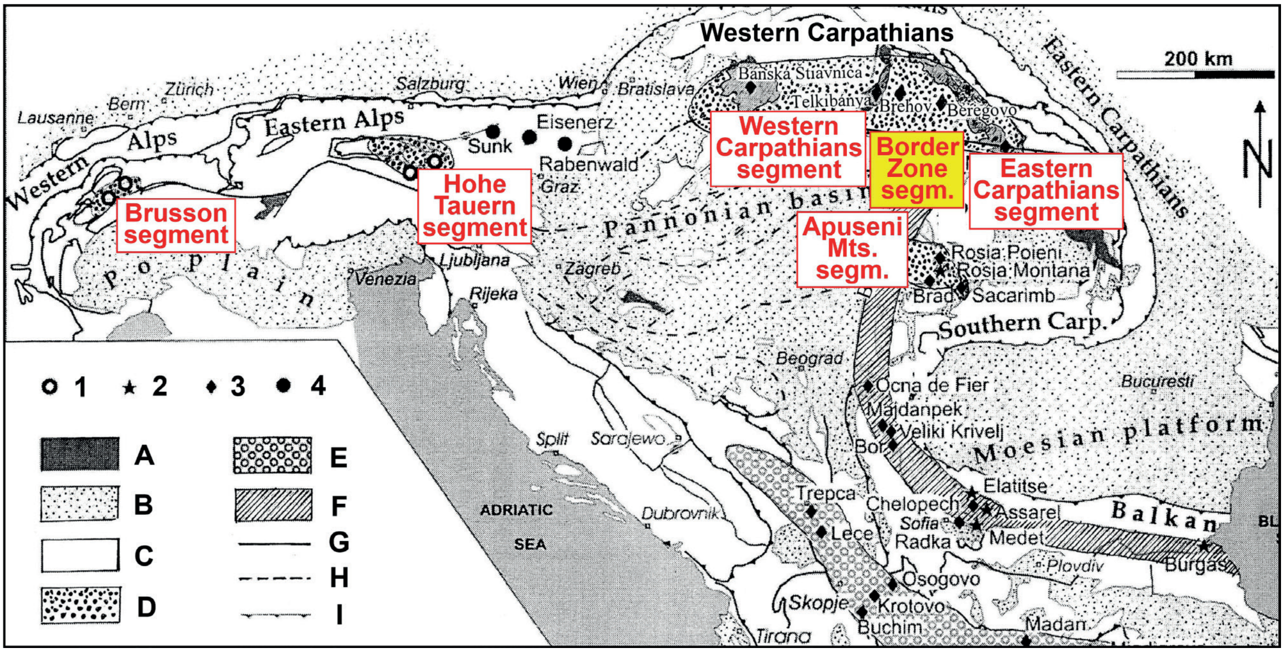


Fig. 1. Simplified tectonic map displaying distribution of six major segments of Internal Carpathian–Alpine Cenozoic metallogenetic belt within the Alpine-Balkan-Carpathian-Dinaride (ABCD) region (slightly modified after Heinrich and Heubauer, 2002, by Bacsó, 2014). Ore deposits: 1 – Orogenic Au; 2 – Porphyry Cu-Mo-Au; 3 – Polymetallic Pb-Zn-Ag-Au ores – e.g. skarn, low-sulphidation polymetallic vein and carbonate mineralization, high-sulphidation massive sulphide; 4 – metamorphogenic mineralization (siderite, magnesite, talc). Lithotectonic and metallogenic explanations: A – Neogene volcanic and plutonic rocks; B – Oligocene–Neogene basins; C – Alpine-Balkan-Carpathian-Dinaride orogenic zones (sensu Heinrich and Heubauer, 2002); D – Internal Carpathian–Alpine Cenozoic metallogenetic belt; E – Oligocene-Miocene Serbomacedonian Rhodope metallogenetic belt; F – Late Cretaceous (Apuseni–Balkan) Banatite magmatic-metallogenetic belt ("Banatite belt" sensu l.c.); G – Major strike-slip fault; H – Inferred fault; I – Major thrust.

From the nearer perspective the Brehov ore deposit lies in the center of the "Border Zone" segment between W. Carpathians and E. Carpathians and areally extends westward, including the submeridional Hornád lineament zone. Eastward the "Border Zone" segment extends up to Chust town submeridional lineament, included. The northern boundary of the "Border Zone" segment is represented by the tectonic line of the Pieniny Klippen Belt, while the southern boundary includes the Recsk–Baia Mare subequatorial lineament (Fig. 2).

The "Border Zone" metallogenetic segment consists of principal metallogenetic sectors encompassing following ore fields:

a) The Brehov–Zemplín metallogenetic sector encompasses the Brehov base metal and gold ore field and the Zemplín base metal ore field;
b) The Telkibánya metallogenetic sector in Hungary encompasses the Telkibánya gold and silver ore field;
c) The Zlatá Baňa metallogenetic sector encompasses three ore fields: The Zlatá Baňa base metal and gold ore field, the Dubník mercury ore field, and the Dubník precious opal field;
d) The Begaň–Beregovo–Kvasovo metallogenetic sector in Ukraine encompasses three ore fields: The Muzievo gold, silver and base metal ore field, the Kvasovo gold, silver and base metal ore field and the Begaň barite, alunite and base metal ore field.

All metallogenetic sectors are located within the Prešov–Kráľovský Chlmec graben and all ore deposits are developed on the intersections of the submeridional and subequatorial lineaments (Figs. 2 and 3).

The neighbouring Brehov submarine ore deposit and Zemplín submarine base metal ore structure form the **Brehov–Zemplín fully submarine base and gold metal metallogenetic sector** (Figs. 3, 5a, 5b and 11), located on the submeridional Ondava lineament zone, form satellite ore structure to the ore deposits on the Hornád lineament zone, as well as to Telkibánya metallogenetic sector located west, and to the Zlatá Baňa metallogenetic sector located north-west (Figs. 3, 5a, b).

Despite of the regional-geological similarities between the principal volcanogenic deposits of the "Border Zone" metallogenetic segment between the W. Carpathians and E. Carpathians, there exist also distinct local differences. First of all, the Telkibánya and Zlatá Baňa metallogenetic sectors occur in the central volcanic zones of middle sized stratovolcanoes, while the Brehov–Zemplín metallogenetic sector is connected only with smaller and very simple volcanic edifices (not with stratovolcanoes).

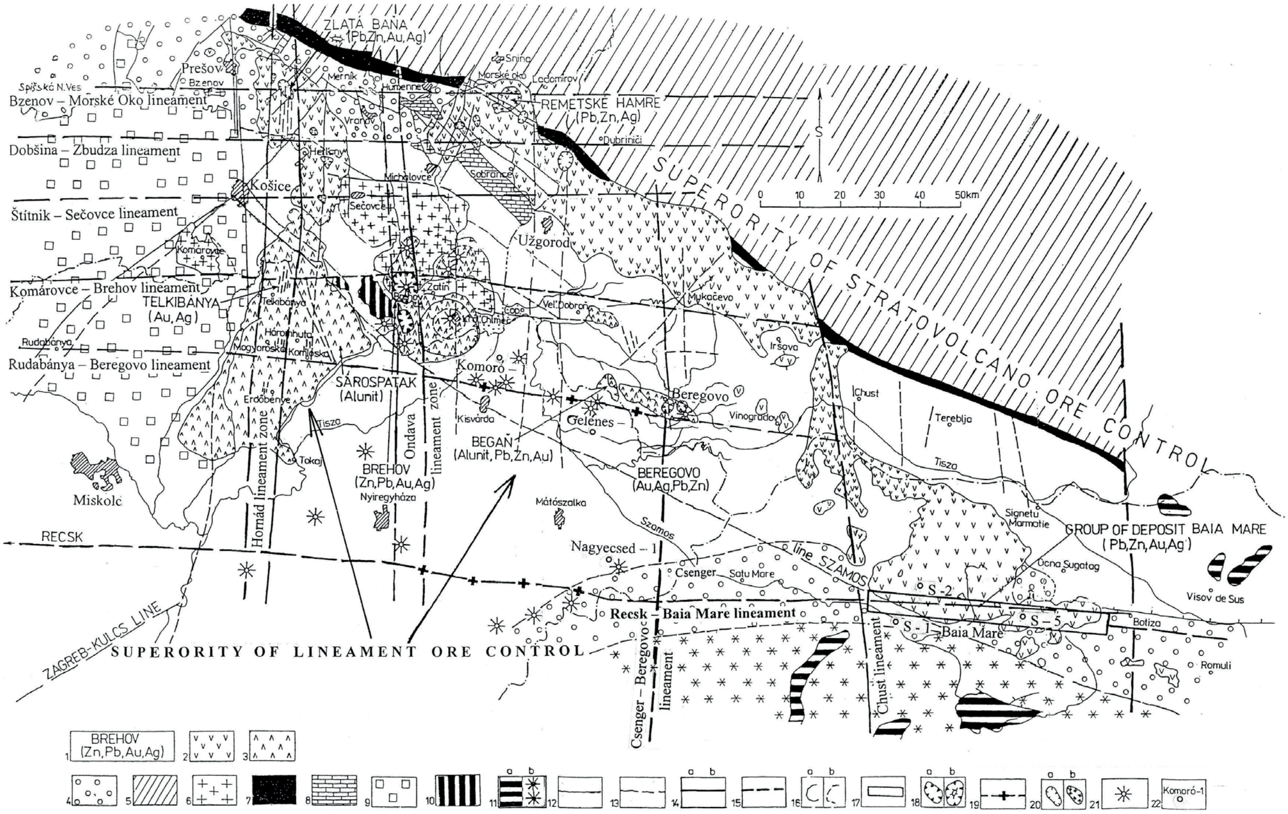


Fig. 2. Deep fault structures of the "Border Zone" segment between Western and Eastern Carpathians and the Eastern Carpathian Segment and their relation to magmatism and Neogene ore mineralizations. Geological interpretation of geological and geophysical data by Bacsó, 2014). 1 – principal ore deposit and ore occurrence; 2 – andesitic and rhyodacitic volcanics, Upper Badenian to Pannonian; 3 – rhyodacitic and andesitic volcanics, Upper Badenian–Sarmatian; 4 – Late Cretaceous and Paleogene sediments of the Internal Carpathians; 5 – Cretaceous and Paleogene sediments of the Outer Carpathians; 6 – ophiolite complex; 7 – Mesozoic and Paleogene sediments of the Klippen Belt; 8 – Mesozoic sediments of the Krížna nappe, Internal Western Carpathians; 9 – Paleozoic and Mesozoic sediments of Internal Western Carpathians; 10 – Late Paleozoic and Mesozoic sediments of Internal Carpathians ("Zemplín Island"); 11 – crystalline complexes of Northern Transylvania: a) on surface, b) covered with younger sediments; 12 – shallow faults; 13 – assumed shallow faults; 14 – interpreted lineaments; 15 – assumed lineaments; 16 – geological boundaries: a) proved, b) assumed; 17 – big group of Neogene ore deposits near city Baia Mare; 18 – submarine caldera: a) without central elevation, b) with central elevation; 19 – gravity anomaly in the lower crust (upwarping Neogene magmatics); 20 – subaerial central volcanic zone of stratovolcano: a) in form of eroded crater, b) in form of eroded caldera; 21 – buried volcanic structure; 22 – deep drillhole.

Despite the Telkibánya and Zlatá Baňa metallogenetic sectors are located in the same Hornád submeridional lineament zone, they are genetically very different. Telkibánya ore field represents a subaerial, epithermal, low-sulfidation precious metal deposit, with excellent developed classical long-vein ore structures, while the Zlatá Baňa ore field represents only partly subaerial and partly submarine ore structure, where only in very rudimentary conditions short and small ore vein developed. For the essential part of the Zlatá Baňa base and gold metal ore deposit the **ore mineralized tectonic zones** are characteristic and not classical vein type structures (Tőzsér, 1972; Kaličiak & Ďuďa, 1980; Burian et al., 1985; Divinec et al., 1988).

The relations between the Brehov–Zemplín submarine metallogenetic sector and the Beregovo partly submarine and partly subaerial metallogenetic sector are very complicated. The Beregovo metallogenetic sector is developed not only on the intersection of different submeridional and subequatorial lineaments, but the pre-Neogene basement is very different, too. The Brehov–Zemplín Neogene metallogenetic sector lies on the Zemplín Paleozoic-Mesozoic block, while the Begaň–Beregovo–Kvasovo Neogene metallogenetic sector is developed in the Krichevo Mezozoic-Paleogene elevation with ophiolites. In the Brehov–Zemplín metallogenetic sector there are essentially present the bimodal (rhyodacite, quartz diorite porphyry, andesite) Neogene magmatics, while in the Begaň–Beregovo–Kvasovo metallogenetic sector there are present only rhyolite-rhyodacite unimodal Neogene magmatics (Vityk & Krouse, 1994; Biruk & Skakun, 2000).

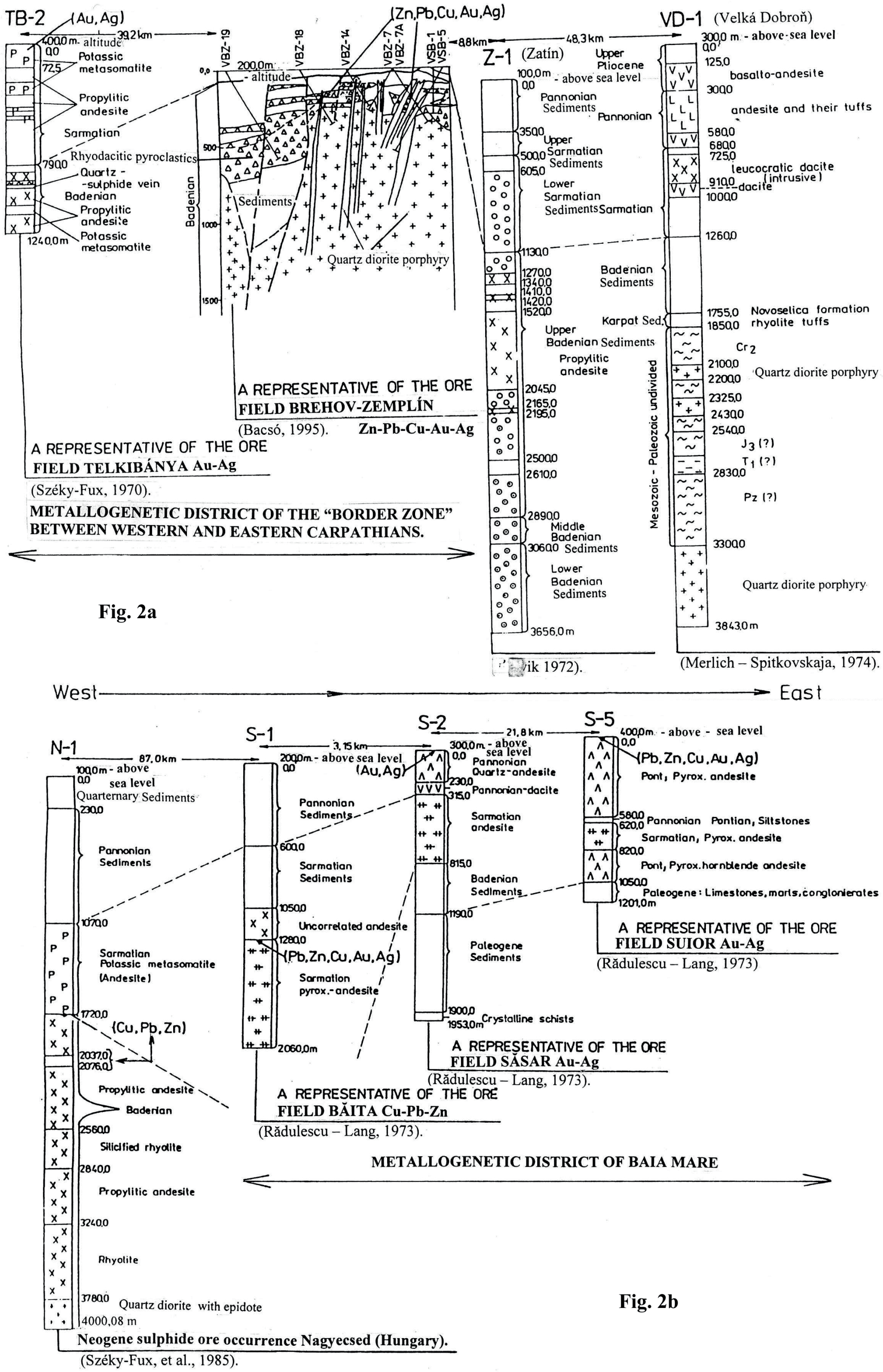


Fig. 2a, b. Geological and metallogenetic representative deep drillhole profiles: a) along the eastern part of the Komárovce–Brehov lineament within the "Border Zone" segment between Western and Eastern Carpathians; b) along the eastern part of the Recsk–Baia Mare lineament within the Eastern Carpathian segment.

Deep faults constitute the global network on the whole "Border Zone" between W. Carpathians and E. Carpathians and lineaments facilitated the magma penetration. The Mesozoic ophiolite rocks are connected with deep faults, similarly to Neogene magmatics (Soták et al., 1993; Faryad, 1999; Savu, H., 2009). First of all, concerning plate tectonics the ultramafic rocks are considered as an undeniable indicator of deep faults (Franklin et al., 1981; Sato, 1991; Ohmoto, 1996). Finally, the so-called small Neogene intrusions (for example in the deeper part of the Brehov ore deposit they are directly connected with the Komárovce–Brehov subequatorial lineament, which is in agreement with their subvolcanic character (Fig. 2a). In the "Border Zone" of the W. Carpathians and E. Carpathians it is possible to define orthogonal pattern of deep faults (E–W; N–S). The main deep faults divide the basement of the "Border Zone" into following blocks with different geological structures and development: The Iňačovce–Krichevo area block, the Zemplinicum elevated block, the Slanské vrchy Mts. block, the Baia Mare ore district block and the Beregovo elevated block.

Ophiolites in the "Border Zone" between the W. Carpathians and E. Carpathians represent tectonically transported assemblages of ultramafic rocks, gabbro, basalt pillow lavas, commonly capped by chert or other pelagic sedimentary rocks. Their occur in linear deep tectonic zones of Eastern Slovakia and are generally interpreted as fragments of oceanic crust and mantle that have been thrust (obducted) on the adjacent continental margin. By this way some lineaments, or at least some their segments, represent the geosuture zones.

In the "Border Zone" of the W. Carpathians and E. Carpathians we have distinguished six subequatorial deep faults (from the south to the north):

The **Recsk–Baia Mare lineament** (Figs. 2 and 2b) as the master subequatorial deep fault, representing a backbone of the Internal Carpathian–Alpine Cenozoic metallogenetic belt, with rich porphyry copper deposit near the village of Recsk (Hungary) and large ophiolite bodies on Darnó and Szarvaskő hills. In the eastern part of the lineament a group of big epithermal, low-sulfidation base metal and gold deposits is developed at the Baia Mare town. The ore-bearing Neogene quartz diorite porphyry subvolcanic bodies crop out along the deep faults (Fig 2b; Széky-Fux et al., 1985).

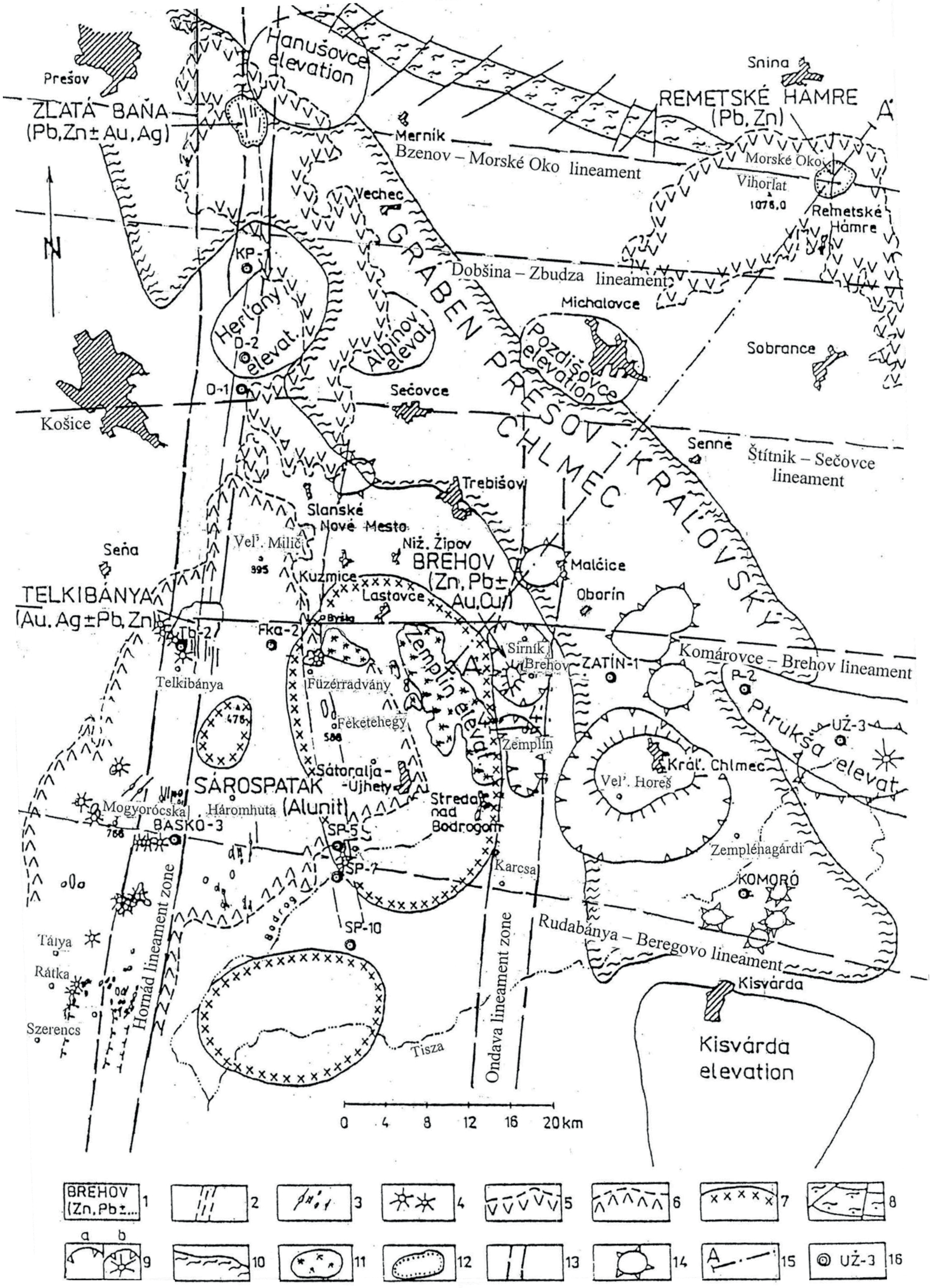
The **Rudabánya–Beregovo subequatorial lineament** is indicated by the Rudabánya Fe and base metal deposit (Szakáll & Kovács, 1995; Földessy et al., 2009), by lacustrine hydrothermal exhalative mineralizations near Háromhuta and Mogyoróska villages in the Tokaj Mts. (Gyarmati, 1977), by buried volcanoes in Tokaj Mts. and gold-silver and base metal deposits near Beregovo settlement. Along the Rudabánya–Beregovo subequatorial deep fault also other ore-bearing Neogene subvolcanic bodies are buried (Fig. 2; Vityk et al., 1994; Biruk & Skakun, 2000).

The **Komárovce–Brehov subequatorial lineament** is indicated by large bodies of ophiolites near village of Komárovce, by gold-silver deposit Telkibánya, by the base metal-gold deposit Brehov, by Neogene subvolcanic bodies near village of Veľká Dobroň (Ukraine). (Figs. 2 and 2a; Merlich & Spitkovskaja, 1974; Hovorka et al., 1977; Bacsó, 2000). The continuation of the Komárovce–Brehov lineament to the west is traced by occurrences of ophiolites near villages of Komjáti (Hungary) and Bohúňovo (Slovakia).

The **Štítnik–Sečovce subequatorial lineament** traced along the Rožňava discontinuity zone (the Meliata unit s.s.), which represents the southern border of the Gemericum and is characterized by the presence of blueschist, serpentinites, as well as very low grade sediment, that partly thrust on Paleozoic sequences of Gemericum (Faryad et al., 1998). On the east, near villages of Pavlovce, Blatná Polianka, Rebrín and Senné (Slovakia), the Štítnik–Sečovce lineament is traced by the deep drillholes intersecting the ophiolites. (Mořkovsky & Cverčko, 1987; Gnojek et al., 1991; Faryad, 1999).

The **Dobšiná–Zbudza subequatorial lineament zone** in its western segment follows the crustal discontinuity related to earlier Paleozoic Rakovec suture zone (Németh, 2002). In earlier interpretation it was supposed that serpentinized peridotites at the village of Jaklovce were exhumed along this lineament, representing the northern branch of Meliata Ocean (Faryad et al., 1998), but later their displaced position as Paleo-Alpine nappe outlier was proved (Németh et al., 2021). The eastern continuation of this lineament was intersected by deep drilling hole near village of Zbudza, revealing a large body of serpentinized peridotite (Mořkovsky & Cverčko, 1987; Kozur & Mock, 1997).

Fig. 3. Detail of the deep fault structural and metallogenic scheme for region around the Zemplín Paleozoic-Mesozoic elevation (Bacsó, 2014, compiled using own geological data and geophysical data from Pospíšil & Bodoky, 1981–1990). 1 – principal ore deposit; ore, occurrence; 2 – hydrothermal veins; 3 – lacustrine siliceous deposit; 4 – centre of Cenozoic hot-spring activity; 5 – mostly subaerial andesitic volcanics, Upper Badenian–Pannonian; 6 – mostly submarine rhyodacite and andesite volcanics, Upper Badenian–Sarmatian; 7 – gravimetric anomalies produced by Neogene magmatics; 8 – Klippen Belt, Mesozoic–Paleogene; 9 – submarine caldera: a) without central elevation, b) with central elevation; 10 –Prešov–Kráľovský Chlmec graben; 11 – Paleozoic-Mesozoic elevation of "Zemplín Island"; 12 – subaerial central volcanic zone; 13 – interpreted deep lineaments; 14 – buried Neogene volcanic structure; 15 – geological cross section; 16 – deep drillhole.



Prešov
ZLATÁ BAŇA
(Pb, Zn ± Au, Ag)
Hanušovce elevation
Snina
REMETSKÉ HÁMRE
(Pb, Zn)
A'
Merník
Bzenov – Morské Oko lineament
Morské Oko
Vihorlat
1076,0
Remetské Hámre
Vechec
GRABEN PREŠOV – KRÁĽOVSKÝ CHLMEC
N
KP-1
Dobšina – Zbudza lineament
Michalovce
Herľany elevat.
D-2
Albinov elevat.
Pozdišovce elevation
Sobrance
D-1
Sečovce
Košice
Senné
Štítnik – Sečovce lineament
Trebišov
Slanské Nové Mesto
Veľ. Milič
Niž. Žipov
Seňa
395
BREHOV
(Zn, Pb ± Au, Cu)
Malčice
Kuzmice
Lastovce
TELKIBÁNYA
(Au, Ag ± Pb, Zn)
Oborín
Byšta
Fka-2
Tb-2
Zemplín elevat.
A
Sirník
Brehov
ZATÍN-1
Komárovce – Brehov lineament
P-2
Telkibánya
Füzérradvány
Ptruksa elevat.
476
Feketehegy
588
UŽ-3
Zemplín
Kráľ. Chlmec
Veľ. Horeš
Sátoralja-Újhely
SÁROSPATAK
(Alunit)
Mogyorócska
Háromhuta
Streda nad Bodrogom
768
BASKÓ-3
SP-5
Zemplénagárdi
SP-7
Karcsa
KOMORÓ
Hornád lineament zone
Ondava lineament zone
Bodrog
SP-10
Rudabánya – Beregovo lineament
Tályа
Rátka
Kisvárda
Szerencs
Tisza
Kisvárda elevation
0 4 8 12 16 20 km
BREHOV (Zn, Pb ±...) 1
2
3
4
5
6
7
8
a b 9
10
11
12
13
14
A 15
UŽ-3 16

The **Bzenov–Morské oko subequatorial lineament** on the west is traced by a large magnetic "ophiolite" anomaly near the village of Bzenov, by the drillhole V-1, intersecting the serpentinite body in the southern periphery of the city of Prešov (Slávik, 1974), by the base metal and gold ore deposit Zlatá Baňa in the Slanské vrchy Mts., and by the base metal ore field near Morské oko in the Vihorlat Mts. Along the Bzenov–Morské oko subequatorial lineament the ore-bearing Neogene subvolcanic diorite porphyry bodies occur (the Zlatá Baňa and Morské oko ore fields; Figs. 2, 3 and 4; Tözsér, 1972; Slávik, 1974; Kaličiak & Ďuďa, 1980; Gnojek, 1987; Bacsó & Ďuďa, 1988; Divinec et al., 1988).

The complementary submeridional lineament to the above mentioned set of subequatorial lineaments in the "Border Zone" between W. Carpathians and E. Carpathians is represented by the **Hornád lineament zone** among the Zlatá Baňa base and gold metal deposit, the Telkibánya precious metal deposit and the lacustrine hydrothermal-exhalative mineral occurrences near villages of Háromhuta and Mogyoróska in the Tokaj Mts. (Hungary – Gyarmati, 1977).

The Ondava submeridional lineament zone is developed app. 25–35 kilometers east from the Hornád submeridional lineament zone. That lineament zone is traced from north to south by the Malčice buried volcanoes, by the Brehov–Sirník interpreted caldera and by Neogene ore deposit near village of Brehov, by the Zemplín–Somotor interpreted caldera and by the submarine ore field near the village of Zemplín, as well as by the buried volcanics and subvolcanic bodies near the village of Somotor (Figs. 2, 3, 5a and 5b).

3 Local Geology – the Brehov–Zemplín ore sector

The Brehov–Zemplín ore sector is located 16–22 km to SSE of the town of Trebišov. It forms a N–S oriented, 15 km long zone, wide 6–8 km, along the Ondava interpreted submeridional lineament zone. The submarine, hydrothermal mineralization of the Brehov–Zemplín metallogenetic sector is located in the immediate transition zone between the Zemplín Paleozoic elevation in the western side, and the Neogene Prešov–Kráľovský Chlmec graben on the eastern side (Figs. 2, 3, 4, 5a and 5b). In the northern part of this structure is located the Brehov–Sirník interpreted, buried submarine caldera with the Brehov volcanogenic, stratabound base and gold metal deposit. In the southern part of this structure the Zemplín–Somotor interpreted buried caldera is developed, with the Zemplín volcanogenic, andesitic, stockwork-feeder zone base metal ore occurrences.

Both ore mineralizations, near the Brehov village, as well as near the Zemplín village were formed within a resurgent caldera horst structure in the submarine environment. In the case of the Brehov area, the caldera probably opened along outward dipping faults, which was promoted by magma degassing, seawater influx and high temperature leaching, resulting in origin of the metal rich hydrothermal fluids. The thick rhyodacitic pyroclastics and epiclastics accumulation within the caldera has disposed with increased permeability, being exploited by mineralizing solutions. The specific caldera processes were the key factors in the formation of possible mineral ore deposits (Franklin et al., 1981; Sato, 1990; Ohmoto, 1996).

3.1 The Brehov ore field

3.1.1 Ore resources of the Brehov submarine hydrothermal deposit

As revealed by extended deposit survey (Bacsó, 1995a, b), before attenuation of mining survey and ores exploitation in Slovakia, the Brehov volcanogenic, strata-bound, base and gold metal deposit contained a total of known resources of mostly semi-massive, heterolithic, sulphide-matrix breccia ores: 11.965 million metric tons (MT); grading: 0.821 wt. percent Pb; 1.466 wt. percent Zn; 0.212 wt. percent Cu; 0.424 g/t Au.

The total tonnage of ore at the end of the most extensive survey in the middle 1990s:

a) 8.392 million metric tons (MT) represent Pb, Zn, Cu ore, grading:

a_1) 0.943 wt. % Pb;

a_2) 1.86 wt. % Zn;

a_3) 0.119 wt. % Cu;

a_4) 0.017 g/t Au;

b) 0.837 million metric tons (MT) represent Pb, Zn, Cu, Au ore, grading:

b_1) 2.206 wt. % Pb;

b_2) 2.100 wt. % Zn;

b_3) 0.113 wt. % Cu;

b_4) 0.646 g/t Au;

c) 1.177 million metric tons (MT) represent Cu ore, grading:

c_1) 0.034 wt. % Pb;

c_2) 0.125 wt. % Zn;

c_3) 1.150 wt. % Cu;

c_4) 0.024 g/t Au;

d) 1.558 million metric tons (MT) represent Au ore, grading:

d_1) 0.014 wt. % Pb;

d_2) 0.018 wt. % Zn;

d_3) 0.664 wt. % Cu;

d_4) 2.804 g/t Au.

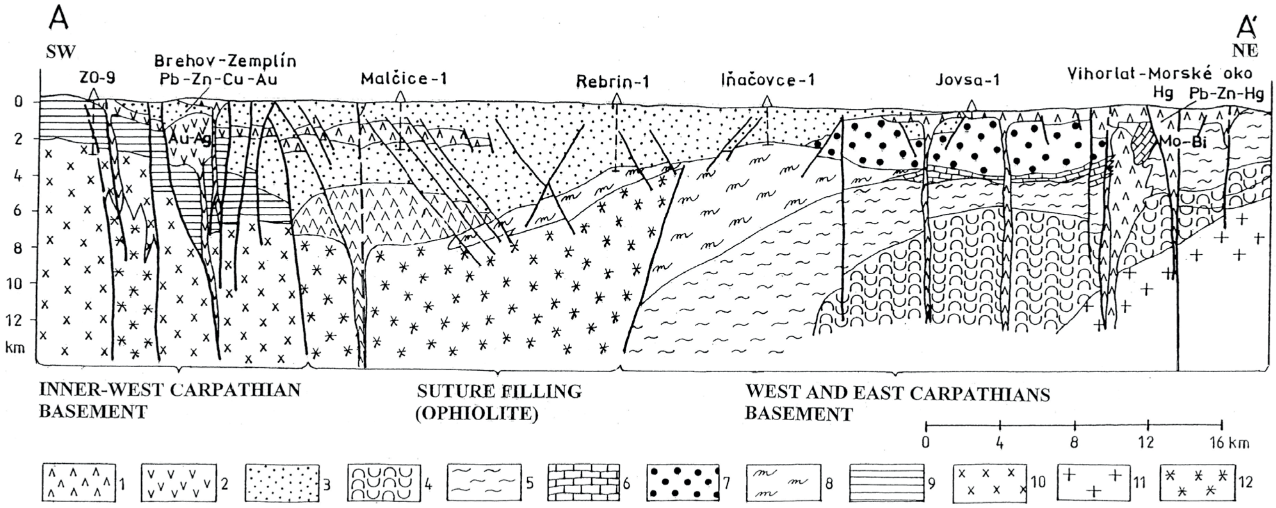


Fig. 4. Cross section through Pannonian basin ("Zemplín Island" ridge) to outer flysch Carpathians (Vihorlat Mts.) (Bacsó, 2014). 1 – Neogene andesite volcanics; 2 – Neogene rhyodacite magmatics; 3 – sediments of the Transcarpathian depression; 4 – Dukla flysch belt; 5 – Magura flysch belt; 6 – Klippen Belt; 7 – Humenné Mesozoic – Krížna nappe; 8 – Iňačovce–Kričeva unit; 9 – Late Paleozoic Zemplín Group; 10 – Zemplinicum; 11 – crystalline basement of Eastern Europe; 12 – ophiolite (serpentinized peridotite).

3.1.2 Paleontology and stratigraphy of the Brehov ore deposit

Based on stratigraphic results from the drillholes VBZ-1A, VSB-6, VSB-9 and VBZ-18, Zlinská in 1993 stated that the prospecting area of Brehov and its surroundings (drillhole VS-17 near the village of Cejkov) is built of sediments extending from Lower Badenian to Lower Sarmatian. These, taking into account the lithology, represent an equivalent of the Nižný Hrabovec Formation, the Vranov Fm., the Lastomír Fm. and the Stretava Fm.

In the Brehov ore deposit, the ore-bearing inner-caldera volcanic sedimentary sequence was dated by the fauna of *Spiroplectinella carinata* and *Bullimino-bolivino* zones to Wieliczkan and marine Kosovian, representing the transition of Middle and Upper Badenian. The ore-bearing volcanic-sedimentary sequence of calcareous claystone, alternating with hydrothermally altered rhyodacite explosive breccias and rhyodacite lapilli pumice tuffs as well as rhyolite epiclastics, is developed in the whole deposit area from surface down to 100–400 m depth (Zlinská, 1993; Bacsó, 1995a, b).

The total depth of the submarine emplacement of the volcanic-sedimentary ore-bearing sequence and of the sulphide mineralization still remains an open question. The presence also of subaerial Sarmatian andesite in this region, sedimentary facies and structures, typical for littoral environment, the presence of a neritic fauna in the Upper Badenian pelites in the hanging wall of mineralization and the mechanical constrains on stockwork fracturing favour the interpretation of genesis in a shallow-water environment (Bacsó, 2014).

3.1.3 Geological setting of the Brehov ore deposit

The Brehov ore deposit, located in the immediate western neighbourhood of the Brehov village, was developed in the center of the southern part of buried-submarine caldera Brehov–Sirník (Figs. 2, 3, 5a, b and 6). The vertical lithostratigraphic column of the Brehov ore deposit and diagrammatic presentation of the tectonic setting is in Fig. 7.

Available knowledge about the geological setting of the Brehov ore deposit extends from the surface to a depth of 650 m to the upper part of the quartz diorite porphyry stock body, representing a deepest part, reached by our drilling works. The direct known level of the Brehov ore deposit in the footwall encompasses a stockwork feeder zone of the subaqueous ores. It probably contains the former conduits, through which the metal bearing fluids were ascending and presumably spread on the seafloor. The Brehov feeder zone was located adjacent to quartz diorite porphyry rocks. The footwall mineralization is represented by pyrite-chalcopyrite stockwork veinlets and ore disseminations. The discrete veins are not present.

Within the quartz diorite porphyry footwall feeder zone of the Brehov ore deposit our drillholes intersected also sill and dike bodies of altered fine-grained quartz diorite porphyry, broadly contemporary with the pyrite, chalcopyrite + (pyrrhotine) hydrothermal mineralization. We interpret the quartz diorite porphyry intrusion as a "heater", driving the hydrothermal convective system.

The Brehov ore deposit sulphide mineralization represents distinct geochemically and mineralogically zoned Zn-Pb-Cu system. Cu (in chalcopyrite) dominates in

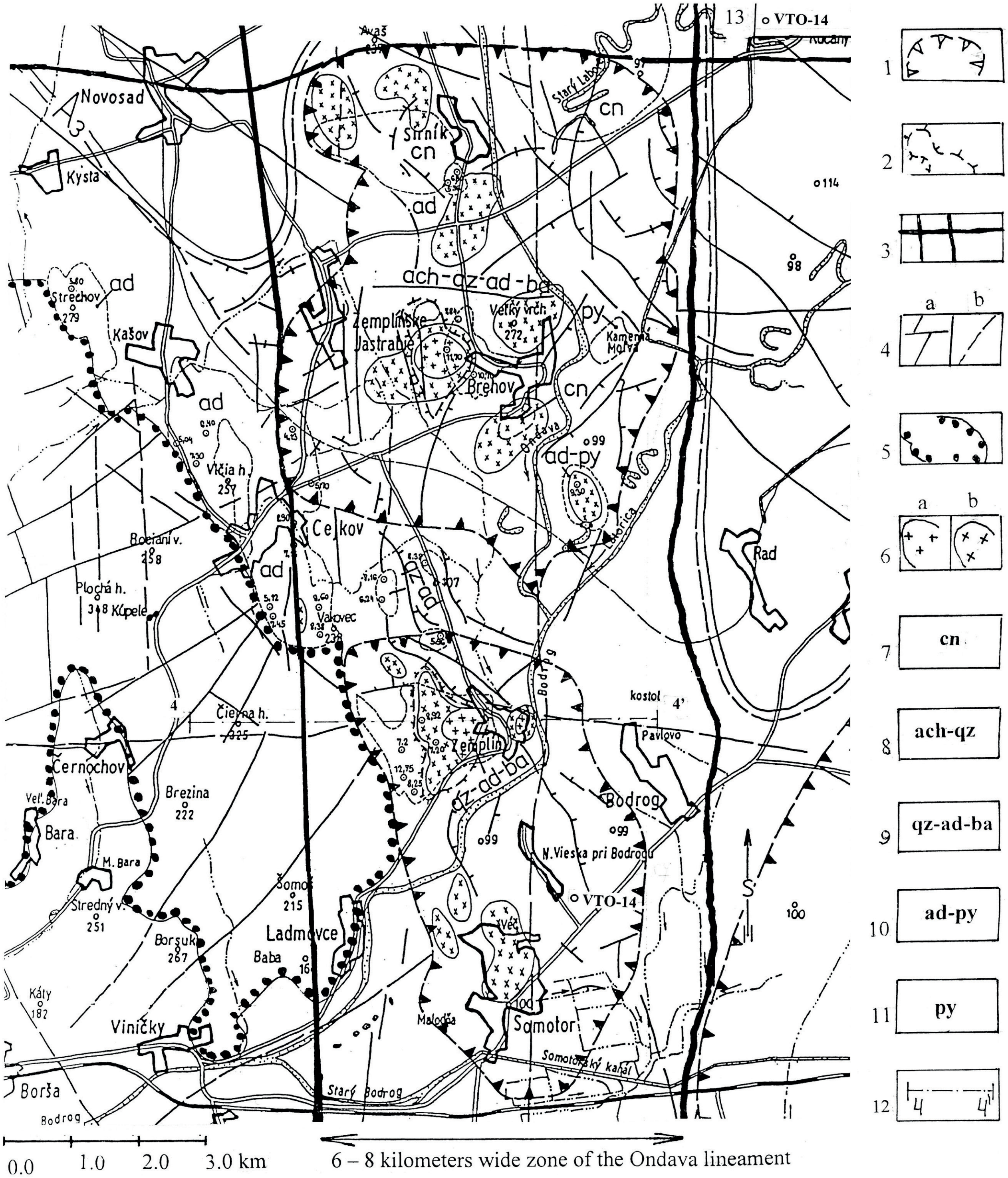


Fig. 5a. Interpreted calderas Brehov–Sirník and Zemplín–Somotor; Neogene magmatic bodies and products of alteration (on surface) (Bacsó, 2014; interpreted and compiled using own geological data and according geophysical data from Velich, Husák & Stránska, 1988–1991).

1 – interpreted fault boundaries of fossil submarine calderas; 2 – interpreted boundaries of elevation inside of caldera; 3 – deep fault; 4 – shallow fault: a) interpreted, b) assumed; 5 – Late Paleozoic-Mesozoic units of Internal Carpathians ("Zemplín Island"); 6 – ore-bearing subvolcanic intrusions: a) proved, b) interpreted. Surface products of hydrothermal alteration: 7 – chalcedony; 8 – agate – jasper – quartz; 9 – quartz – adularia – barite; 10 – adularia – pyrite; 11 – pyrite, 12 – line of cross-section.

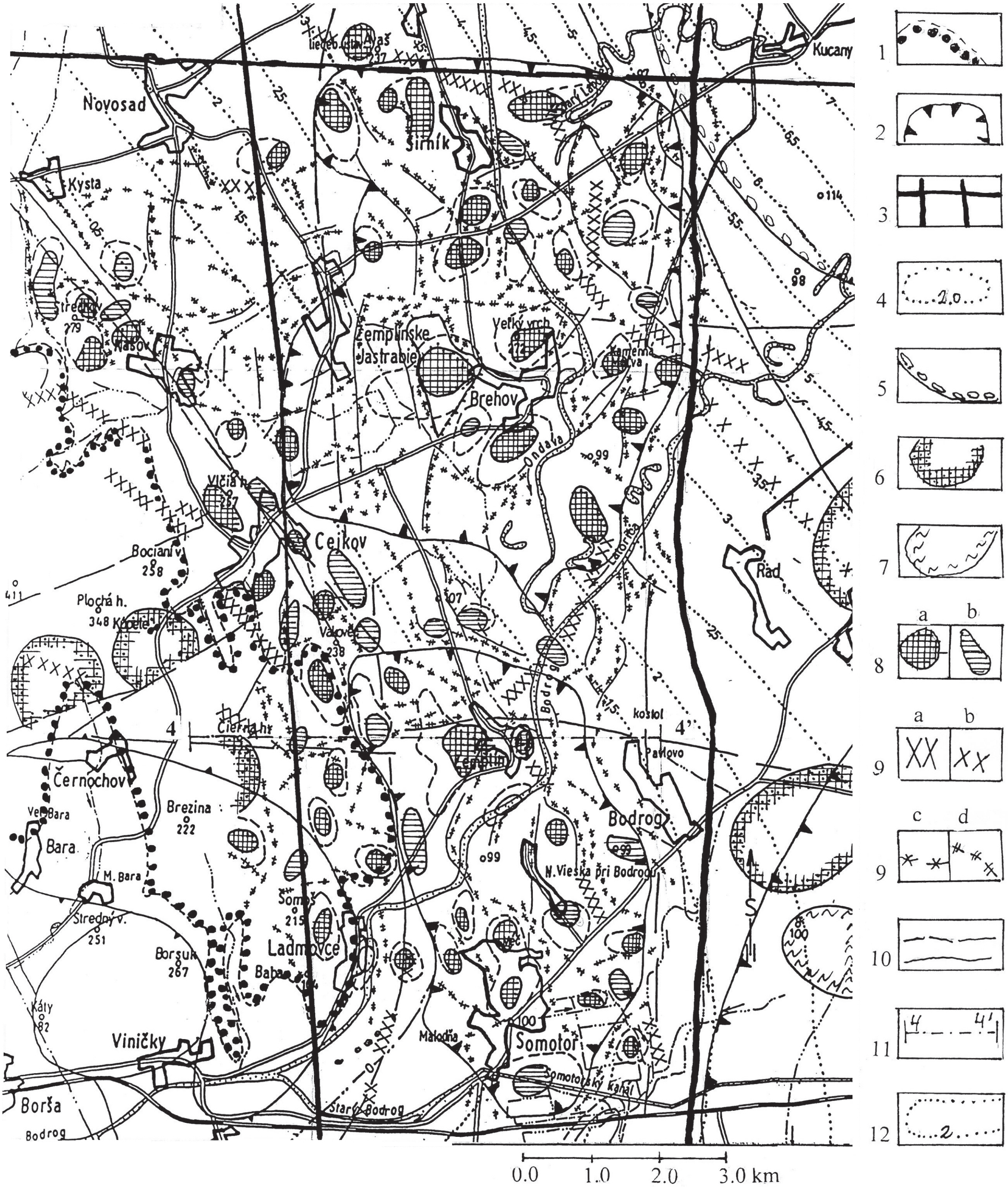


Fig. 5b. Geological and gravimetric schematic map of Brehov–Zemplín area. Interpreted calderas (Bacsó, 2014; interpreted and compiled according own geological data and geophysical data from Velich, Husák & Stránska, 1988–1991). 1 – Late Paleozoic, Mesozoic of Internal Carpathians ("Zemplín Island"); 2 – boundaries of interpreted caldera structures; 3 – deep faults; 4 – outline of Pre-Cenozoic basement surface in East Slovakian depression (based on seismic and gravimetric data – depth in kilometers); 5 – boundaries of Prešov–Kráľovský Chlmec graben structure with negative polarity; 6 – positive density anomalies from regional gravimetrical measurements; 7 – negative density anomalies from regional measurements; 8 – contours of local gravity anomalies: a) positive polarity, b) negative polarity; 9 – density boundaries: a) highly expressive, b) expressive, c) highly distinct, d) distinct; 10 – normal faults, 11 – line of cross-section; 12 – isolines of Pre-Cenozoic basement in kilometers.

the footwall stockwork rocks and the bottom part of the semi-massive sulphide lenses, while Zn-Pb minerals prevail in the center and upper part of the stratabound ore lenses.

Bimodal volcanic rock associations system (rhyodacite volcaniclastics, rhyodacite extrusive bodies, and quartz diorite porphyry bodies) occur near Brehov Fe-Zn-Cu sulphides.

The ore associations of the Brehov volcanogenic ore deposit consist of subhorizontal, stratabound-concordant ore lenses and discordant stockwork ores, members which are formed in a continuous set. The concordant semi-massive lenses of Zn-Pb-Cu-Fe ores are usually underlain by a discordant feeder (pipe) stockwork Fe + Cu + Au zone of ore. The ore twins represent two close contemporary and genetically related, but discordant ore bodies. Semi-massive upper concordant ore bodies consist at least by 40–65 % of fine- to coarse crystalline stratabound metallic minerals, the rest being represented by gangue and rock minerals.

The Brehov submarine base and gold metal deposit manifests similarities to the Kuroko deposits of Japan. The majority of ore mineralization is hosted by rhyodacite pyroclastics and epiclastics, by breccias and partly by calcareous claystone. The Middle Badenian sedimentary calcareous claystone is partly thermally metamorphosed near the contacts with the Late Badenian quartz diorite porphyry bodies. Semi-massive fine-grained sphalerite, galena, chalcopyrite and pyrite are located here with smaller amount of tetrahedrite and quartz, calcite, sericite and chlorite gangue. They form conformable lenses, distributed around former volcanic centre (for example near the summit of Travnický kopec hill west of the Brehov village). Stockwork veinlets and disseminated mineralization contain the same Zn-Pb-Cu minerals as the footwall of the semi-massive stratabound ore bodies.

The moderate to intensive silicification and chloritization of the host rocks of ore mineralization indicates that at least a portion of the stockwork ore predated the emplacement of the semi-massive stratabound ores.

In the Brehov ore deposit the calcareous claystone sedimentary facies occur in association with rhyodacite amygdaloidal flows, coarse-grained epiclastics, rhyodacite breccias to fine laminated tuffs, péperite breccias and tuffs. Many breccias are polymictic, composed of fragments ranging in composition from rhyodacite to quartz diorite porphyry. The clasts are usually present in a fine-grained chlorite matrix. The amygdules and spaces between the rock fragments are often filled with calcite, quartz and pyrite.

The Brehov ore deposit is a part of a resurgent caldera horst, submeridional oriented structure long 2200–2600 m and wide 850–1000 m in east-west direction, located in the center of the southern part of the Brehov–Sirník buried submarine caldera (Fig. 6).

The central gold-bearing zone of the Brehov ore deposit was penetrated by drillholes, VBZ-3, VBZ-7, VBZ-7A, VBZ-14 and VBZ-20. Beside a common type of main and minor ore minerals as sphalerite, galena, chalcopyrite and pyrite, there are present mostly trace minerals – gold, gold with bismuth, native silver, synchysite-Ce, ferberite, wolframite, adularia, brunsvigite, ripidolite, pycnochlorite and Mg-siderite. These trace minerals are typical only for the central part of the Brehov ore deposit (Figs. 6, 7, 8 and 9; Tabs. 1, 2 and 3).

The peripheral part of the Brehov ore deposit extends around the drillholes VBZ-4, VBZ-1A, VBZ-15, VBZ-18, VSB-1, VSB-5, which intersected Zn-Pb-Cu-Fe main ore mineralization with its typical accessoric hydrothermal minerals of tetrahedrite, freibergite, acanthite, bournonite, pearceite, Fe-smithsonite, stibnite, polybasite, Mn-siderite and Zn-ankerite.

3.2 The Zemplín ore field

The Zemplín submarine ore structure is located approximately 6 km south from the Brehov ore field, in the immediate western neighbourhood of the village of Zemplín. The Zemplín ore field is located in the southern continuation of the submeridional Ondava lineament zone in the northern part of the Zemplín–Somotor interpreted submarine buried caldera (Figs. 2–5a, 5b and 11).

The Zemplín ore field was verified by a detail geological, geochemical and geophysical survey, followed by trenching and a set of 300 m and 650 m deep drillholes. As a result of detailed and realized drilling program, below a shallow cover of rhyodacite volcanics (less than 150 m) a big laccolithic, hydrothermally altered body of Middle Badenian extrusive-intrusive pyroxene andesite and microdiorite rock complex was ascertained, with numerous small (thick 1–2 m) chimney polymetallic sulphidic Pb, Zn, Cu ore bodies (Fig. 11).

This strongly altered laccolithic Middle Badenian andesite-microdiorite body represents the host-rock environment for the sulphidic galena, sphalerite, pyrite and chalcopyrite mineralization. On the other side, in the Zemplín ore field the small rhyodacite extrusive bodies of Upper Badenian age represent the ore-bearing substance of the base metal mineralization.

The comprehensive geological interpretation of the ore mineralization in the Zemplín ore field shows that it represents the lower discordant feeder zone of the Kuroko type submarine Neogene sulphide base metal mineralization. The upper submarine concordant – stratabound semi-massive ore zone of the hydrothermal deposit was very probably removed by denudation and erosion in the past.

3.3 The ore-bearing intrusion of the Brehov ore deposit

Due to the strong hydrothermal alteration of the Brehov ore-bearing intrusion, the generally accepted naming

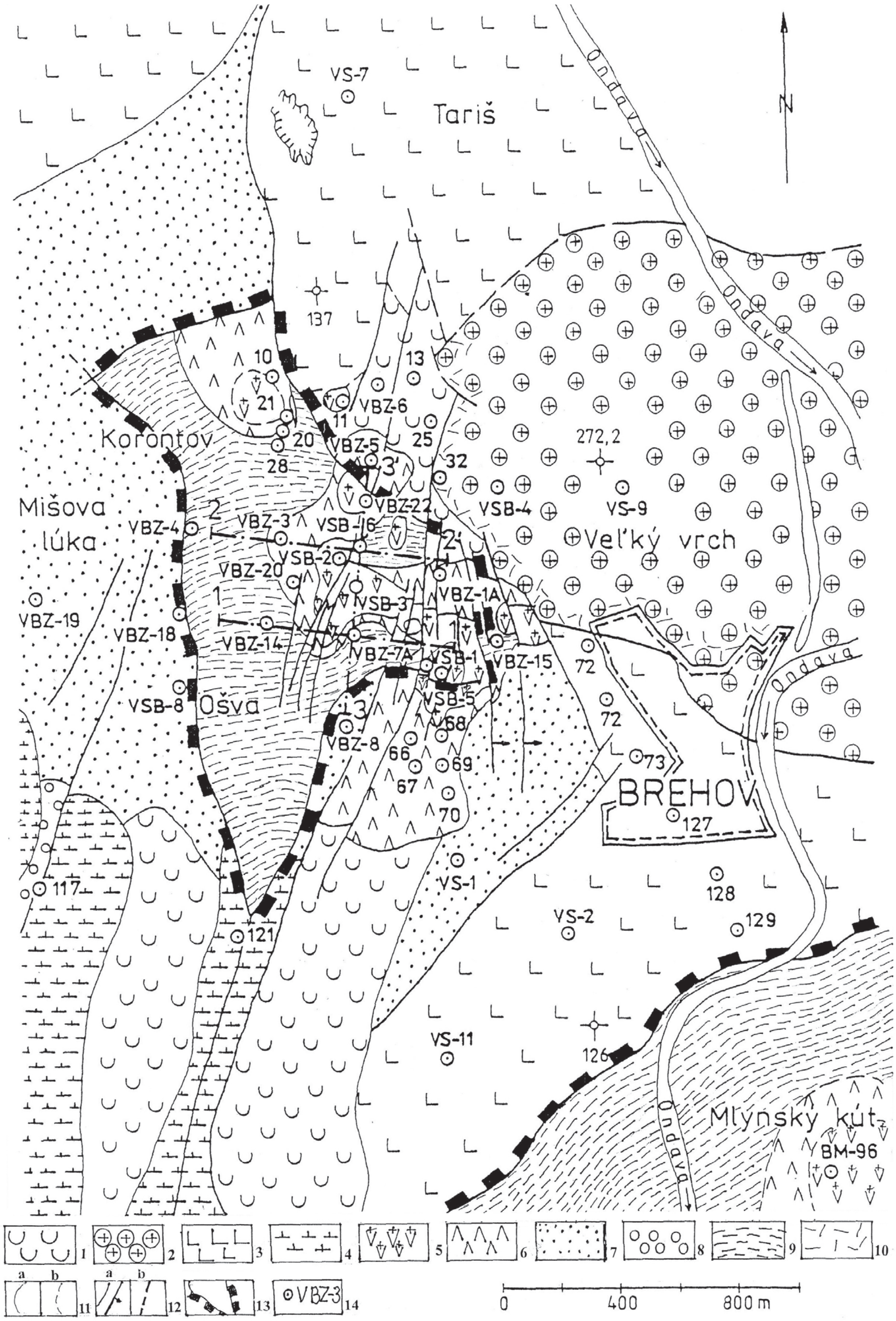


Fig. 6. Schematic geological map of the Brehov submarine hydrothermal ore deposit. 1 – Stretava Fm.: calcareous clays with beds of sand and rhyolite tuff and tuffite, Lower and Middle Sarmatian; 2 – extrusive bodies of pyroxene andesite; 3 – fresh lava flows of pyroxene andesite; 4 – strongly argillized lava flows of pyroxene andesite; 2–4 – Lower Sarmatian; 5 – silicified and adularized rhyodacite extrusions and lava flows; 6 – argillized rhyodacite extrusions and lava flows; 7 – calcareous clays – claystones with beds of siltstone, subsidiary tuffs and tuffites; 8 – Lastomír Fm.: redeposited fine-grained argillized volcaniclastics with pumice; 5–8 – Upper Badenian; 9 – sedimentary rocks of ore bearing volcanosedimentary sequence (claystone, sandstone, mudstone) of the Brehov resurgent caldera, transition sequence of Middle and Upper Badenian; 10 – brecciated rocks; 11 – geological boundaries: a) proved, b) assumed; 12 – faults: a) proved, b) assumed; 13 – ascertained boundaries of the Brehov ore deposit horst structure in the geological map; 14 – drillhole.

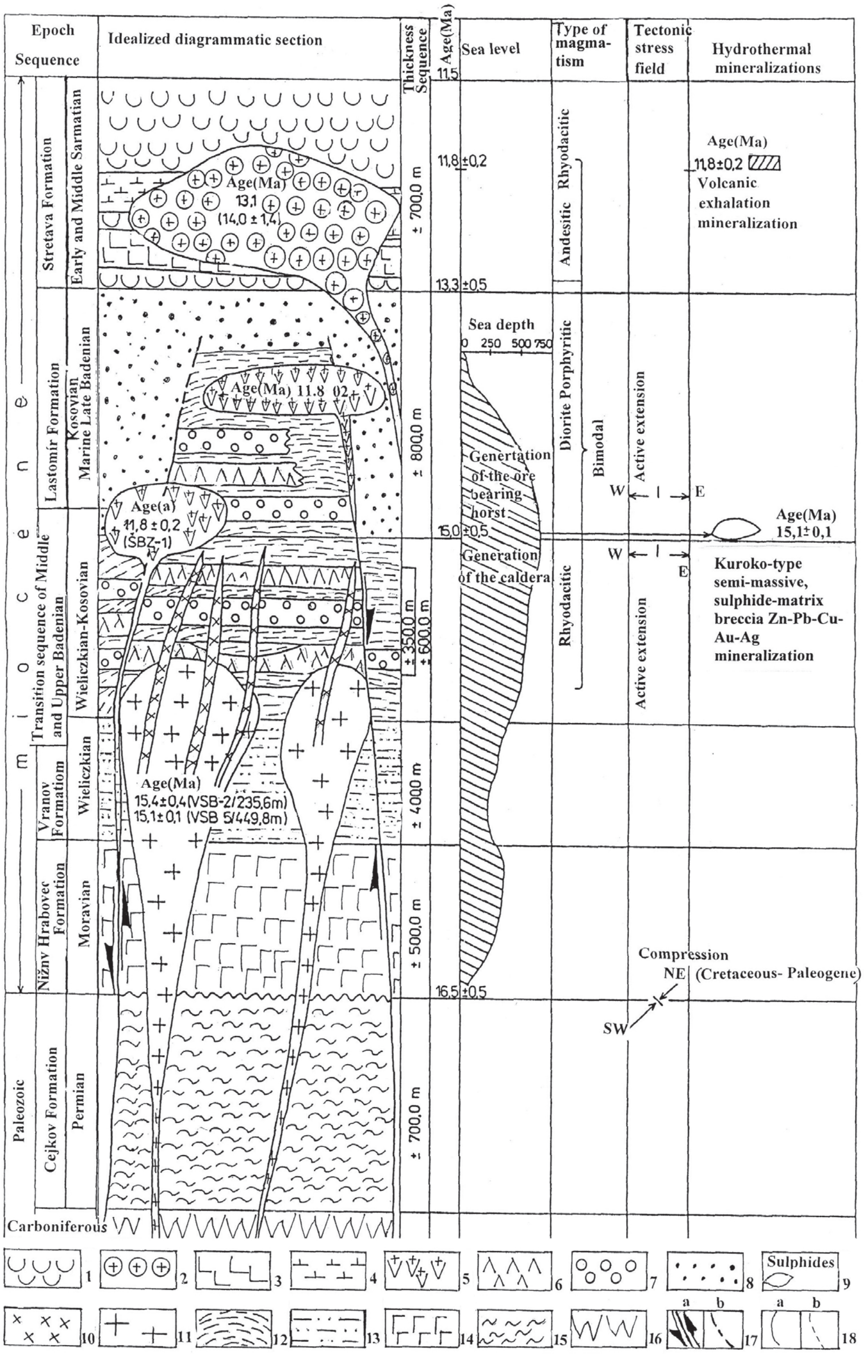


Fig. 7. Lithostratigraphic column of the Brehov ore deposit and diagrammatic presentation of the tectonic setting. 1 – Stretava Fm.: calcareous clays with beds of sand and rhyolite tuff and tuffite, Lower and Middle Sarmatian; 2 – extrusive bodies of pyroxene andesite; 3 – fresh lava flows of pyroxene andesite; 4 – strongly argillized lava flows of pyroxene andesite; 2–4 – Lower Sarmatian; 5 – silicified and adularized rhyodacite extrusions and lava flows; 6 – argillized rhyodacite extrusions and lava flows; 7 – Lastomír Fm.: calcareous clays – claystones with beds of siltstone, subsidiary tuffs and tuffites; 8 – redeposited fine-grained argillized volcaniclastics with pumice; 5–8 – Upper Badenian; 9 – polymetallic Fe-Zn-Pb-Cu-Au-Ag sulphide mineralization of the Brehov deposit; 10 – altered quartz diorite porphyry, sills, dikes; 11 – stock bodies of altered quartz diorite porphyry; 12 – sedimentary part of the ore bearing volcanosedimentary sequence (claystone, sandstone, mudstone) of the Brehov–Sirník resurgent caldera; 9–12 – transition sequence of Middle and Upper Badenian (Wieliczkian–Kosovian); 13 – Vranov Fm.: Grey calcareous claystone and sandstone, Middle Badenian–Wieliczkian; 14 – Nižný Hrabovec Fm.: calcareous sandstone alternating with beds of calcareous siltstone and claystone, Lower Badenian; 15 – Cejkov Fm.: redbrown sandstone, conglomerate, intercalations of sandy shale and rhyodacite tuff, Lower Permian; 16 – Kašov Fm.: green-grey sandstone with pebbles, sandy shale, products of rhyolite-dacite volcanism, Carboniferous; 17 – faults, generation of ore bearing horst: a) interpreted, b) assumed; 18 – geological boundaries: a) interpreted, b) assumed.

conventions for intrusive rocks on the basis of mineralogy and texture cannot be used. Therefore we have applied nomenclature based on chemical composition.

Traditional diagrams use the immobile elements (Floyd & Winchester, 1975, 1978; Winchester & Floyd, 1976, 1977). Actually, these diagrams, particularly the Nb/Y-Zr/TiO_2 diagram of Winchester and Floyd (1977) are in wide use even today. Regarding the Brehov–Zemplín metallogenetic sector (Fig. 12), for classification of altered rocks this diagram seems to work precisely.

Geochemically, the Neogene magmatic rocks in the "Border Zone" segment between W. Carpathians and E. Carpathians are very similar and can be all positioned to the same family of diorite, quartz-diorite and granodiorite magmas.

4 Mineralogical characteristic of the Brehov–Zemplín ore sector

4.1 The Brehov ore field

The Brehov deposit, correspondingly with other classical Kuroko type volcanogenic ore deposits, has two ore-bearing zones: The upper subhorizontal, stratabound, concordant ore-bearing zone of the ore bearing volcanic-sedimentary sequence (containing approximately 65 wt. % of the Kuroko type ore mineralization). The lower discordant, stockwork and feeder zone ore-bearing zone consists of veinlets of polymetallic mineralization in the altered quartz diorite porphyry stock body, containing app. 5 wt. % of the Kuroko ore mineralization. Between the upper and lower ore-bearing zones of the Brehov ore deposit a zone of quartz diorite porphyry sill and dike bodies occurs, with characteristic polymetallic mineralization, similar to hydrothermal veinlets mineralization in the lower ore-bearing zone of the deposit (containing approximately 30 wt. % of ore mineralization).

1. The stratabound, subhorizontal and concordant upper zone of ore mineralization, mostly in the rhyodacite epiclastics and pyroclastics horizons, dominantly in the form of semimassive Kuroko type sulphide matrix-breccia, Fe-Zn-Pb-Cu + Au, + Ag mineralization (Figs. 9 and 10; Tab. 2):
   Main minerals: Sphalerite, pyrite, galena, chalcopyrite, quartz, carbonate;
   Minor minerals: Barite, marcasite, specularite, Mg-siderite, amethyst, Fe-smithsonite, Zn-ankerite, Mn-siderite;
   Trace minerals: Tetrahedrite, pearceite, wolframite, scheelite, acanthite, bournonite, arsenopyrite, Ag-tetrahedrite, polybasite, stibnite, chalkosine, carbonate Ca + TR, monazite.
2. The hydrothermal veinlet minerals of sill and dike bodies of the altered quartz diorite porphyry transition zone, from subhorizontal, concordant, stratabound part of the deposit to discordant veinlet ore of the feeder zone intrusive (Figs. 9 and 10; Tab. 3):
   Main minerals: Pyrite, sphalerite, galena, chalcopyrite, quartz, carbonate;
   Minor minerals: Marcasite, specularite, gold, siderite, barite, Mg-siderite;
   Trace minerals: Scheelite, wolframite, native silver, acanthite, synchysite-Ce, greenockite (hawleyite?), ferberite, chalkosine, pearceite, cinnabar.
   Though the precious metals represent an important commodity in many Kuroko type deposits (Hannington et al., 1999), in the case of Brehov ore deposit they occur as volumetrically minor minerals (mostly in form of native gold). Visible gold is generally present as inclusions of native gold in major sulphide minerals, whereas silver occurs in Ag-sulphides and sulfosalt minerals such as tetrahedrite and freibergite.
3. The hydrothermal minerals of the discordant stockwork-feeder zone intrusive, from the altered quartz diorite porphyry stock body, mostly in form of veinlets (Figs. 9 and 10; Tab. 1):
   Main minerals: Pyrite, chalcopyrite, quartz, carbonate, chlorite;
   Minor minerals: Galena, sphalerite, adularia, Ca-siderite, marcasite, hematite, pycnochlorite, brunsvigite, ripidolite, Mn-siderite, specularite;
   Trace minerals: Tetrahedrite, native silver, acanthite, gold, gold with bismuth, scheelite, antimonite, barite, Fe-dolomite, carbonate Ce, carbonate.

In altered quartz diorite porphyry stock body, the Mg-chlorite mineralization, forming the fissure filling was intersected by the drillholes in the deeper part of the Brehov ore deposit. The Mg-chlorite mineralization indicates the presence of ophiolites in the near basement of the Brehov ore deposit (Tab. 1; Fig. 10). Similar Mg-rich chlorite was described by Herzig and Friedrich (1987) from the famous ophiolite locality Agrokipia on the Cyprus island.

A few kilometers north of Brehov ore deposit, the deep-oil drillholes Rebrín 1, Blatná Polianka 1, Senné 2, Senné 8, Pavlovce 1, Zbudza 1, located in the Pozdišovce–Krichevo geological unit in Paleogene–Mesozoic basement, have intersected the ophiolite body, mostly of serpentinized peridotites (Mořkovsky & Cverčko, 1987; Gnojek, 1987; Gnojek et al., 1991).

Caverns and fissures in the volcano-sedimentary ore-bearing sequences are partly filled with crystals of pure quartz, honey yellow sphalerite with dodecahedron crystals, crystals of galena and pyrite, sometimes with chalcopyrite. Within 1 centimeter wide caverns the pure slices of younger barite and in places also kaolinite are frequently visible. Synsedimentary polymetallic mineralization in the environment of sedimentary rocks presents sporadically in thin interbeds.

In the intrusive quartz diorite porphyry bodies (stocks, sills and dikes), the polymetallic ore mineralization has a character of veinlets, first of all pyrite and chalcopyrite, rarely with presence of sphalerite, galena, and in some places marcasite. Microscopic study has ascertained tetrahedrite, bournonite, scarce galenobismutite and pyrrhotite. In some grains of galena is present rare matildite (with increased content of silver, up to 2 %).

The bodies of quartz diorite porphyry with strong chloritization are bearing mostly carbonate and hematite mineralization in the form of veinlets, nests, and pods. In some places, in small fissures the bigger concentrations of chalcopyrite, pyrite, marcasite and relicts of pyrrhotite occur. From carbonate the Fe-dolomite is more often frequent, having the FeO content of 10.4–39.6 %, MgO 11.5–18.9 %, CaO 1.1–28.0 %. The hematite contains increased contents of vanadium, up to 0.046 %. The druses of crystallic light-violet amethyst were found, too.

1. The most frequent associations of hydrothermal minerals in the Brehov ore deposit are as follows: 1. The barite-quartz-pyrite + marcasite, hematite, rutile (so-called barite "ores");
2. Polymetallic ore with predominance of sphalerite, galena + chalcopyrite, barite, carbonate, tetrahedrite, bournonite, pyrite, marcasite (black ores);
3. Polymetallic ore with predominance of chalcopyrite, less marcasite, sphalerite, galena, tetrahedrite, bournonite, galenobismutite, pyrrhotite, pyrite (yellow ores);
4. Carbonates, quartz, hematite + chalcopyrite, pyrite, marcasite, pyrrhotite.

There can be summed up that polymetallic mineralization of the Brehov ore deposit consists of sphalerite, galena, pyrite, chalcopyrite, barite with hematite as main minerals. Quartz is present in the entire section of the ore deposit.

The most widespread ore mineral is sphalerite. The colour of sphalerite is from honey-yellow to brown (in the deeper part of the deposit). In sphalerite grains the rare inclusions of chalcopyrite or pyrrhotite occur. From the trace elements in sphalerite there were ascertained Sn (10–30 g/t), Ag (20–105 g/t), and Cd (0.27–0.37 g/t). The Fe contents in sphalerite are very low, mostly 0.3–1.0 %. In some sphalerites (in the center and deeper parts of the deposit), the very high contents of Ga (3.8–4.0 %) were ascertained. The contents of Ag in galena are around 5.0 g/t. The contents of Ag in chalcopyrite are only around 40 g/t. In barite in trace amounts there are present PbO (0.134–0.176 %) and SrO (1.23–2.52 %). Hematites contain low amount of TiO_2 (around 150 g/t).

4.2 The Zemplín ore field

Main minerals: Galena, sphalerite, pyrite, marcasite, quartz, amethyst, chalcedony calcite, dolomite and barite;

Minor minerals: Hematite, chalcopyrite, arsenic-pyrite, siderite;

Trace minerals: Tetrahedrite, chalkosine, Ag-tennantite, native silver, As-polybasite, acanthite, greenockite, (hawleyte?), mckinstryite, pearceite, scheelite.

Ore minerals are mostly connected with quartz-carbonate veinlets and occur in fissures and small caverns of the extrusive-intrusive altered pyroxene andesite body. Only very rare ore minerals are present in form of impregnations, mostly as cement between breccia fragments of andesite. Many times small crystals of galena, or sphalerite are in association with druses of quartz and kaolinite-illite, fulfilling small cavities.

From the hydrothermal alterations the hematitization, argillization, silicification and chloritization are the most widespread (Fig. 11).

Remark: Electron microprobe analyses of monomine-rallic multigrain aggregates were conducted with CAM-SCAN LINK-AN 10 000 system, at the Research Institute ČSVP, in Stráž pod Ralskem, Czech Republic. Analyst: M. Scharmová and P. Súlovský. A total of 500 sulphide and gangue minerals were analysed, in order to obtain quantitative chemical data from mineral grains of the Brehov and Zemplín ore fields.

5 The Brehov submarine volcanogenic sulphide ore deposit – position within the Internal Carpathian–Alpine Cenozoic metallogenetic belt

Within the Internal Carpathian–Alpine Cenozoic metallogenetic belt, the Brehov ore deposit is located in the "Border Zone" segment between W. Carpathians and E. Carpathians, which is bearing a number of fully and partly submarine volcanogenic base metal and gold-silver ore deposits.

The first essential difference between the "Border Zone" segment of the W. Carpathians and E. Carpathians ore fields and those in other five large segments of the Internal Carpathian–Alpine Cenozoic metallogenetic belt is that the "Border Zone" segment ore fields are volcano-genetically and metallogenetically partly or fully developed in submarine environment, while the other five large segments of the Internal Carpathian–Alpine Cenozoic metallogenetic belt are developed mostly or exclusively in subaerial environment. Second principal difference between the "Border Zone" segment ore fields on one side and the subaerial ones in other segments of Internal Carpathian–Alpine Cenozoic metallogenetic belt on the other side is that in the "Border Zoner" segment the classical large epithermal, low-sulfidation vein deposits are not present, being so typical for all fully subaerial Neogene ore deposits of the Internal Carpathian–Alpine Cenozoic metallogenetic belt, first of all for the Western Carpathians segment, Eastern Carpathians segment and the Apuseni Mts segment.

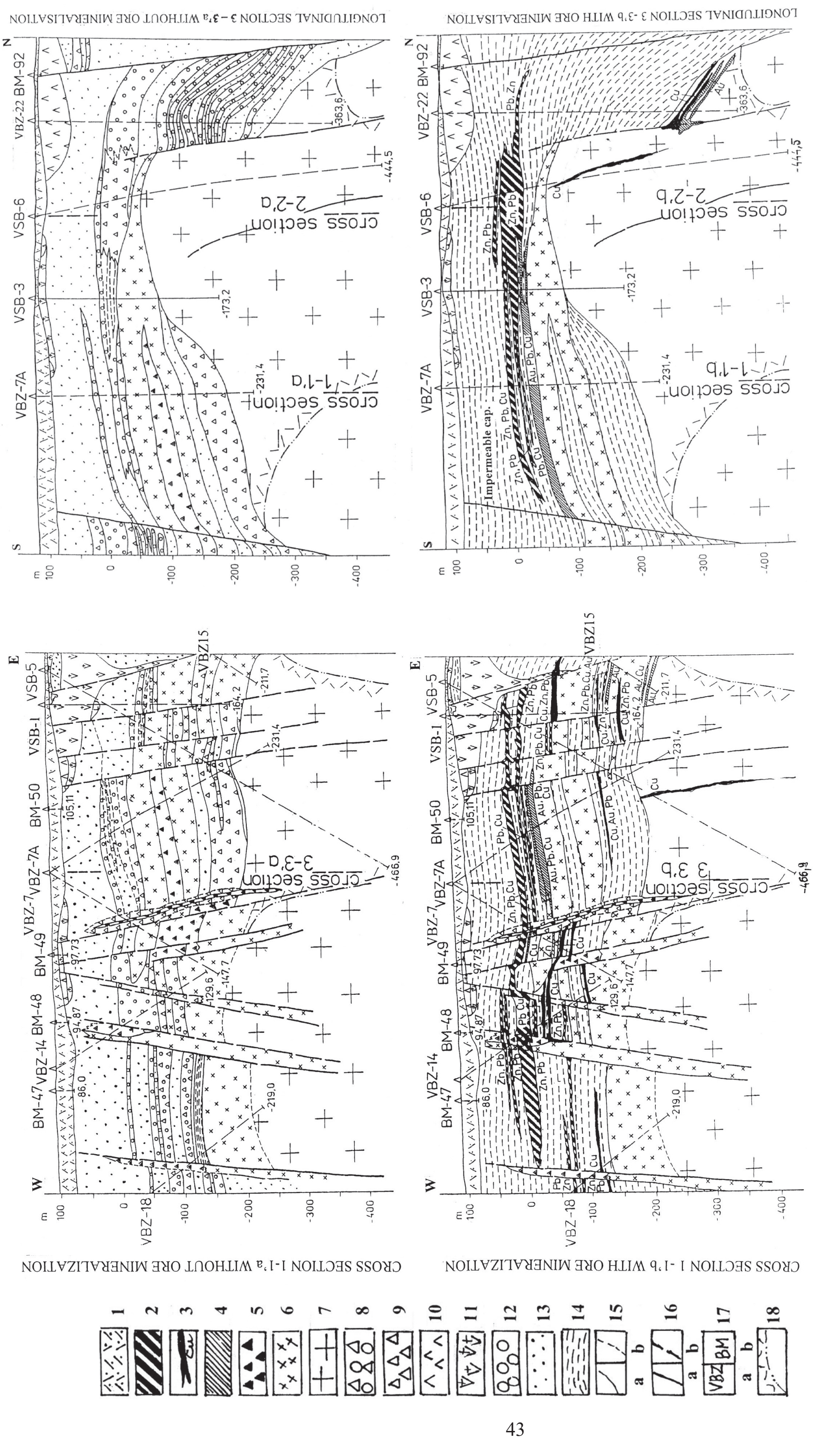


Fig. 8. Evidence of stratabound character of the Neogene ore mineralization in the volcanosedimentary sequence of the Brehov–Sirník interpreted resurgent caldera: ore mineralization is restricted to the volcanic part of the sequence. 1 – Quaternary clay, loam, sand; 2 – heterolithic semi-massive sulphide matrix-breccia Zn-Pb-Fe ore of claystone, sandstone, rhyodacite and its tuff, quartz diorite porphyry; 3 – magmatic hydrothermal semi-massive sulphide matrix-breccia Cu-Fe ore; 4 – siliceous stringer and disseminated Fe-Cu-Au ore of quartz diorite porphyry stock body of sills and dikes of quartz diorite porphyry; 5 – magmatic hydrothermal breccia of quartz diorite dikes; 6 – altered quartz diorite porphyry sills and dikes; 7 – stock body of altered quartz diorite porphyry; 8 – altered breccia of rhyodacite and its tuff; 9 – altered rhyodacite tuff and tuffite; 10 – argillized rhyodacite extrusions and lava flows; 11 – silicified and adularized rhyodacite extrusions and lava flows; 2–11 – Upper Badenian; 12 – hydrothermal explosive rhyodacite breccia; 13 – sedimentary part of the ore bearing volcanosedimentary sequence (claystone, sandstone, mudstone); 14 – undivided ore bearing volcanosedimentary sequence – transition from Middle to Upper Badenian (Wieliczkian–Kosovian); 15 – geological boundaries: a) proved, b) assumed; 16 – faults: a) proved, b) assumed; 17 – drillholes: a) deep 300–600 m; b) deep 10–100 m; 18 – brecciated hydrothermal vent (conduit) boundaries.

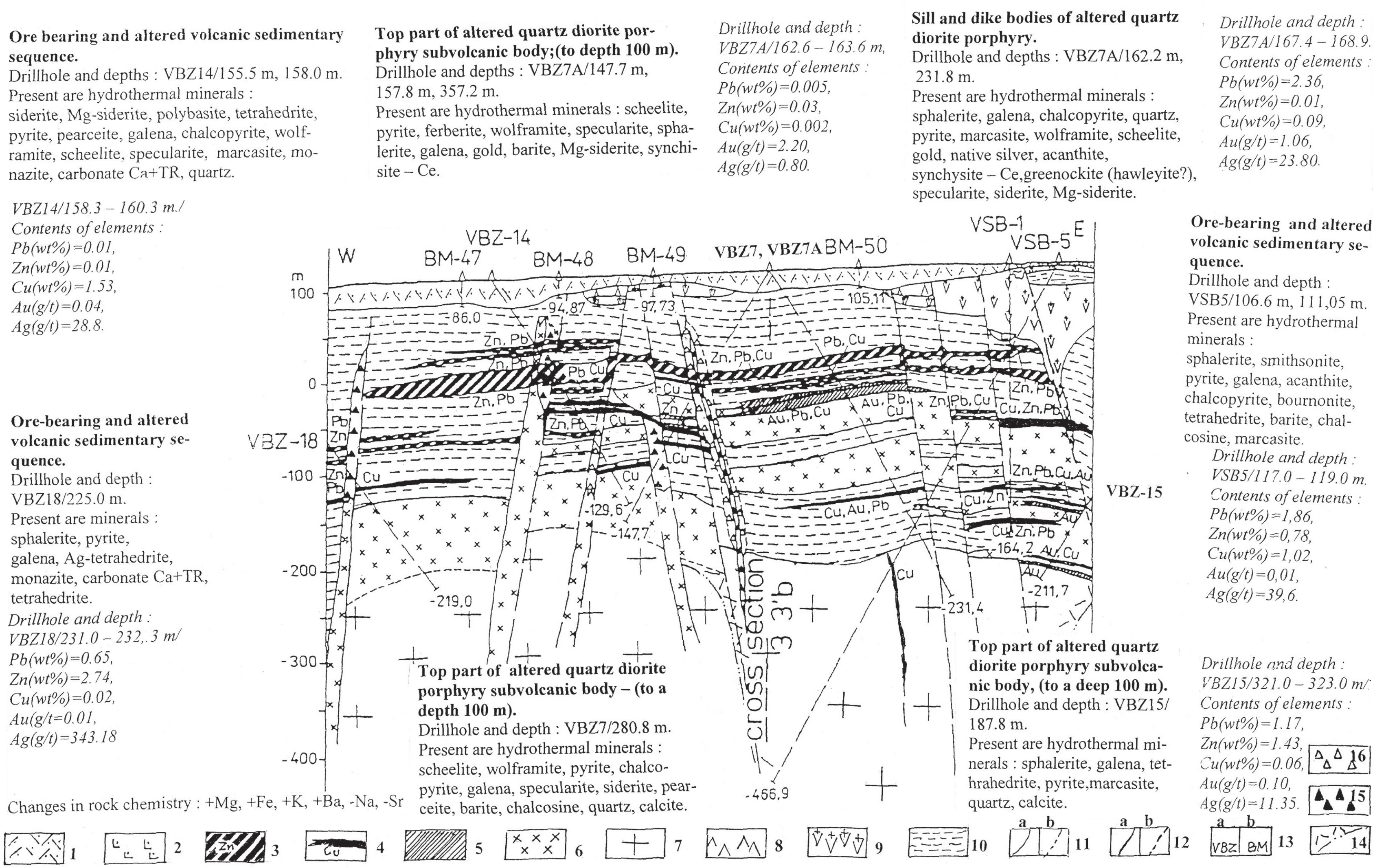


Fig. 9. Representative hydrothermal mineral assemblage from the Brehov ore deposit, cross-section 1–1`: 1 – Quaternary clay, loam and sand; 2 – Early Sarmatian dike body of pyroxene andesite; 3 – heterolithic semi-massive sulphide matrix breccia Zn-Pb-Fe ore in claystone, sandstone, rhyodacite and rhyodacite tuff; 4 – magmatic hydrothermal semi-massive sulphide matrix breccia Cu-Fe ore; 5 – siliceous stringer and disseminated Fe-Cu-Au ore; 6 – altered quartz diorite porphyry sills and dikes; 7 – stock body of altered quartz diorite porphyry; 8 – argillized rhyodacite extrusions and lava flows; 9 – silicified and adularized rhyodacite extrusions and lava flows; 3–9 – Late Badenian; 10 – undivided ore bearing volcanosedimentary sequence – transition from Middle to Upper Badenian; 11 – geological boundaries: a) proved, b) assumed; 12 – faults: a) proved, b) assumed; 13 – drillholes: a) deep 300–650 m; b) deep 10–100 m; 14 – brecciated hydrothermal vent (conduit) boundaries; 15 – magmatic hydrothermal breccia of quartz diorite porphyry dikes; 16 – heterolithic breccia of altered claystone, sandstone, rhyodacite tuff, rhyodacite, quartz diorite porphyry.

Top-part of the altered diorite porphyry subvolcanic body,(to a depth 100 m).
Drillhole and depth : VBZ20/184,9 m/.
Present are hydrothermal minerals :
hematite, chalcopyrite, siderite, galena, acanthite, monazite, carbonate Ca+REE, carbonate Ce, gold, gold with Bi, native silver.

Drillhole and depth :
VBZ20/222.40 – 228.4 m/.
Contents of elements :
Pb(wt%)=0.002,
Zn(wt%)=0.013,
Cu(wt%)=0.738,
Au(g/t) = 1.3
Ag(g/t) = 1.27

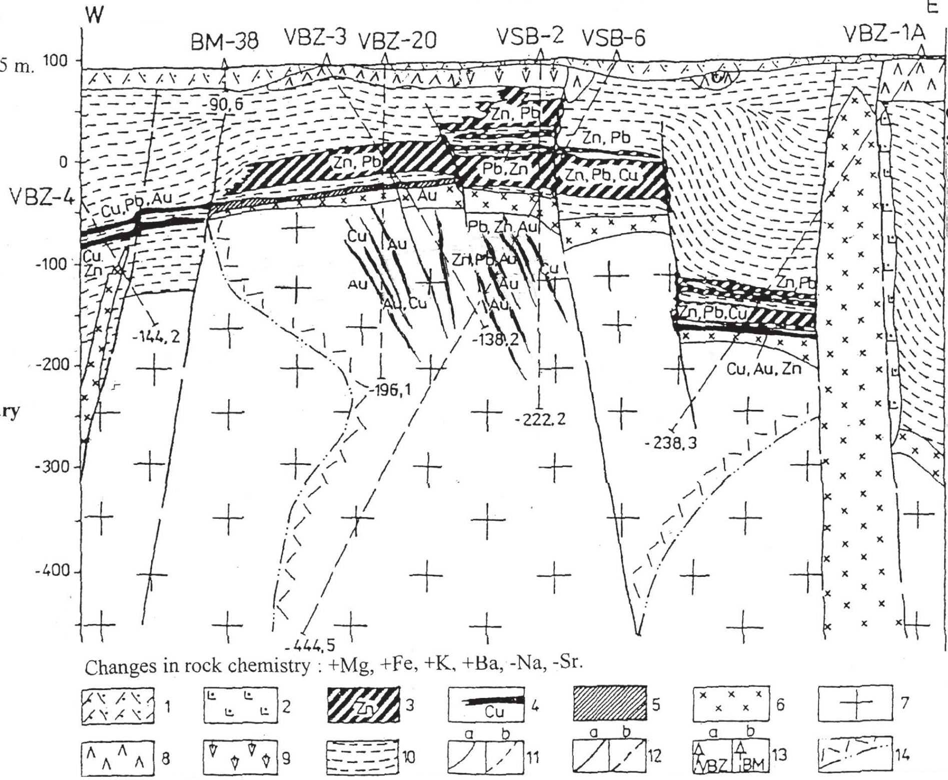
Deeper part of the diorite porphyry subvolcanic body, (more than 100 m).
Drillhole and depths : VBZ3/205.0 m, 253.5 m.
Present are hydrothermal minerals :
pyrite, marcasite, galena, sphalerite, chalcopyrite, tetrahedrite, Ca-siderite, native silver,acanthite. calcite, monazite, quartz.
Drillhole and depth :
VBZ3/134.0 – 135.5 m/.
Contents of elements :
Pb(wt%)=0.04,
Zn(wt%)=0.04,
Cu(wt%)=0.02,
Au(g/t)=8.07,
Ag(g/t)=2.49,

Ore-bearing, altered volcanic-sedimentary sequence.
Drillhole and depth :VBZ4/180.6 m.
Present are hydrothermal minerals :
tetrahedrite, pearceite, galena, chalcopyrite, pyrite, marcasite, barite, amethyst, arsenopyrite, quartz, calcite.
Drillhole and depth :
VBZ4/193.0 – 195.0 m/.
Contents of elememts :
Pb(wt%)=0.40,
Zn(wt%)=0.90,
Cu(wt%)=0.59,
Ag(wt%)=12.3,

Deeper part of the diorite porphyry subvolcanic body, (more than 100 m).
Drillholes and depths : VSB2/223.6 m, 265.5 m. VSB6/601.5 m,.
Present are hydrothermal minerals:
pyrite, marcasite, quartz, carbonate, specularite, pycnochlorite, brunsvigite, ripidolite, adularia, Mg-siderite, dolomite, apatite, zircon, REE-carbonate.

Drillhole and depth :
VSB2/190.6 – 191.7 m/.
Contents of elements :
Pb(wt%)=0.01,
Zn(wt%)=0.03,
Cu(wt%)=8.54,
Au(g/t)=0.01,
Ag(g/t)=10.29,

Drillhole and depth :
VSB6/150.7 – 151.7 m.
Contents of elements :
Pb(wt%)=1.39,
Zn(wt%)=2.14,
Cu(wt%)=0.02,
Au(g/t)=1.10,
Ag(g/t)=5.8.



Ore-bearing, altered volcanic-sedimentary sequence.
Drillhole and depth : VBZ1A/288.0 m.
Present are hydrothermal minerals :
stibnite, barite, scheelite, Mn-siderite, monazite, quartz.
Drillhole and depth :
VBZ1A/291,2 – 293,2 m/.
Pb(wt%)=1,33,
Zn(wt%)=4,24,
Cu(wt%)=0,06,
Au(g/t)=0,06,
Ag(g/t)=27,2.

Top part of the altered diorite porphyry subvolcanic body, (less than 100 m).
Drillhole and depth : VBZ1A/315.75 m.
Present are hydrothermal minerals :
quartz, carbonate, pyrite, marcasite, sphalerite, chalcopyrite, galena, antimonite, barite,scheelite,, Mn-siderite,
Drillhole and depth :
VBZ1A/326.0 – 327.0 m.
Contents of elements :
Cu(wt%)=0.85,
Au(g/t)=0.07,
Ag(g/t)=48.

Fig. 10. Representative hydrothermal mineral assemblage from the Brehov ore deposit, cross-section 2–2`. Explanations see in Fig. 9.

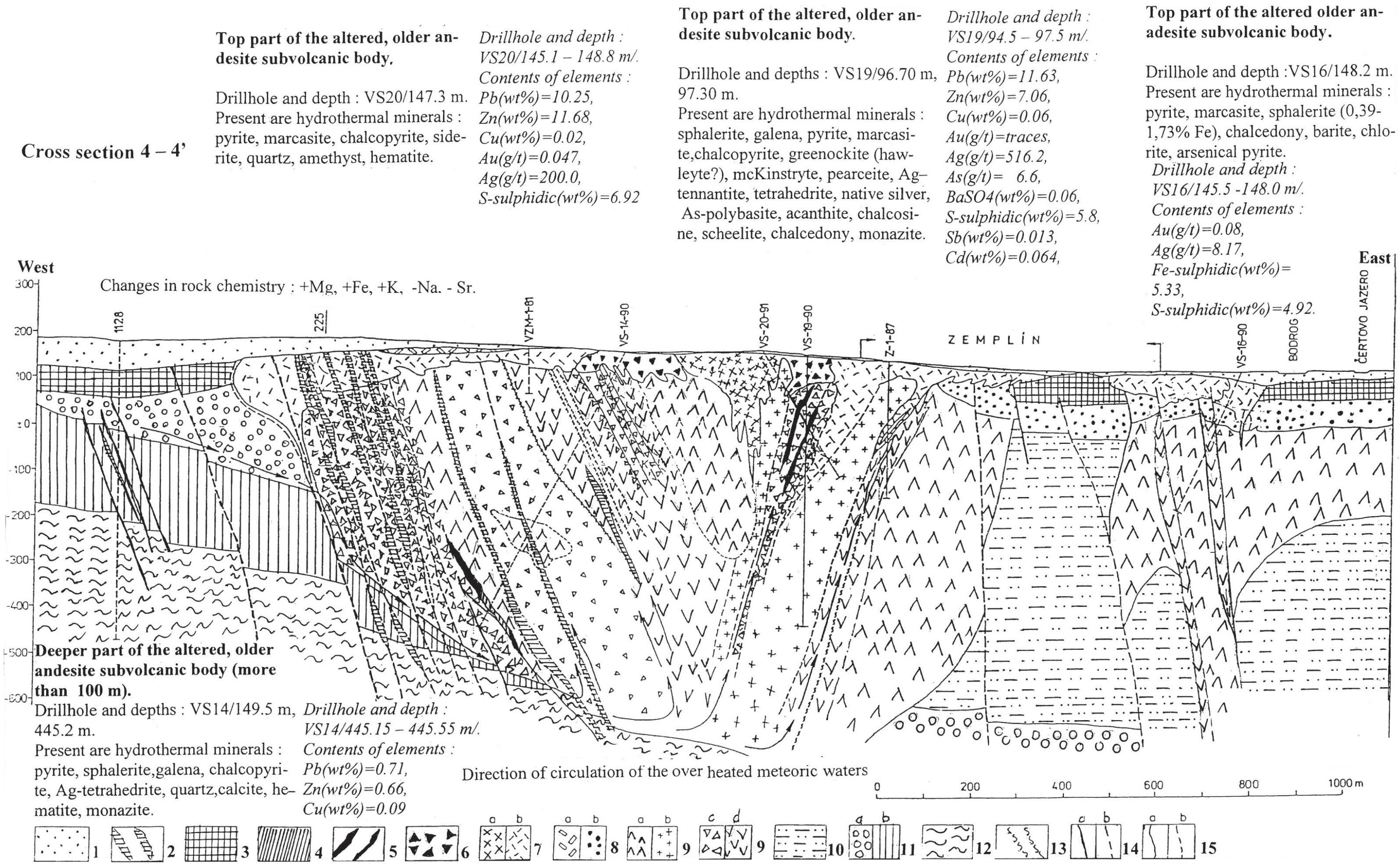


Fig. 11. Representative hydrothermal mineral assemblages and their relationship to ore geology. Submarine hydrothermal center near village of Zemplín in eastern Slovakia. 1 – Quaternary alluvial deposits; 2 – dike bodies of basaltic andesite, Upper Sarmatian; 3 – Kochanovce Fm.: calcareous clays, lignite seams, rhyodacitic tuffs, tuffites, Middle Sarmatian; 4 – zone of veinlets, impregnations, poor hydrothermal Zn-Pb-Fe-Ag mineralization in andesitic environment; 5 – rich Zn-Pb-Ag-Fe ore in andesitic chimneys; 6 – altered, brecciated rhyodacite with amethyst–quartz veinlets in vesicles; 4–6 – Upper Badenian–Lower Sarmatian; 7 – rhyodacite extrusions, irregularly fractured, with quartz, chalcedony (jasper) veinlets and zones of K-metasomatism: a) massive rock with adularization, silicification and argillization, b) brecciated, altered rhyodacite; 8a – redeposited, altered volcaniclastics of rhyodacite, mostly brecciated and with silicification; 8b – weakly altered, redeposited volcaniclastics of rhyodacite; 9 – altered subvolcanic bodies: a) coarse-grained intrusive andesites with vesicles, b) fine-grained intrusive altered andesite, both near sulphidic Zn-Pb-Ag-Fe mineralization with adularia, sporadically with barite, c) autoclastic breccia of strongly altered intrusive andesite, d) zones of weakly altered, brecciated intrusive andesite; 7–9 – Upper Badenian; 10 – Vranov Fm.: calcareous claystones, sandstones, Middle Badenian; 11 – Lúžna Fm.: a) conglomerates, b) sandstones, Lower Triassic; 12 – Cejkov Fm.: sandstones, conglomerates, Lower Permian; 13 – linear zones of brecciation, 14 – faults: a) inferred, b) interpreted; 15 – geological boundaries: a) inferred, b) interpreted.

Inside the "Border Zone" segment between W. Carpathians and E. Carpathians, the nearest (app. 39 km west) of Brehov submarine ore deposit is located the Telkibánya "subaerial" ore deposit with several differences:

A) The Brehov ore structure is located on the proximal eastern flank of the Paleozoic–Mesozoic Zemplín elevation, the Telkibánya ore structure is located on the distal western flank of the Zemplín elevation.

B) The Brehov ore deposit is fully a product of submarine development, the Telkibánya gold-silver ore deposit represents an epithermal, fully subaerial, low-sulfidation, vein metallogenetic structure and only volcanogenetically it has developed partly in submarine magmatic conditions.

The evidences of partly submarine character of the volcanogenic environment of Telkibánya ore field ("Telkibánya stratovolcano") are as follows:

1. In the Telkibánya deposit area, the drillhole Telkibánya-2 demonstrates below 790 m thick Sarmatian andesite volcanic sequence the volcanic and sedimentary rocks of Badenian age (proven by microfossils in the sediments).
2. The submarine dacitic-andesitic lavas and péperitic breccias, interbedded with shallow marine sediments in the Füzérkajata-2 drillhole indicate the contemporaneous subsidence of the Tokaj Mts. volcano-tectonic graben with volcanic activity (the Telkibánya ore deposit area).
3. Towards the end of the Badenian time, volcanic activity was represented by dacite domes, tuffs of dacite-rhyolite composition and tuff breccia deposited in a shallow marine environment.
4. An accumulation of rhyolite pyroclastics, alternating with shallow marine clays and marls in the Upper Badenian–Lower Sarmatian reflects the repeated sinking of the Tokaj Mts. graben, which is proved also by recent recognition of occurrences of péperites and hyaloclastite breccias in the cores of Telkibánya-1, Telkibánya-2 and Telkibány-9 drillholes, which indicates that part of the Early Sarmatian volcanism, producing the Lower Sarmatian andesites indeed took place under subaqueous conditions (Molnár et al., 2000).

The conformity between the rift (lineament) settings of subaerial low-sulfidation epithermal Telkibánya deposit and the submarine Kuroko type Brehov deposit raises the possibility that transitional deposit types may exist with prevailing shallow water conditions. Indeed the Zlatá Baňa ore deposit in the Slanské vrchy Mts., which formed during bimodal volcanism and rifting of an andesitic arc, has character of partly submarine, and partly subaerial structure.

The Zlatá Baňa stratovolcano, bearing the base metal and gold mineralization deposit, in the central volcanic zone has two spatially and timely complicated zones. The lower zone of volcanosedimentary rhyolitic-acidic composition of Eggenburgian–Badenian age and the upper andesitic, diorite porphyric zone with the age from Sarmatian to Lower Pannonian (12.2–10.0 Ma age; Repčok et al., 1988). The demonstration, that in Sarmatian time the volcanogenetic and metallogenetic processes also had partly submarine, and partly subaerial nature in the Zlatá Baňa ore structure represent the situation that base and gold metal mineralizations are developed only in the form of **mineralized tectonic zones** and not in the form of epithermal veins, occurring e.g. in typical Neogene subaerial epithermal vein deposits in the Banská Štiavnica ore district (Slovakia), in the Baia Mare ore district and the Apuseni Mts (both in Romania).

The position of the Zlatá Baňa ore deposit in the north-western deep centre of the Prešov–Kráľovský Chlmec graben (Fig. 3) indicates that with high probability this ore structure – at least partly – developed in submarine conditions.

According to Gessel (1878), the precious opal mineralization in the Dubník (Libanka) deposit is concentrated in two concordant, subhorizontal beds of so called "opal bearing" country rocks, and not in discordant vein type epithermal structures, which means, with high probability that the Dubník precious opal deposit and the whole Zlatá Baňa base metal and gold deposit developed, at least partly, also in submarine environment. The first precious opal-bearing layer is 30–80 m thick and its known extent is about one kilometer; the second precious opal-bearing bed situated westly is 10–30 meters thick, and has of about 70 meters strike length.

In the "Border Zone" segment between W. Carpathians and E. Carpathians within the Internal Carpathian–Alpine Cenozoic metallogenetic belt, another subtype of transitional – from submarine to subaerial – ore deposits is represented by the Begaň–Beregovo–Kvasovo metallogenetic sector in Transcarpathian part of Ukraine (Fig. 2).

Our new geological and metallogenetic interpretation (Bacsó, 2014) of the gold, silver and base metal mineralization in Begaň–Beregovo–Kvasovo ore sector, based on data and descriptions from Lazarenko et al. (1968), Skakun et al. (1992), Gozhik (1993), Biruk and Skakun (2000) and Emetz (2001) is as follows:

In the Begaň–Beregovo–Kvasovo ore sector a special subtype of Kuroko Sarmatian shallow submarine ore deposit (Muzievo) has developed, having two genetic-morphological features of economically important Au-Ag-base metal mineralizations:

1. The Sarmatian upper concordant, subhorizontal stratabound shallow zone of mushroom shaped gold-rich hydrothermal quartz-barite irregular

lenses (Au-ore shoot veinlets) in the "Upper Tuffs" horizon, usually very close to the contact with the underlying subhorizontal clayey sediments. Until now six Au-rich lenses were discovered. The ore bodies are irregular, funnel, or mushroom shaped, with diameters usually not exceeding 50 m. The ores consist of quartz, barite, clay minerals, gold, silver, as well as minor amount of pyrite. The average contents of gold in the lenses are 31 g/t Au, and 21 g/t Ag.

2. The lower discordant part of the Muzievo ore deposit is mostly in the "Middle Tuffs" horizon in the form of steep dipping Au-bearing veins and Au-bearing vein zones. The vein-form Au mineralization is represented by 17 veins, also of Sarmatian age, which are concentrated in a 1200 m wide zone. The length of veins varies from 300 to 1000 m.

Both parts (concordant and discordant) of the special Kuroko type shallow submarine Muzievo gold-silver-base metal mineralizations are exclusively developed only in the host volcanosedimentary sequence of Eggenburgian–Pannonian age.

6 Conclusions

The Kuroko type submarine, volcanogenic, stratabound, sulphide ore deposit near village of Brehov and ore occurrence near village of Zemplín in the Eastern Slovakia represent a new type of hydrothermal mineralization in the Internal Carpathian–Alpine Cenozoic metallogenetic belt, being characterized geologically, mineralogically and metallogenetically in this publication. The Brehov ore deposit manifests a complex stratabound submarine development with concordant main sulphide upper deposit part and less important discordant veinlets and disseminated impregnations of feeder zone in its lower part.

Our knowledge about Brehov volcanogenic stratabound base metal and gold deposit we gained by geological mapping, geochemical and geophysical regional and detail survey, by trenching and from drillholes. The field survey was followed by geological and metallogenetic interpretations.

In the Internal Carpathian–Alpine Cenozoic metallogenetic belt preferably in the "Border Zone" segment of this belt between W. Carpathians and E. Carpathians, there are geological conditions for discovery of more 2–4 similar submarine base metal and gold deposits – with the higher probability in the areas of interpreted submarine Sirník–Brehov and Zemplín–Somotor calderas.

The Internal Carpathian–Alpine Cenozoic metallogenetic belt consists of six naturally individualized regional segments, from west to east they are as follows:

1. The Western Alps Brusson segment;
2. The Eastern Alps Hohe Tauern segment;
3. The Western Carpathians segment;
4. The "Border Zone" segment between Western and Eastern Carpathians;
5. The Eastern Carpathians segment;
6. The Apuseni Mountains segment.

Within the Internal Carpathian–Alpine Cenozoic metallogenetic belt the **"Border Zone"** segment between Western and Eastern Carpathians has four principal metallogenetic sectors:

a) The Brehov–Zemplín metallogenetic sector; with two ore fields;
b) The Telkibánya metallogenetic sector; with one ore field;
c) The Zlatá Baňa metallogenetic sector; with two ore fields and one precious opal field;
d) The Begaň–Beregovo–Kvasovo metallogenetic sector; with three ore fields.

In the "Border Zone" segment and in the Western Carpathian segment of the Internal Carpathian–Alpine Cenozoic metallogenetic belt the discontinuous bodies of **exhumed ophiolites** indicate the course of suture zones, representing crustal discontinuities, being preferably used for establishing younger subequatorial lineament zones.

Complementary submeridional oriented Hornád and Ondava lineament zones are accompanied with the Miocene ore-hosted volcanic structures (submarine and subaerial) with the ore fields of Brehov, Zemplín, Zlatá Baňa, Dubník and Telkibánya.

Miocene gold mineralization in the "Border Zone" segment between W. Carpathians and E. Carpathians is richest in the Muzievo (Beregovo) ore field (4–8 g/t) and in the Brehov ore field (2–3 g/t).

The most favourable conditions for Miocene rhyolite-rhyodacite **volcanosedimentary** Au-Ag-base metal ore host-rock sequences development in the near surface beds were in the Brehov–Zemplín and Begaň–Beregovo–Kvasovo metallogenetic ore sectors. In these sectors the ore-bearing Miocene intrusive-extrusive complexes are represented by quartz diorite porphyry, intrusive andesite and extrusive–intrusive rhyodacite bodies.

Only the "Border Zone" segment between W. Carpathians and E. Carpathians has fully or partly submarine origin of Miocene volcanogenic base and precious metal deposit in the region.

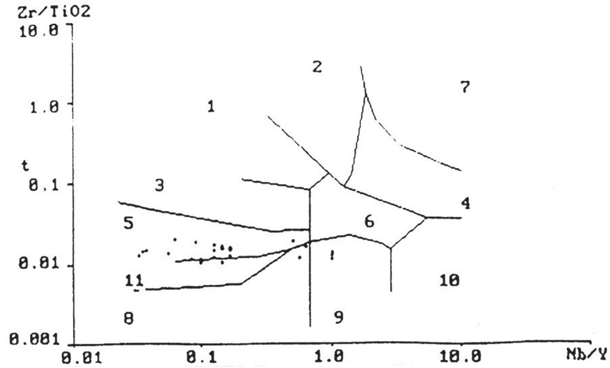
The geological, mineralogical and metallogenetic findings and revealed regional relations in the case of Brehov base metal and gold deposit indicate that the geological aspects of Neogene ore deposits in the Carpathians can be interpreted taking into account the theory of lineaments origin based on crustal discontinuities being indicated by the linear ophiolite zones occurrences on the surface or revealed in boreholes.

Acknowledgement

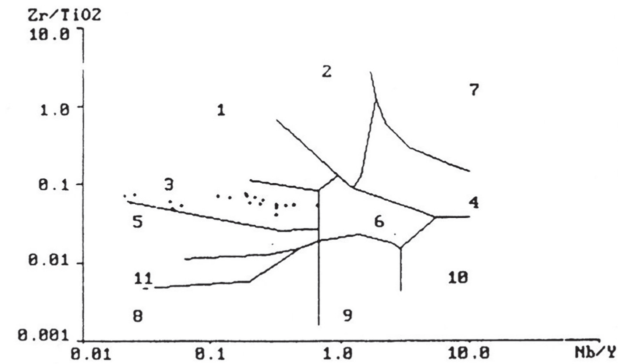
Author is grateful for extended ore exploration in Eastern Slovakian Neogene volcanic fields held in the 1970s–1990s, providing valuable primary data, being summed up in this article. Constructive comments and suggetions by Zoltán Németh (ŠGÚDŠ) and anonymous reviewer are greatly appreciated.

Samples of magmatic rocks, from boreholes in depth:	Mineralogical composition. ("Phenocrysts"). Holocrystalline altered-transformed groundmass	K-feldspar	Quartz	Carbonate	Sericite	Chlorite
VSB-1/178.5 m	87.9	9.1	3.0	–	–	–
VSB-2/153.5 m	70.8	8.5	15.3	5.4	–	–
VSB-2/247.5 m	79.9	11.6	5.1	3.4	–	–
VSB-2/333.2 m	74.9	11.3	3.7	0.4	–	9.7
VSB-2/340.5 m	75.4	18.9	2.2	3.5	–	–
VSB-5/438.0 m	71.7	3.6	–	2.9	15.2	6.6
VSB-5/611.0 m	78.3	3.5	–	7.1	6.6	4.5
VSB-5/647.5 m	78.2	4.5	–	7.9	9.4	–
VSB-6/158.5 m	78.4	14.7	3.3	–	–	3.6
VSB-6/370.5 m	78.2	2.5	–	2.1	11.9	5.3
VSB-6/606.5 m	76.8	8.2	–	4.8	–	10.2
VSB-6/649.0 m	80.3	13.1	–	4.1	2.5	–
VSB-3/219.0 m	75.5	–	–	10.9	–	13.6
VSB-3/140.0 m	79.9	–	4.8	5.6	–	9.7
VSB-3/135.5 m	80.0	–	6.4	13.6	–	–

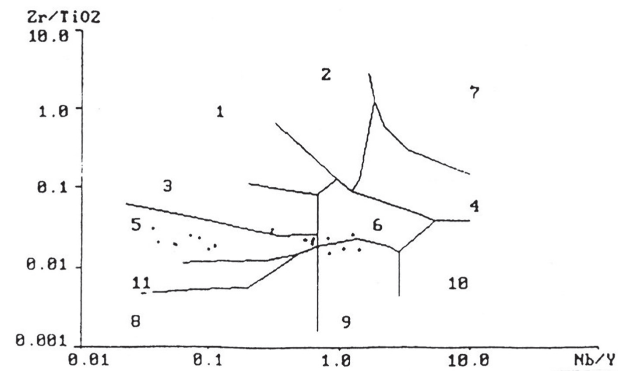
Nb/Y–Zr/TiO_2 diagram for volcanic rocks. (Winchester & Floyd, 1977)



Extrusive – intrusive altered, ore-host andesite and microdiorite; Middle Badenian age; Zemplín ore field (29 samples).



Ore-bearing quartz diorite porphyry; Brehov ore field; Upper Badenian age (24 samples).



Post ore andesite and dacite; Brehov, Veľký vrch (272), Lower Sarmatian age; Brehov ore field (22 samples).

1 – rhyolite; 2 – comendite pantelerite; 3 – rhyodacite, dacite; 4 – trachyte; 5 – andesite; 6 – trachyandesite; 7 – phonolite; 8 – subalvalinc basalt; 9 – alcaline basalt; 10 basanite; 11 – andesite/basalt.

Fig. 12. Basic petrographic and planimetric evaluation (in wt. %) of the altered submarine ore bearing Brehov intrusion – altered quartz diorite porphyry (Bacsó, 2014) and classification of altered Neogene magmatic rocks from individual levels of the Zemplín ore field after Winchester & Floyd (1977).

References

Bacsó, Z. & Ďuďa, R., 1988: Metalogenéza a rudné formácie rudného poľa Remetské Hámre. *Miner. Slov., 20, 3, 193–220.*

Bacsó, Z., 1995a: Subvulkanické telesá Východného Slovenska, polymetalické, drahokovové, vzácnekovové a ortuťové rudy. Vyhľadávací prieskum. Stav k 1. 9. 1995. Záverečná správa. *Manuscript. Bratislava, archive. St. Geol. Inst. D. Štúr, 171 p.*

Bacsó, Z., 1995b: Brehov západ, polymetalické rudy; Vyhľadávací prieskum. Stav k 15. 4. 1995. Záverečná správa. *Manuscript. Bratislava, archive. St. Geol. Inst. D. Štúr, 206 p.*

Bacsó, Z., 2000: Geology, mineralogy of the submarine volcanogenic sulphide deposit near Brehov in Eastern Slovakia: A genetic ore formation model. *Miner. Slov., 32, 265–267.*

Bacsó, Z., 2014: The Brehov volcanogenic and stratabound base metal and gold deposit (Eastern Slovakia). *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–38.*

Biruk, S. & Skakun, L. Z., 2000: Bismuth minerals of the Beregovo ore field: Mineral assemblages and spatial zonation (Transcarpathian Ukraine). *Geol. Quart., 44, 1, 39–46.*

Burian, J., Slavkay, M., Štohl, J. & Tőzsér, J., 1985: Metallogenesis of neovolcanites in Slovakia. *Bratislava, Alfa, 269 p.*

Dilek, Y. & Furnes, H., 2014: Ophiolites and their origins. *Elements, 10, 93–100.*

Divinec, Ľ., Kotuľák, P., Repčiak, M., Kaličiaková, E. & Ďuďa, R., 1988: Ložisko Zlatá Baňa vo svetle nových údajov geologického prieskumu. *Miner. Slov., 20, 3, 221–238.*

Emetz, A. V., 2001: Beregovo Au-Ag-Pb-Zn ore filed (Intercarpathian): ore review and genesis. In: Piestrzyński et al. (eds.): Mineral deposits at the beginning of the 21st century. *Lisse, Swets Zeitlinger Publ., 523–526.*

Faryad, S. W., Spišiak, J., Horváth, P., Hovorka, D., Dianiška, I. & Sándor, J., 1998: Meliata unit – petrology, geochemistry and geotectonic position of metabasites. Western Carpathians, Slovakia. *J. metamorphic Geol., 13, 701–714.*

Faryad, S. W., 1999: Exhumation of the Meliata high pressure rocks (Western Carpathians): Petrological and structural records in blueschists. *Acta Montan. Slov., 4, 2, 137–144.*

Floyd, P. A. & Winchester, J. A., 1975: Magma type and tectonic setting discrimination using inmobile elements. *Earth planet. Sci. Lett., 27, 211–218.*

Földessy, J., Németh, N., Gerges, A., Kupi, L. & Tóth, Sz., 2009: Re-discovery of a mining district – the Rudabánya (Hungary) base metal mineralization. Securing the Future 2009 International scientific conference. *8th ICARD, June 22–26, 2009, Skelleftea, Sweden.*

Franklin, J. M., Lyndon, W. & Sangster, D. F., 1981: Volcanic associated massive sulfide deposit. *Econ. Geol., 75th Anniv. Vol., 485–627.*

Gessel, S., 1878: A vörösvágási, Dubniki opálbányák földtani viszonyai. *Mathem. Természett. Közl. (Budapest), 15, 213–222.*

Gilmour, P., 1977: Mineralized intrusive breccias as guides to concealed porphyry copper systems. *Econ. Geol., 72, 290–298.*

Gnojek, I., 1987: Magnetická anomálie u Bzenova, jz. od Prešova. *Miner. Slov. 19, 2, 169–173.*

Gnojek, I., Hovorka, D. & Pospíšil, L., 1991: Sources of magnetic anomalies in the pre-Tertiary basement of Eastern Slovakia. *Geol. Carpath., 42, 3, 169–180.*

Gozhik, M. F., 1993: The Beregovo gold – polymetallic district. *Fieldtrip guide, IUGS/UNESCO – Modeling workshop, Budapest, 35–49.*

Gyarmati, P., 1977: A Tokaji hegység intermediár vulkanizmusa. *Magy. áll. Földt. Intéz. Évk., 58, 1–225.*

Hannington, M. D., Poulsen, K., H., Thompson, J., F., H. & Sillitoe, R. H., 1999: Volcanogenic gold in the massive sulfide environment. *Econ. Geol. Rev., 8, 325–356.*

Heinrich, Ch. & Neubauer, F., 2002: Cu-Au-Pb-Zn-Ag metallogeny of the Alpine – Balkan – Carpathian – Dinaride geodynamic province. *Mineral. Depos., 37, 533–540.*

Herzig, P. M. & Friedrich, G. H., 1987: Sulphide mineralization, hydrothermal alteration and chemistry in the drillhole CY-2a, Agrokipia, Cyprus. Cyprus Crustal Study project: Initial Report, Holes Cy – 2, CY – 2a. *Energy, Mines Res., Canada, 103–138.*

Hovorka, D., Snopko, L. & Zlocha, J., 1977: Gabropegmatit z ultrabazického telesa pri Komárovciach. *Miner. Slov., 9, 1, 11–20.*

Ishiwatari, A., 1985: Alpine ophiolites: product of low-degree mantle melting in a Mesozoic transcurrent rift zone. *Earth Planet. Sci. Lett., 76, 1–2, 93–108.*

Kaličiak, M. & Ďuďa, R., 1980: Development in time and formational subdivision of the mineralization in the Zlatá Baňa area (Slanské vrchy Mts.). *Miner. Slov., 13, 1, 1–23.*

Kaličiak, M., Lexa, J. & Határ, J., 1985: Hydrothermal mineralization at the village Zemplín. *Geol. Zbor. Geol. carpath., 36, 216–229.*

Kozur, H. & Mock, R., 1997: New paleographic and tectonic interpretations in Slovakian Carpathians and their implications for correlations with the Eastern Alps and other parts of the Western Tethys, Part 2: Inner Western Carpathians. *Miner. Slov. 29, 3, 164–209.*

Kutina, J., 1980: Are lineaments ineffective guides to ore deposits? *Glob. Tecton. Metallog., 1, 2, 200–205.*

Lang, B., 1979: The base metal-gold hydrothermal ore deposits of Baia Mare, Romania. *Econ. Geol., 74, 1336–1351.*

Lazarenko, E. A., Gnilko, M.. K. & Zayceva, V. N., 1968: Metallogeny of the Transcarpathians. *Lviv Univ. press, 178 p.*

Lexa, J. & Kaličiak, M., 2000: Geotectonic aspects of the Neogene volcanism in Eastern Slovakia. *Miner. Slov., 32, 205–210.*

Mayo, E. B., 1958: Lineaments tectonics and some ore districts of the Southwest. *Min. Engng, 10, 11, 1169–1175.*

Merlich, B. V. & Spitkovskaja, S. M., 1974: Deep faults, Neogene magmatism and ore deposition of the Transcarpathians. *Vyšča škola, 172 p.*

Molnár, F., Zelenka, T. & Pécskay, Z., 2000: Geology, styles of mineralization and spatial temporal characteristics of the hydrothermal system in the low-sulfidation type epithermal gold-silver deposit at Telkibánya. *Geol. Carpath., 46, 205–215.*

Mořkovsky, M. & Cverčko, J., 1987: Magnetic anomalies in the Neogene basement of East Slovakia lowland. *Miner. Slov., 19, 3, 255–260.*

Németh, Z., 2002: Variscan suture zone in Gemericum: Contribution to reconstruction of geodynamic evolution and metallogenetic events of Inner Western Carpathians. *Slovak Geol. Mag., 8, 3–4, 247–257.*

Németh, Z., Radvanec, M., Kobulský, J., Gazdačko, Ľ., Putiš, M. & Zákršmidová, B., 2012: Allochthonous position of the Meliaticum in the North-Gemeric zone (Inner Western Carpathians) as demonstrated by paleopiezometric data. *Miner. Slov., 44, 57–64.*

Neubauer, F., 2002: Contrasting Late Cretaceous with Neogene ore provinces in the Alpine-Balkan-Carpathian-Dinaride collision belt. *Geol. Soc. London, Spec. Publ.*

Neubauer, F. & Heinrich, Ch., 2003: Late Cretaceous and Tertiary geodynamics and ore deposit evolution of the Alpine--Balkan-Carpathian-Dinaride orogen. Mineral Exploration and Sustainable Development. *In: Eliopoulos et al. (eds.): Millpress, Rotterdam.*

O`Driscoll, E. S. T., 1981: Structural corridors in Landsat lineament interpretation. *Mineral. Depos., 16, 85–101.*

O`Driscoll, E. S. T., 1985: The application of lineament tectonics in the discovery of the Olympic Dam Cu-Au-U deposit at Roxby Downs, South Australia. *Glob. Tecton. Metallog., 3, 43–57.*

Q`Driscoll, E. S. T., 1986: Observation of the lineament-ore relation. *Phil. Trans. Royal. Soc. London, 317, 195–218.*

Ohmoto, H., 1996: Formation of volcanogenic massive sulphide deposits: The Kuroko perspective. *Ore geol. Rew., 10, 135–177.*

Pécskay, Z. & Molnár, F., 2002: Relationships between volcanism and hydrothermal activity in the Tokaj Mountains, Northeast Hungary, based on K-Ar ages. *Geol. Carpath., 53, 5, 303–314.*

Quadt, A. (ed.), 2002: The Timing and Location of Major Ore Deposits in an Evolving Orogen. *Geol. Soc. London, Spec. Publ., 204, 81–102.*

Popescu, C. Gh. & Neascu, A., 2010: Metallogeny of east Carpathians with special view to the metallogenetic district of Baia Mare, Bucuresti. *Ser. geol., XLIII, 19–26.*

Pospíšil, L. & Bodoky, T., 1981: Deep structure and magmatism of Neogene age in the Transcarpathian depression (Eastern Slovakia and NE Hungary). *Miner. Slov., 13, 4, 289–306.*

Rădulescu, D. & Lang, B., 1973: Sugesti privind intrpretarea structurii geologice a părtii de nord a muntiloir Gutii. *Bucuresti, D. S. Inst. Geol., LIX.*

Repčok, I., Kaličiak, M. & Bacsó, Z., 1988: Age of some volcanics of Eastern Slovakia. *Západ. Karpaty, Sér. Mineral. Petrogr. Gechém. Metalogen., 11, 75–88.*

Richards, J. P., 2000: Lineaments Revisited. *Soc. Econ. Geol., 14–20.*

Richards, J. P., Boyce, A. J. & Pringle, M. S., 2001: Geological evolution of the Escondida area, northern Chile. A model for spatial and temporal localization of porphyry Cu mineralization. *Econ. Geol., 96, 2.*

Sato, T., 1990: Volcanogenic massive sulfide deposits – with special reference to Kuroko type Deposits. *Manuscript. Geol. Surv. Japan, 1–36.*

Savu, H., 2009: Genesis of the Carpathian ophiolitic suture and origin of its varied magmatic rocks, Romania. *Proc. Rom. Acad. Sci., Ser. B, 2–3, 141–150.*

Skakun, L. Z., Matkovsky, O. I. & Gohzik, M. F., 1992: Au ores of Beregovo ore field. *Vest. Lvov Univ. Scr. Geol., 11, 128–145.*

Slávik, J., 1972: Pochované vulkanické pohorie na juhu východného Slovenska. *Geol. Práce, Spr., 58, 45–56.*

Slávik, J., 1974: Vulkanizmus, tektonika a nerastné suroviny neogénu východného Slovenska a pozícia tejto oblasti v Neoeurope. *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–341.*

Soták, J., Spišiak, J. & Biroň, A., 1993: Metamorphic sequences with "Bündnerschiefer" lithology in the Pre-Neogene basement of the Eastern Slovakian basin. *Mitt. Österr. geol. Gesell. (Wien), 111–120.*

Soták, J., Szakáll, S. & Kovács, Á., 1995: Silver minerals from Rudabánya (N. Hungary). *Acta mineral. petrogr. (Szeged), XXXVI, 5–15.*

Szakáll, S. & Kovács, Á., 1995: Silver minerals from Rudabánya (N. Hungary). *Acta mineral. petrogr. (Szeged), 36, 5–15.*

Széky-Fux, V., 1970: The Telkibánya mineralization and its Intra-Carpathian connections. *Budapest, Academic Press, 1–266.*

Széky-Fux, V., Pap, S. & Barta, I., 1985: Geological results of the boreholes Nagyecsed – 1 and Komoró 1 from the Nyírség, NE Hungary. *Bull. Hung. Geol. Soc., 115, 63–77.*

Sillitoe, R. H. & Hedenquest, J., 2003: Linkages between volcanotectonic settings, ore-fluid compositions, and epithermal precious metal deposits. *Soc. Econ. Geol., Spec. publ., 10, 1–29.*

Tőzsér, J., 1972: Záverečná správa z vyhľadávacieho prieskumu v Prešovsko-Tokajskom pohorí. *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–239.*

Velich, R., Husák, L. & Stránska, M., 1991: Veľký Brehov – gravimetria. Záverečná správa. *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–42.*

Velich, R., 1993: Interpretácia významnych anomálií tiažového poľa v širšom okolí Brehova; *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–23.*

Vityk, O., M. & Krouse, R. H., 1994: Fluid evolution and mineral formation in the Beregovo gold-base metal deposit, Transcarpathia, Ukraine. *Econ. Geol., 89, 547–565.*

Winchester, J. A. & Floyd, P. A., 1976: Geochemical magma type discrimination application to altered and metamorphosed basic igneous rocks. *Earth planet. Sci. Lett., 28, 459–469.*

Winchester, J. A. & Floyd, P. A., 1977: Geochemical discrimination of different magma series and differentiation products, using immobile elements. *Chem. Geol., 20, 325–343.*

Zlinská, A., 1992: Zur biostratigraphischen Gliederung des Neogens des Ostslowakischen Becken. *Geol. Práce, Spr., 96, 51–57.*

Zlinská, A., 1993: Biostratigrafické a paleoekologické hodnotenie horninových vzoriek v rámci úlohy Subvulkanické telesá Východného Slovenska a Brehov. *Manuscript. Bratislava, archive St. Geol. Inst. D. Štúr, 1–21.*

Zlinská, A., 2004: Charakteristika litostratigrafických jednotiek neogénu Východoslovenskej panvy na základe foraminifer. *Geol. Práce, Spr., 109, 131–141.*

Vulkanogénne stratiformné polymetalické a zlatorudné ložisko Brehov (východné Slovensko): jeho pozícia a genetické vzťahy v rámci vnútrokarpatsko-alpínskej kenozoickej metalogenetickej zóny

Submarinné vulkanogénne stratiformné sulfidické ložisko typu Kuroko v oblasti obce Brehov a rudné výskyty v oblasti obce Zemplín na východnom Slovensku reprezentujú nový typ hydrotermálnej mineralizácie vo vnútrokarpatsko-alpínskej kenozoickej metalogenetickej zóne. Ložisko Brehov reprezentuje komplexný stratiformný submarinný vývoj s konkordantne vystupujúcou hlavnou sulfidickou mineralizáciou vo vrchnej časti ložiska. Žilná mineralizácia sprevádzaná sulfidickými impregnáciami sa nachádza v spodnej časti mineralizovaného horizontu.

Vnútrokarpatsko-alpínsku kenozoickú metalogenetickú zónu tvorí šesť segmentov (zo západu na východ; obr. 1): 1. západoalpský segment oblasti Brusson; 2. východoalpský segment pohoria Taury; 3. západokarpatský segment; 4. segment „hraničnej zóny“ medzi Západnými Karpatmi a Východnými Karpatmi; 5. východoalpský segment; 6. segment Apusenských vrchov.

Segment „hraničnej zóny“ medzi Západnými Karpatmi a Východnými Karpatmi (obr. 2, 2a) pozostáva zo štyroch hlavných metalogenetických sektorov: a) brehovsko-zemplínsky metalogenetický sektor s dvomi doteraz známymi rudnými poľami (obr. 3 – 12), b) metalogenetický sektor v oblasti obce Telkibánya s jedným rudným poľom, c) metalogenetický sektor v oblasti obce Zlatá Baňa s dvomi rudnými poľami a výskytmi vzácneho opálu, d) metalogenetický sektor v oblasti Begaň – Beregovo – Kvasovo s tromi rudnými poľami. V tomto segmente „hraničnej zóny“ a tiež v segmente Západných Karpát sa výskyty kenozoickej mineralizácie viažu na priebeh transkrustálnych diskontinuít zo skorších orogénnych procesov, resp. sú spojením viacerých segmentov takýchto oslabených zón buď s ekvatoriálnym, alebo meridionálnym priebehom vytvárajúcim kontinuálne extenzné štruktúry, tzv. lineamenty. Napríklad submeridionálny hornádsky a ondavský lineament je zónou miocénnej vulkanickej aktivity a s ňou spätej mineralizácie (submarinnej alebo subaerickej): rudných polí Brehov, Zemplín, Zlatá Baňa, Dubník a Telkibánya. Medzi najbohatšie miocénne zlatorudné mineralizácie v „hraničnej zóne“ medzi Západnými Karpatmi a Východnými Karpatmi patria rudné polia Muzievo (Beregovo; 4 – 8 g/t) a Brehov (2 – 3 g/t).

Najpriaznivejšie podmienky na vývoj miocénnej ryolitovo-ryodacitovej vulkanosedimentárnej Au-Ag polymetalickej mineralizácie v hostiteľských horninových sekvenciách v plytko uložených vrstvách boli v rudných sektoroch Brehov – Zemplín a Begaň – Beregovo – Kvasovo. Rudonosné miocénne intruzívno-extruzívne komplexy v týchto rudných sektoroch sú vytvárané kremenitými dioritovými porfýrmi a extruzívno-intruzívnymi ryodacitovými telesami.

V rámci vnútrokarpatsko-alpínskej kenozoickej metalogenetickej zóny v nami skúmanom segmente „hraničnej zóny“ medzi Západnými Karpatmi a Východnými Karpatmi dokladáme, že miocénna vulkanogénna polymetalická a vzácnokovová mineralizácia má úplne alebo čiastočne submarinný pôvod. Predpokladá sa, že predovšetkým segment „hraničnej zóny“ medzi Západnými Karpatmi a Východnými Karpatmi disponuje geologickými predpokladmi na výskyt ďalších 2 – 4 podobných submarinných polymetalických a zlatorudných ložísk – s najväčšou pravdepodobnosťou v oblastiach interpretovaných submarinných kalder Sirník – Brehov a Zemplín – Somotor.

Regionálne súvislosti vychádzajúce z geologických, mineralogických a metalogenetických zistení v prípade polymetalického a zlatorudného ložiska Brehov indikujú, že vznik neogénnych rudných ložísk v zóne Karpát môže byť interpretovaný aj teóriou lineamentov ako celokôrových diskontinuít, ktoré sa vygenerovali pozdĺž priebehu skorších sutúrnych zón indikovaných ofiolitmi, prípadne s príspevkom viacerých ďalších oslabených zón korešpondujúceho smeru.

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