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REVIEW

ORE MINERALIZATIONS OF THE ĎUMBIERSKE TATRY MTS. (WESTERN CARPATHIANS, SLOVAKIA)

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Abstract: The Ďumbier part of the Nízke Tatry Mts. is known especially for the exploitation of Sb and Au ores. It belongs to the important ore districts within the Western Carpathians. It is built by a Variscan crystalline complex of the Tatric Unit, cover Mesozoic and Mesozoic nappes. Ore mineralizations were divided into 10 major types: the uranium, molybdenum, tungsten (scheelite), As-Fe-Au (arsenopyrite-pyrite with gold), Au-quartz, antimony with Fe, Cu, Pb, Sb, Bi, Ag sulphides, Pb (galena) — base-metal, siderite with Cu, Sb sulphides, Ba (barite) with Cu sulphides and the hematite one. Most of the known mineralization types can be linked to the evolution of Variscan basement metamorphic and magmatic rocks. Some mineralization types were recrystallized or remobilized from surrounding rocks during the Alpine metallogenetic cycle.

Key words: Nízke Tatry Mts., ore mineralization, metallogeny.

Introduction

The Ďumbier part of the Nízke Tatry Mts. (hereinafter the Ďumbierske Tatry Mts.) used to belong to important ore districts in the Western Carpathians. In the past it was known for its resources of gold (in alluvial sediments since the 13th century), later Fe and Cu ores (in the 18th and 19th century) and stibnite along with Ag and Au (first half of the 17th century until the end of the 20th century). The principal extracted metal was antimony. The deposit Magurka was in its flourishing times (1782–1867) one of the largest Sb-Au producers in Europe. Exploitation of the Dúbrava deposit terminated in 1993. It yielded about 25,000 tonnes of antimony, ranking the deposit among the medium-sized world deposits. In the last decades the galena deposit Jasenie-Soviansko and W-Au deposit Jasenie-Kyslá were explored. Up-to-date results of geological, metallogenetical and mineralogical research of the deposits Dúbrava, Magurka, Dve Vody, Jasenie-Kyslá and another occurrences are put in parallel with older data and opinions on their genesis. None of the deposits is exploited nowadays.

Geological settings

The western part of the Nízke Tatry Mts. — the Ďumbier anticline is built by a Tatric crystalline complex with a granitoid pluton in its northern part and metamorphic rocks in south. The crystalline is enveloped by Mesozoic, less Upper Paleozoic subautochthonous and Mesozoic allochthonous nappe sequences. Permo-Triassic terrigenous and evaporitic formations are known to occur at several places as the members of the sedimentary sequences. Mesozoic cover is locally infolded and sunken into the crystalline. The Tatric complexes meet the Veporic and Hronic ones along the Čertovica tectonic line at the S and NE margin (Fig. 1). Geological map of the Nízke Tatry Mts. (Biely 1992) summarizes the newest data about the geological settings.

The regionally metamorphosed rocks of the Western Carpathians yield radiometric ages (Rb/Sr) of 400-380 Ma (Cambel et al. 1990). The most common metamorphic rock type in the Ďumbierske Tatry Mts. is biotite and two-mica gneiss with banded texture, often plastically deformed. Biotite paragneisses are found in the southern part of the mountains. They were metamorphosed at 610–690 °C and 400–470 MPa (Krist et al. 1992). Biotite and two-mica gneisses with augen texture dominate in the western part. Regional metamorphism of the calc-silicate rocks produced erlans (Krist et al. 1992) and skarnoids (Pitoňák & Spišiak 1992).

Originally volcano-sedimentary rocks were changed into concordant bodies of amphibolitic gneisses and amphibolites several hundred metres long and up to 10 m thick. Hovorka et al. (1994) designated the banded amphibolitic rocks as the Leptyno-Amphibolite Complex, regarding them as polymetamorphosed recrystallized rock sequences of lower continental crust. The P-T conditions of metamorphosis were estimated by Janák et al. (1993) to 700–750 °C and 1000–1400 MPa corresponding to the environment of lower crust. The thermal maximum of the metamorphosis was dated to 400–450 Ma ($^{40}Ar/^{39}Ar$, Janák et al. l.c.).

Metasediments and metavolcanic rocks with metaantracite to semigraphite of organic origin (Molák et al. 1986) form long and narrow bodies in augen gneisses. According to fossil microflora (Planderová 1986) their age is Lower to Middle Devonian. Biotite phyllites to phyllitic schists of the type

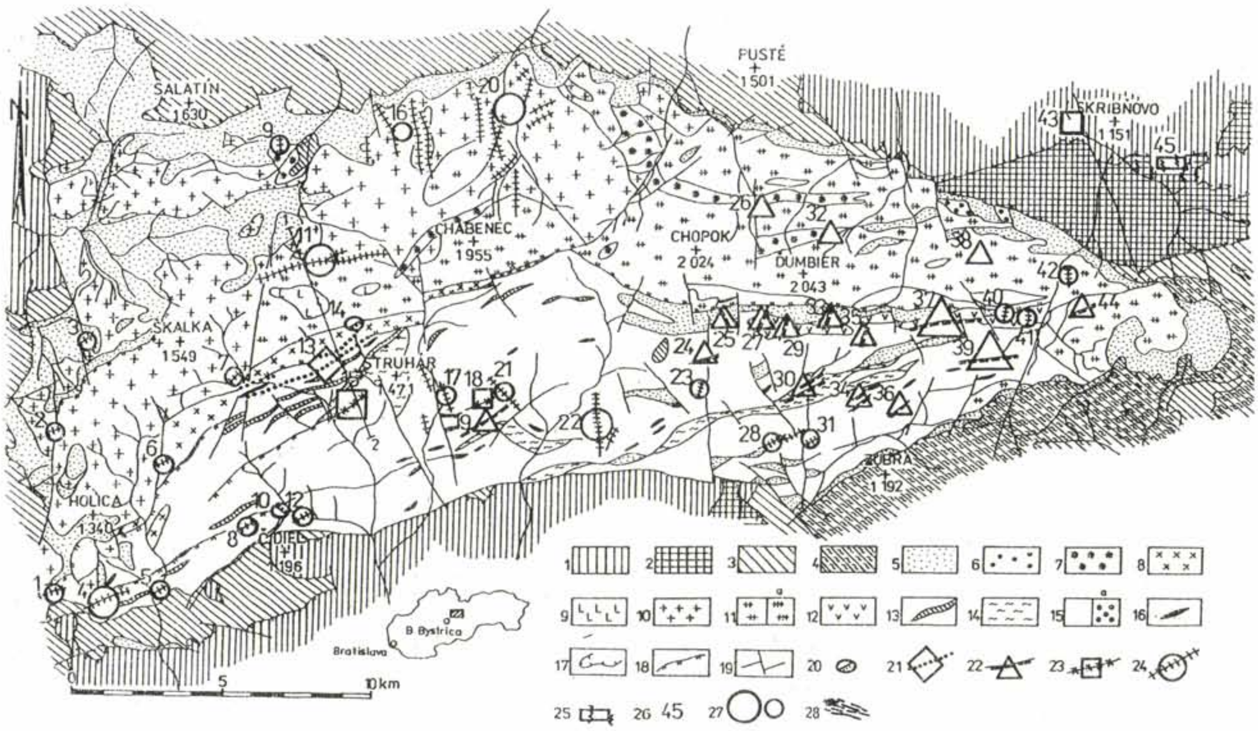

Fig. 1. Schematic map of the ore deposits in the Ďumbierske Tatry Mts. (compiled by Slavkay, geological situation adapted after Biely 1992). Hronic Unit: 1 — quartzites, sandstones, shales, limestones and dolomites (Triassic-Cretaceous), 2 — shales, sandstones, conglometares with beds mostly of basaltic volcanogenic rocks (Carboniferous-Permian); Veporic Unit: 3 — shales, sandstones, arkoses, dolomites and limestones (Permian-Cretaceous), 4 — granitoids and crystalline rocks, serpentinites, amphibolites (Paleozoic-Proterozoic ?); Tatric Unit: 5 — quartzites, shales, sandstones, limestones, dolomites (Triassic-Cretaceous), 6 — arkoses, graywackes (Permian), magmatic rocks, 7 — leucocratic granites, 8 — biotite granodiorites to tonalites with nebulitic structures, 9 — biotite and two-mica granites (type Latiborská hoľa), 10 — muscovite-biotite granodiorites to granites (type Prašivá), 11 — biotite tonalites to granodiorites (type Ďumbier), a — areas of anisotropic structure (in section, Fig. 3), 12 — biotite to two-mica granites (type Králička); Metamorphosed rocks: 13 — phyllites, metavolcanoclastic rocks, paragneisses with graphitic admixture, 14 — orthogneisses (type Struhár), 15 — biotite and two-mica gneisses with augen or banded structure, biotite paragneisses (in section, Fig. 3), 16 — amphibolite gneisses and amphibolites, 17 — nappe overthrust planes, 18 — upthrusts, 19 — geological boundaries and faults; Deposits (with indication of direction of the lode): 20 — gold ores, 21 — tungsten ores, 22 — iron ores, 23 — base metal ores, 24 — antimony ores, 25 — barite veins, 26 — locality number, 27 — large or important deposit, small deposit or occurrence, 28 — veins and stockworks with veinlets and disseminated mineralization (in section, Fig. 3), line 1-2 in the map marks the section in Fig. 3. *Locality number* (large or important deposit in bold letters): 1 — Hiadeľ (Sb), 2 — Korytnica (Sb, Au), 3 — Banskô, Liptovská Lúžna (Sb, Au), **4 — Medzibrod (Sb, Au)**, 5 — Javorinka (Sb), 6 — Ramžené (Sb, Au), 7 — Husárka (Sb), 8 — Seče (Sb, Au), 9 — Malé Železnô (Sb, Au, Mo), 10 — Jasenie-Suchý potok (Au), **11 — Magurka (Sb, Au)**, 12 — Jasenie-Suchá dolina (Sb, Au, Ag), **13 — Jasenie-Kyslá (W,Au)**, 14 — Špiglová dolina (Au), **15 — Jasenie-Soviansko (Pb, Ag)**, 16 — Rišianka (Sb, Au), 17 — Lomnistá-Studená dolina (Sb, Au), 18 — Ždiar, Dve Vody (Ba, Pb), 19 — Ždiar, Dve Vody (Fe, Cu), **20 — Dúbrava (Sb, Au)**, **21 — Dve Vody (Sb, Au)**, **22 — Lom (Sb, Au)**, 23 — Bystrianka (Sb), 24 — Standiarka (Fe), 25 — Trangoška /Ba, Fe, Pb, Cu), 26 — Demänovka (Fe), 27 — Zadné Komôrky (Fe, Cu), 28 — Hviezda, Mlynná dolina (Sb, Au), 29 — Raktár (Fe), 30 — Mlynná dolina (Fe), 31 — Mlynná dolina, Zingoty (Sb, Pb), 32 — Ludarová hoľa, Krečaková (Fe), 33 — Kačské, Mlynná dolina (Fe), 34 — Malý Gápeľ (Fe), 35 — Kralička, Mária (Fe, Ba), 36 — Jarabá-Trojička (Fe), **37 — Stará Boca-Pod Ištván (Fe)**, 38 — Liptovský Ján-Rovná hoľa (Fe, Ba), **39 — Vyšná Boca-Kliesňava (Fe)**, 40-41 — Vyšná Boca, Chopec (Sb, Au, Pb, Zn, Cu), 42 — Nižná Boca (Sb, Au, Cu), 43 — Malužiná, Olovienka (Pb), 44 — Vyšná Boca-Fišiarky (Fe), 45 — Malužiná (Ba).

Klinisko are known to occur locally in the northern part between leucocratic granites and subautochthonous Mesozoic.

Biotite tonalites to granodiorites (the Ďumbier type) prevail in the eastern part of the granitoid pluton. Temperature of crystallization of their magmatic minerals is 690-730 °C. Equigranular muscovite-biotite granodiorites to granites predominate in the western part. They are locally porphyric, with xenoliths of crystalline schists. Crystallization temperature was estimated to 670-700 °C. Both major granitoid types were dated by the Rb/Sr method to 368 ± 22 Ma, IR_{Sr} = 0.7078(4) (Cambel et al. 1990).

Biotite to two-mica granites (the Králička type) are developed in a narrow zone of E-W strike westward from the Vyšná Boca village. Crystallization temperature is 670-690 °C. They were affected by alkaline metasomatism. Cambel et al. (1990) determined its age to 365 ± 17 Ma (Rb/Sr). According to their geological position (Siegl 1976) and the IR_{Sr} = 0.71571(6) they are closely related to the ambient metamorphosed rocks. Crystalline rocks (migmatites) gradually pass into the granitoids of the Králička type.

Muscovite-biotite granites (the Latiborská type) are found in the area SW from the elevation point Chabenec as bodies in granodiorites of the Ďumbier type. The southern margin of the pluton is rimmed by a zone of biotite granodiorites to tonalites with nebulitic structure considered by Siegl (1976) to represent the primary pluton border with gradual transition to granitoids. Less abundant rock types are leucocratic granites, quartz diorites to diorites, porphyres, porphyrites, lamprophyres as well as pegmatites and aplites.

Peraluminous granites of the Králička type and the Latiborská type belong to the S-type granitoids, while the Ďumbier and Prašivá granitoids represent metaluminous I-type granodiorites to tonalites (Petrík et al. 1993).

Rigid and ductile tectonic deformations are developed in two chief systems, the first one having appr. meridional (N-S to NNW-SSE) direction, the second one latitudinal (E-W to NE-SW) direction. The primary age of the deformation structures is Variscan but they were reactivated during the Alpine orogeny. They played decisive role in the formation of hydrothermal sulphide mineralization (Siegl 1976).

The preliminary $^{40}Ar/^{39}Ar$ results suggest that regionally penetrative high-temperature mineral assemblages and associated ductile structural elements within basement elements of the Tatric basement Nappe Complex are likely all largely related to Late Paleozoic (Variscan) tectonothermal activity: 332 Ma (P.A.) and 322 Ma (T.G.A.) from muscovite of mylonitic orhogneisses (Bystrá dolina Valley). The Alpine tectonothermal record appears to be restricted to discrete intermediate- or low-temperature ductile shear zones developed in basement elements, and a relatively low-temperature metamorphism and deformation in Permian-Mesozoic structural cover (80-100 Ma) (Dallmeyer et al. 1993).

The ore mineralization

Localization of the hydrothermal deposits depended upon the nature of structural and lithological factors from the times of their development in the original sedimentary basins to the orogenesis and Alpine shortening of the crust in their allochthonous position.

Andrusov et al. (1951) categorized in their comprehensive report the ore formations into few chief types: *1)* formation of carbonate Fe-ores (siderite and ankerite veins with barite and pyrite, tetrahedrite and chalcopyrite), *2)* fm. of quartz-Sb-Au ores, *3)* fm. of quartz veins with Pb minerals, *4)* gold-bearing pyrite-arsenopyrite fm. Many further authors (Kravjanský 1959; Hak & Losert 1963; Hak 1966; Čillík 1978; Slavkay 1988 and others) dealt with the problematics of genesis and age of the ore formations. Recent detailed studies of exploited deposits along with studies of the surface and drill-hole samples enabled to gather valuable genetical information. On the basis of these detailed works we distinguish 10 basic mineralization in the Ďumbierske Tatry Mts. (Tab. 1). Various ore mineralization types are often found together in one deposit, however, they differ in genesis and age.

U-mineralization. Uraninite originated in the Dúbrava (20) deposit in the final stages of the formation of granite muscovite pegmatite. Uraninite forms up to 1 cm large scarce euhedral crystals in feldspars and muscovite. Pegmatite veins are transected by younger scheelite and quartz-stibnite veins. Uraninite mineralization in pegmatite may be regarded as the oldest ore mineralization type within the Ďumbierske Tatry Mts. (Chovan 1990a). Stankovič & Jančula (1987) found minute autunite crystals probably of supergene origin in the Malé Železné (9) deposit on a fracture of a quartz-stibnite vein in muscovite granite.

Mo-mineralization. Occurrences of this mineralization type are seldom. Molybdenite was found in the Malé Železné (9) deposit in muscovite pegmatites and aplitic granites of Variscan age that intrude Lower Paleozoic LT metamorphosed crystalline rocks. Aplitic granites bear signs of greisenization. Pegmatite veins with molybdenite are intersected by younger quartz-stibnite veins with N-S direction (Michalenko 1960). Rare quartz-molybdenite veinlets occur in granitoids of the Dúbrava (20) deposit. Their relationship to other mineralization types is unclear, however, they belong to the higher-thermal, older types (Chovan et al. 1995).

W (scheelite) mineralization. Occurrences of scheelite (and gold) mineralization are known in the area of Jasenie and in the Sb deposit Dúbrava. The most promising ones are those at the southern slopes of the Nízke Tatry Mts. in a giant zone more than 15 km long and 500-1000 m wide (Pulec et al. 1993). The area of Jasenie-Kyslá (13) is the most significant one within the zone. It is built predominantly by banded and augen migmatites with concordant layers and lenses of amphibolites and amphibolitic gneisses. Granitoids outcrop northward from the productive zone. Three types of mineralization are developed: *1.* hydrothermal vein and stockwork type — quartz veins up to 40 cm thick with NE-SW direction, veins of several m thickness (up to 5 m) have N-S direction and dip to E (Fig. 2, ore structures 1, 3). The veins transect various crystalline rocks but those located in amphibolites contain the richest scheelite and gold ores. *2.* Stockwork and impregna-

Table 1: Principal types of mineralizations in the Ďumbierske Tatry Mts.

MINERALIZATION	DEPOSITS	COUNTRY ROCKS
URANIUM—uraninite, autunite	Dúbrava (20), Malé Železné (9)	pegmatites
MOLYBDENUM—molybdenite	Malé Železné (9), Dúbrava (20)	pegmatites, granodiorites
TUNGSTEN—scheelite	Jasenie-Kyslá (13), Dúbrava (20)	gneisses
As-Au—asp, py±invisible gold	Dúbrava (20), Magurka (11), Jasenie-Kyslá (13), Soviansko (15), Medzibrod (4)	granodiorites, gneisses
GOLD	Magurka (11), Špiglová (14), Mlynná dolina (28), Dve Vody (21)	granodiorites, gneisses
ANTIMONY—stibnite (asp+py (Au), gold, sph, ga, Pb-Sb sulph, td (Ag), Cu-Pb-Sb (Bi) sulbarite)	Dúbrava (20), Magurka (11), Lom (22), Medzibrod (4), Malé Železné (9), Rišianka (16), Dve Vody (21), Mlynná dolina (28), Lomnistá (17)	granodiorites, gneisses
BASE METALS—galena (Ag), sphalerite, barite	Soviansko (15), Ždiar-Dve Vody (18), Malužiná-Olovienka (43)	gneisses, Triasic sediments
Fe-SIDERITE—Cu, Sb, Pb, Bi sulphide	Vyšná Boca (39), Ždiar-Dve Vody (19), Trangoška (25)	gneisses, granodiorites, Triassic sediments
Ba—barite + Cu sulphide	Malužiná (45)	Permian basalts sediments
Fe—hematite	Magurka (11), Jasenie (15), Trangoška (25)	granodiorites, gneisses, Triassic sediments

Abbreviations of minerals: asp — arsenopyrite, py — pyrite, sph — sphalerite, ga — galena, td — tetrahedrite, sulph — sulphosalts

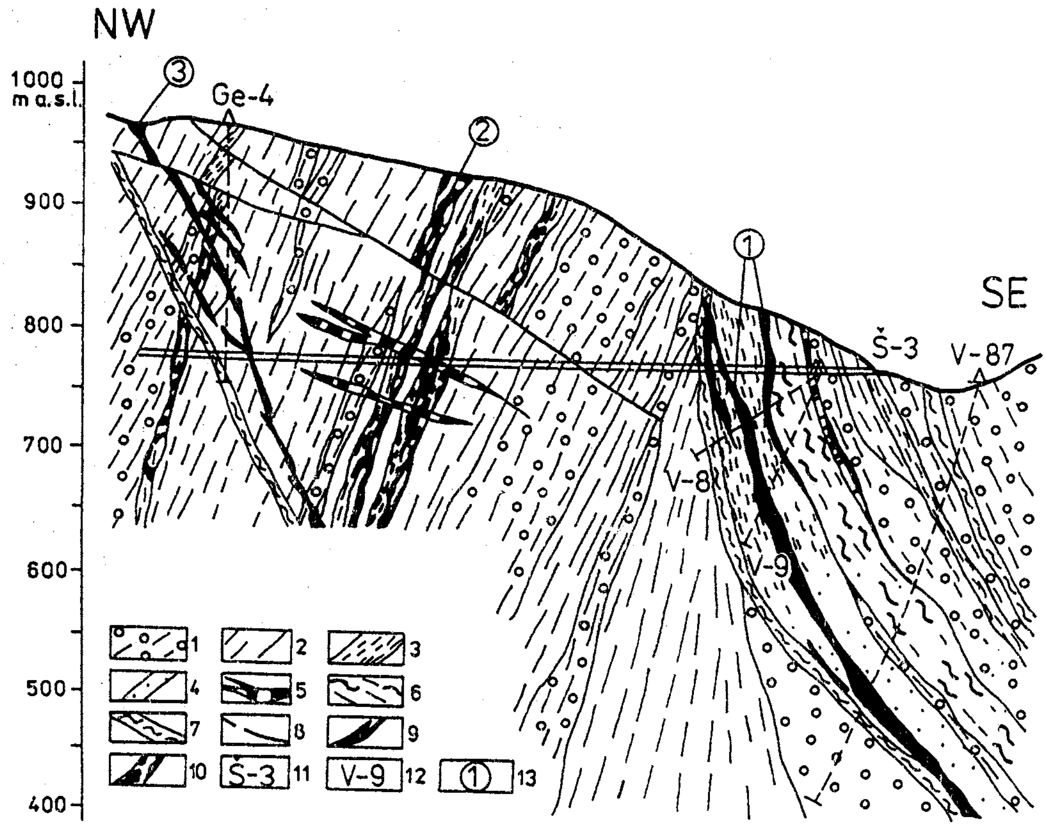

Fig. 2. Geological section across the ore zone Jasenie-Kyslá (W, Au) in the area of the adit S-3 (adapted after Bláha & Barton 1991). 1 — ophtalmitic migmatites, 2 — stromatitic migmatites, 3 — biotite paragneisses, 4 — amphibolites, 5 — dykes of leucocratic granites, 6 — mylonitized stromatitic migmatites, 7 — major mylonitized faults, 8 — faults, 9 — quartz-scheelite mineralization, 10 — scheelite mineralization in amphibolites, 11 — adit Š-3, 12 — realized drill-holes, 13 — designation of ore structures.

tion type is focused along the chief tectonic structures with lower, only locally elevated W content. Silicified zones are about 2 m thick. *3.* Dispersed scheelite can be found in various rock types, most often in amphibolites (Fig. 2, ore structures 2, 3). From the economical point of view it is quite insignificant (Molák & Pecho 1983).

Accesory chromite and magnetite in metaultramafic rocks and very rare quartz-carbonate veinlets with pyrite, chalcopyrite, tetrahedrite, sphalerite, galena, ullmanite and gersdorffite is reported from the deposit Jasenie-Kyslá (Stankovič & Jančula 1982; Spišiak et al. 1988).

Mineralization was formed during two epochs: Hercynian age (305 ± 4 Ma, Ar/K from biotite) is assigned to the pegmatites, scheelite, gold, sulphide and carbonate mineralization. Remobilized carbonate-sulphide mineralization is of Alpine age (78.4-81.9 Ma, Ar/K from sericite) (Bláha 1994).

Short and thin (max. 10 cm) quartz-pyrite veinlets with E-W strike occur at the Dúbrava (20) deposit (Čillík et al. 1979). They contain scheelite in those parts where they intersect migmatite lenses. Occasionally scheelite occurs as impregnations in migmatites (Chovan et al. 1995). The younger sulphide mineralization penetrates among the pyrite as well as scheelite grains. It is represented by Fe-dolomite, bismuthinite, tetradymite, chalcopyrite, chalcostibite and tetrahedrite. Gold in quartz is rare (Chovan & Michálek 1988). No scheelite was found in the quartz-sulphide veins of the main stibnite stage. Quartz-scheelite and quartz-sulphide vein systems are separated tectonically and younger age of the sulphide veins was confirmed at each intersection.

As-Au (arsenopyrite-pyrite mineralization with "invisible" gold). Arsenopyrite mineralization is present in almost every occurrence of stibnite ores as the older, higher thermal one. There is evidence of similar position of this mineralization type also from the galena deposit Soviansko (15), in the scheelite deposit Jasenie-Kyslá (13) and elsewhere. This mineralization type is known in large quantities also from the deposit Medzibrod (4) (Fig. 9). Pyrite-arsenopyrite mineralization at the Dúbrava (20) deposit is the oldest one among the sulphide mineralization. It borders the chief stibnite veins. Fine-grained arsenopyrite and pyrite forms impregnations in gray quartz and hydrothermally altered wall rocks. Euhedral arsenopyrite is infrequently seen also on separate quartz veinlets. The "invisible" gold concentrates especially in arsenopyrite (avg. 100 ppm), less in pyrite. Both arsenopyrite and pyrite show typical growth zonality.

Mössbauer spectra of arsenopyrite from the Dúbrava deposit show two IS values: a minor one (-0.45 mm/s) corresponding to metallic gold (Fig. 4a) and a notable one (+3.54 mm/s) corresponding to chemically bound gold. The IS values from the samples of the Jasenie deposit (-0.97 mm/s) are shifted toward the region of metallic gold (Fig. 4b) (Andráš & Ragan 1995).

Au-mineralization. This mineralization type is most commonly found together with the stibnite mineralization in the

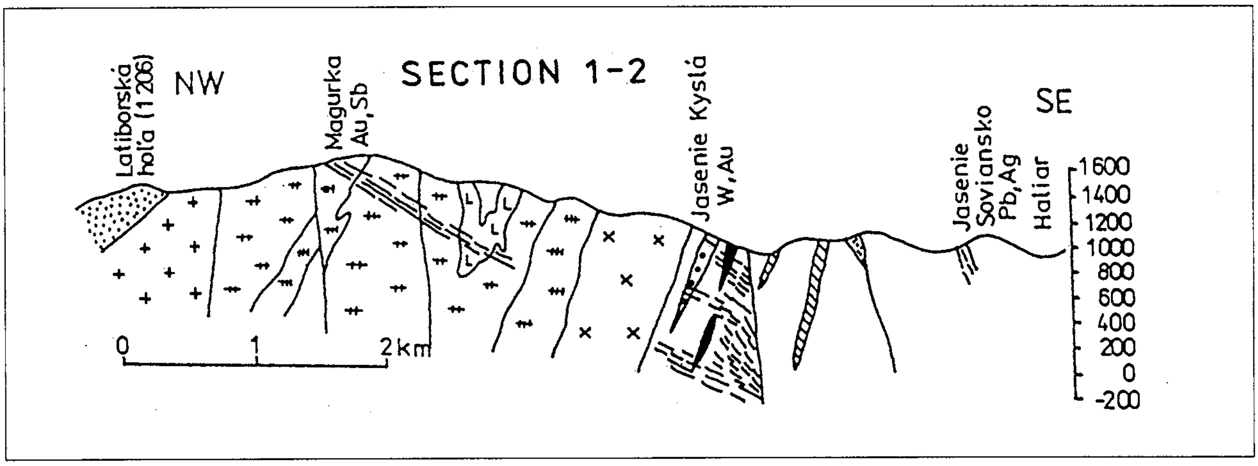

Fig. 3. Schematic section 1-2 of the Magurka, Jasenie-Kyslá and Soviansko deposit. Explanations see Fig. 1.

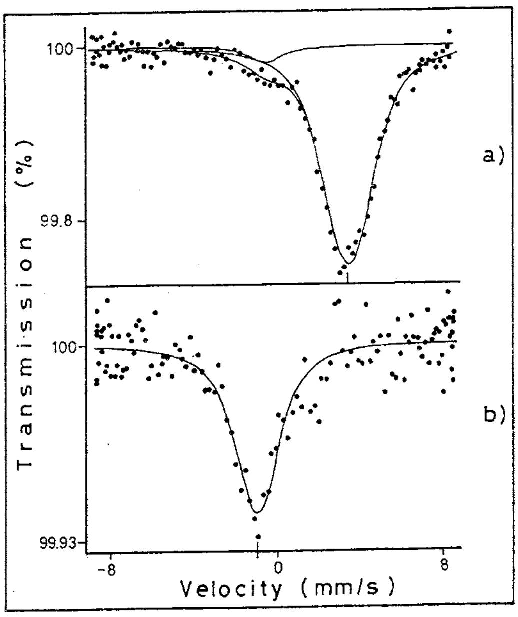

Fig. 4. Mössbauer ^{179}Au spectra of gold-bearing arsenopyrites from a — Dúbrava, b — Jasenie-Kyslá deposit (after Andráš & Ragan 1995).

deposits Magurka (11), Dve Vody (21), Mlynná dolina (28) as well as in the scheelite deposit Jasenie-Kyslá (13). Separate occurrences of the Au-mineralization are known in the area of Jasenie-Suchá dolina Valley (10) and Špíglová dolina Valley (14) where the ore grades from drill-hole and underground samples reach 3.5-5.5 ppm Au.

The most important representative of the quartz-gold mineralization is the deposit Magurka (11). The vein system is made up by parallel veins with E-W strike dipping 30-40 °C to S (Fig. 3). Their thickness varies from several cm to 4 m, in average 0.5 m. The vein system is about 3 km long and located in granitoid rocks. Mining fields were about 1600 m long, 300 m wide with vertical extent of 400 m. The upper portions of the veins were gold-bearing, the lower ones were dominated by stibnite (Koutek & Pouba 1956; Meier 1868).

Mineralization was formed during several stages. The first stage is typical of impregnations of minute anhedral and subhedral arsenopyrite crystals. The second one is the most significant gold carrier. Gold grains and leaves occur in quartz

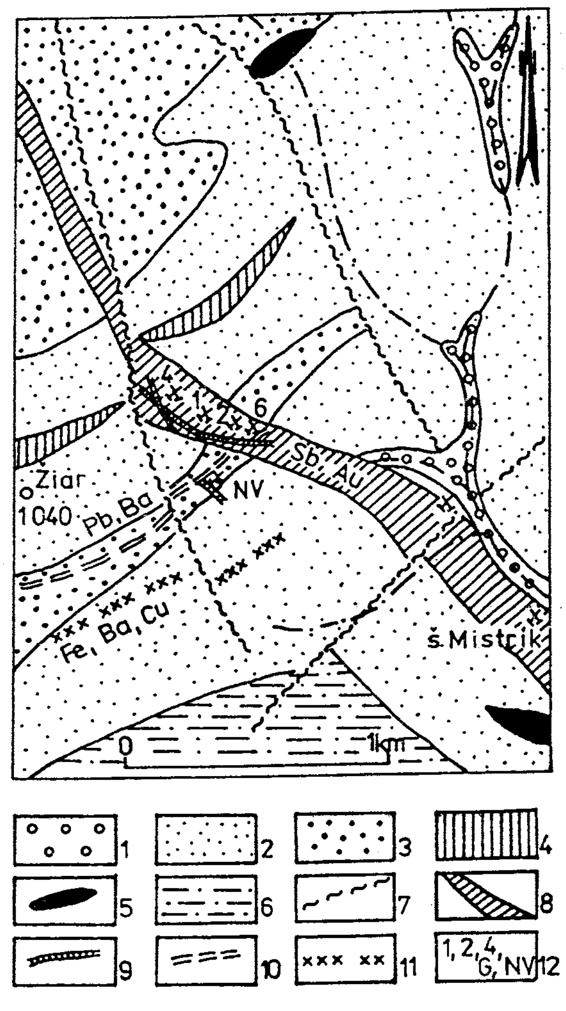

Fig. 5. Mineralized zones in the vicinity of the Dve Vody deposit (adapted by Slavkay after Michálek 1992). 1 — fluvial flood loams or gravelly loams (Holocene), 2 — biotite and two-mica gneisses with banded structure, 3 — biotite and two-mica gneisses with augen structure, 4 — metasediments and metavolcanoclastic rocks with subgraphitic admixture, 5 — amphibolites, 6 — orthogneisses (type Struhár), 7 — main faults, 8 — zone of Sb, Au ores, 9 — stibnite veins, 10 — zones of Pb, Cu ores, 11 — zone of Fe, Ba, Cu ores, 12 — adit numbers.

together with scarce arsenopyrite and pyrite. The third stage bears two mineral assemblages, the older one being composed of quartz-carbonate gangue and pyrite, sphalerite, galena, bournonite and Pb-Sb sulfosalts with higher Pb content (boulangerite), while the younger one holds stibnite and Pb-Sb sulfosalts with lower Pb content (zinckenite). Small portion of gold crystallized in this stage. Probably still younger is the Ag-bearing tetrahedrite stage with chalcopyrite, chalcostibite, pyrite, sphalerite and occasional gold with elevated Ag content. An independent tetrahedrite mineralization (different chemical composition of tetrahedrite) underlies the chief vein system at the locality Striebornica. Hematite mineralization is the youngest one (Chovan et al. 1995).

Certain part of gold was found to be chemically bound in arsenopyrite in the oldest mineralization type (WR analysis up to 8 ppm Au). Metallic gold in quartz has high fineness with little admixture of Ag, sometimes also Hg. Its average composition (34 analyses) is 95.7 wt. % Au, 2.3 % Ag. Another type of metallic gold is closely related to the younger sulphide mineralization where gold often fills fractures in sulphides. Its average composition (12 analyses) is 88.6 wt. % Au and 9.4 wt. % Ag (Chovan et al. l.c.).

The deposits Dúbrava and Magurka seem to be similar regarding the development of the mineralization. However, the veins in Magurka contain considerable quartz-gold assemblage. Alluvial sediments of the Ľupčianka creek below the Magurka deposit are enriched by gold leaves and in the past they were exploited for gold. Chemical composition of primary gold and gold from placers does not differ.

Ore structure of the Au-Sb deposit Dve Vody (21) is about 700 m long with WNW-ESE strike and dip to NNE (Fig. 5). Veins of 0.6-1.3 m thickness and stockworks in biotite and two-mica gneisses with small amphibolite lenses are composed of quartz, arsenopyrite, pyrite, sphalerite, ankerite, stibnite of two generations, Pb-Sb sulfosalts and calcite (Kantor 1948). Minor amounts of chalcostibite and other sulphides are present too. Gold grades are exceptionally as high as 60 ppm, usual content is 5-12 ppm. Gold is seen mainly as gold grains. Galena and lesser amounts of boulangerite are found in the E-W trending veins (Hak 1966). NE-SW structures carry, in turn, siderite mineralization with quartz and tetrahedrite with elevated silver content. The siderite mineralization is considered to be younger than the Au-Sb mineralization (Slavkay 1989).

Gold from the deposit Jasenie (13) was reported to occur as: *a)* anhedral grains up to 0.5 mm large in quartz together with scheelite mineralization, *b)* interstitial grains in quartz, *c)* aggregates of gold grains with tetrahedrite, chalcopyrite, Bi-Te minerals, *d)* inclusions in arsenopyrite, pyrite and chalcopyrite. Gold is usually homogeneous with chemical composition Au 88.6-99.9 wt. % and Ag 0.4-9.6 wt. % (Bláha 1994).

Sb-mineralization. Antimony deposits in the Nízke Tatry Mts. were the most important ones from the viewpoint of exploitation. They served as sources of antimony, silver and gold. The deposits Magurka (11), Dúbrava (20), Medzibrod (4) and Lom (22) were the most intensively exploited ones. Numerous smaller deposits and occurrences include especially Rišianka (16), Malé Železné (9), Husárka (7), Lomnistá (17), Dve Vody (21), Mlynná dolina (31), Boca (42) and others (Fig. 1). The ore mineralization is focused into hydrothermal veins with transitions into stockwork and impregnation types. Quartz veins with either N-S or E-W strike are from several cm up to 4 m thick. They are located in mylonitic zones, along faults in Variscan granitoids, metamorphic rocks

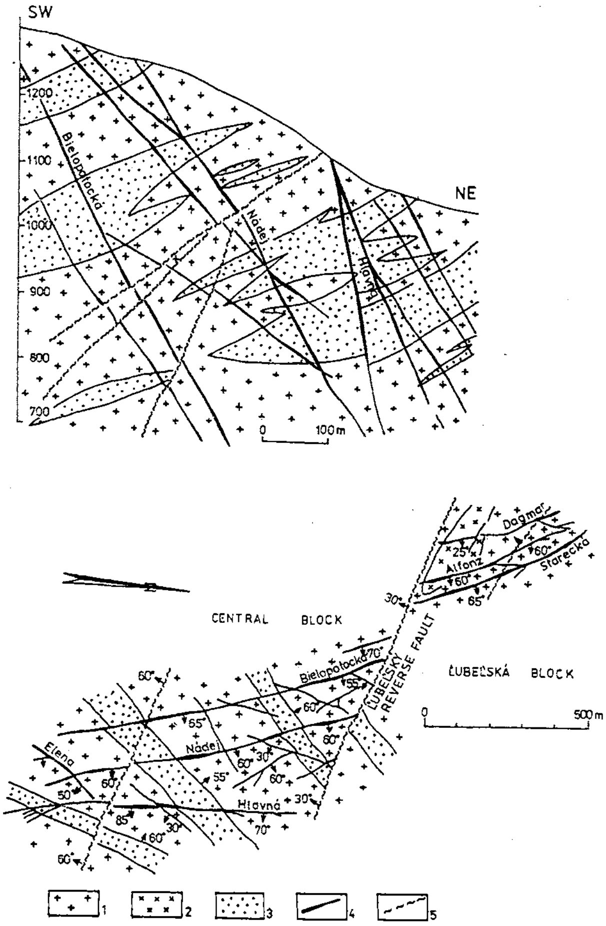

Fig. 6. Schematic section and structural scheme of the Dúbrava Sb deposit (after Michálek 1992). 1 — muscovite-biotite granodiorites to tonalites (type Prašivá), 2 — leucocratic granites, 3 — migmatites and gneisses, 4 — main veins of antimony ores with their names, 5 — faults.

and migmatites. The deposit Medzibrod (4) is an exception, composed of bedded veins and lenses in phyllonites.

The deposit Dúbrava (20) yielded greatest quantities of antimony over the last four decades. Biotite granodiorites and tonalites are the main rock types in the area of the deposit. Granites, aplites and pegmatites are less abundant. Migmatites and gneisses form elongated bodies representing relics of the crystalline cover (Fig. 6). The best quality ores originated at the intersection of the chief vein system of N-S strike with diagonal veins. Besides, Sb-mineralization occurs also in veinlets and stockworks in mylonite zones or nearby the quartz veins (Michálek 1986).

The oldest U-mineralization in pegmatites was followed by several stages of hydrothermal mineralization. (Chovan et al. 1995). Molybdenite mineralization and the quartz-pyrite veins belong to the oldest and the highest thermal ones. The oldest mineralization of the chief N-S veins consists of arsenopyrite and pyrite with the "invisible" gold, chemically bound predominantly in arsenopyrite. Sb-mineralization was divided into the older sphalerite-zinckenite and younger stibnite substage. Younger tetrahedrite mineralization occurs separately on NE-SW veins or it shares the vein structures with the Sb mineralization. Tetrahedrite, less zinckenite are Ag-bearing. Tetrahedrite is accompanied by common bournonite, chal-

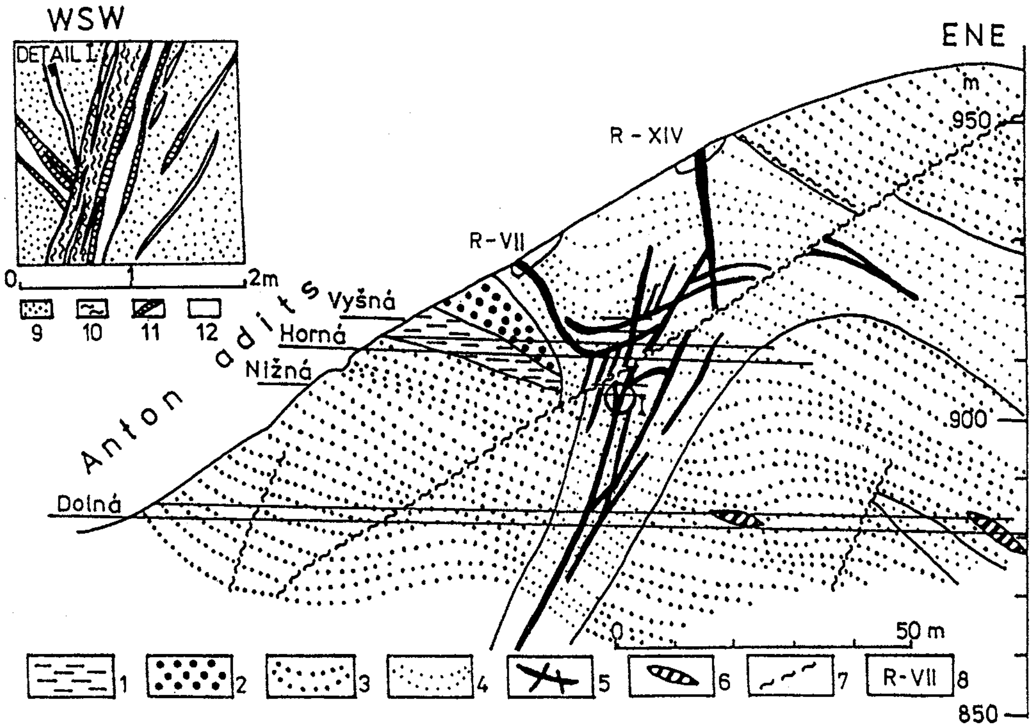

Fig. 7. Schematic section of the Lomnistá deposit and detail of stibnite vein from the Horný Anton adit (Slavkay 1971). 1 — biotite paragneisses, 2 — biotite and two-mica gneisses with augen structure, 3 — biotite and two-mica gneisses with banded structure, 4 — hydrothermally altered gneisses, 5 — bedded veins and veinlets of Sb ores, 6 — pegmatites and aplites, 7 — faults, 8 — surface exploration works. Detail of stibnite vein: 9 — hydrothermally altered composite gneisses, 10 — mylonite, 11 — quartz, 12 — stibnite.

costibite, less chalcopyrite, metasomatic Bi-chalcostibite, "horobetsuite" and Pb-Sb-Bi sulfosalts. Barite is scarce, present either on the tetrahedrite veins or in separate lenses without ore minerals. Barite was found also in the quartzites of the Mesozoic sedimentary cover. Impregnation and stockwork mineralization in close surroundings of the veins consists of gold-bearing pyrite, arsenopyrite and stibnite. Both its age and genesis is equal to that of the vein mineralization.

Zone of bedded veins and coulisse-like lenses of the deposit Medzibrod (4) is appr. 200 m wide and located in phyllonites (Fig. 9) that are relics of retrograde metamorphosis of migmatitized gneisses. The drill-holes samples revealed presence of black shales with disseminated pyrite-arsenopyrite mineralization with 0.8-3.8 ppm of Au. Mineralization is spatially related to the black shales. It encompasses quartz, less carbonate, stibnite, pyrite, arsenopyrite, berthierite, jamesonite and rare tetrahedrite, chalcopyrite and sphalerite. Gold is confined especially to the pyrite-arsenopyrite assemblage. In 1938-1944 the deposit rendered 57 kt of ore with 2.8 wt. % Sb and 4.48 ppm Au.

Mineralization at the Lom (22) deposit is bound to a dislocation of N-S direction (Fig. 8). Vein zone is situated in gneisses, attaining length of about 600 m, thickness 0.2-2 m and known vertical extent 200 m. The major ore mineral was stibnite, less common were quartz, carbonate and pyrite. Rare minerals are arsenopyrite, sphalerite, hematite, zinckenite and gold.

Hydrothermal veins with the Sb-mineralization at the Lomnistá (17) deposit are located in paragneisses and synkinematic migmatites, less in quartz paragneisses (Fig. 7). True veins filled the fan-like fractures genetically related to folding. Direction of the true veins is parallel to the b-axes of the NNW-SSE trending folds with fold planes dipping to NE in anticlinal and synclinal zones. Bedded veins are parallel to the schistosity which is identical to the original stratification of the rocks. A typical saddle vein was formed in the synclinal turn (Slavkay 1971). Seven ore bodies 20-350 m long with known true length of 80 m are built by quartz, Fe-dolomite and stibnite, less pyrite, arsenopyrite, sphalerite, chalcopyrite, berthierite, jamesonite, rarely by pyrrhotite and gold. Ore grades vary in different portions of the veins: Sb 1.5-12 wt. %, As 0.16-0.63 wt. %, Au 0.1-6.3 ppm, Ag 8-30 ppm. Another fold system of NE-SW direction with axis planes dipping to SE is parallel to the structures in Mesozoic rocks. It was generated by the Alpine orogenesis (Slavkay 1971). The two systems coincide in the area of the deposit Dve Vody where the NW-SE structures bear Sb-mineralization and the NE-SW ones consist of veins with Fe, Ba, Cu and Pb minerals.

Base-metal. Vein quartz-galena mineralization is known from the deposits Jasenie-Soviansko (15) and Ždiar-Dve Vody (18). Galena accompanies siderite mineralization in Trangoška and Sb-mineralization in Magurka and elsewhere. Base-metal hydrothermal metasomatic mineralization in Malužiná-Olovienka (43) is developed in Triassic dolomites. The most important representative is the deposit Jasenie-Soviansko (15). Complicated stockwork includes the main vein and nine underlying stringers in a zone of crushed biotite and two-mica gneisses with banded texture (Fig. 10). Single veins are 0.3-1.2 m thick and they reach the depth of more than 200 m. They are clustered in a stockwork of 800 m length, 50-150 m width with appr. ENE strike and 60-70° dip to SE. Mineralization originated during five paragenetical stages (Pouba & Vejnar 1956) — in a quartz-pyrite, older ankerite,

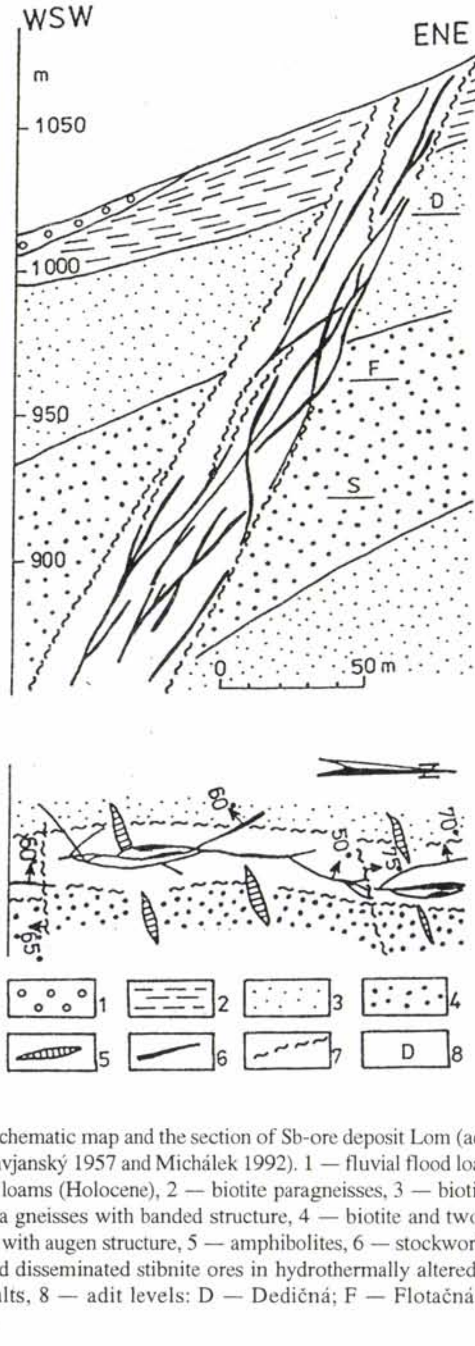

Fig. 8. Schematic map and the section of Sb-ore deposit Lom (adapted after Kravjanský 1957 and Michálek 1992). 1 — fluvial flood loams or gravelly loams (Holocene), 2 — biotite paragneisses, 3 — biotite and two-mica gneisses with banded structure, 4 — biotite and two-mica gneisses with augen structure, 5 — amphibolites, 6 — stockwork with veins and disseminated stibnite ores in hydrothermally altered zone, 7 — faults, 8 — adit levels: D — Dedičná; F — Flotačná; S — Spodná.

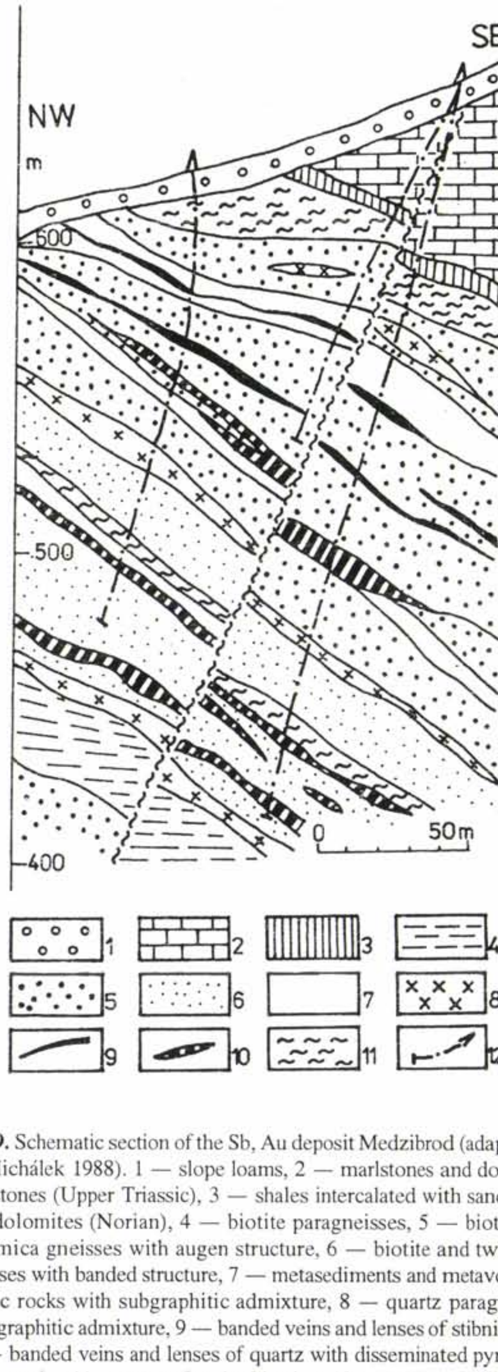

Fig. 9. Schematic section of the Sb, Au deposit Medzibrod (adapted after Michálek 1988). 1 — slope loams, 2 — marlstones and dolomitic limestones (Upper Triassic), 3 — shales intercalated with sandstones and dolomites (Norian), 4 — biotite paragneisses, 5 — biotite and two-mica gneisses with augen structure, 6 — biotite and two-mica gneisses with banded structure, 7 — metasediments and metavolcanoclastic rocks with subgraphitic admixture, 8 — quartz paragneisses with graphitic admixture, 9 — banded veins and lenses of stibnite ores, 10 — banded veins and lenses of quartz with disseminated pyrite and arsenopyrite, 11 — zone of mylonitization, 12 — prospect drill-hole.

base-metal, younger ankerite and a barite one. The chief ore mineral of the base-metal stage is galena occuring with pyrite, sphalerite, tetrahedrite, semseyite, jamesonite, bournonite and chalcopyrite. Quartz-hematite and ankerite-arsenopyrite mineralizations occupy separate veins. They predated formation of the base-metal veins.

Relatively rich galena ores are known from the occurrence Ždiar-Dve Vody (18). Quartz-pyrite-galena veinlets of ENE strike are spatially confined to the quartz-siderite veins. The quartz-barite veins are located in overlying rocks. Veinlets of galena and boulangerite in the Nová Vyšná adit of the Dve Vody (21) deposit dip to SW and intersect older stibnite veins (Kantor & Rybár 1964). Galena mineralization is in all the other Sb deposits of the Nízke Tatry Mts. older than stibnite (Hak 1966; Chovan 1990 etc.). Galena is usually Ag-bearing.

Hydrothermal Pb-mineralization in Malužiná-Olovienky (43) lies in dislocations of Middle Triassic limestones and dolomites of the Choč Nappe. The major mineral is galena sphalerite and chalcopyrite are less abundant. Alpine age of the mineralization is assumed.

Fe-siderite mineralization. Numerous occurrences are found in the area of Boca and Ďumbier, mostly in various types of crystalline schists, less in granitoids but also in Triassic (Trangoška). Eastward from this area, in the surroundings of the

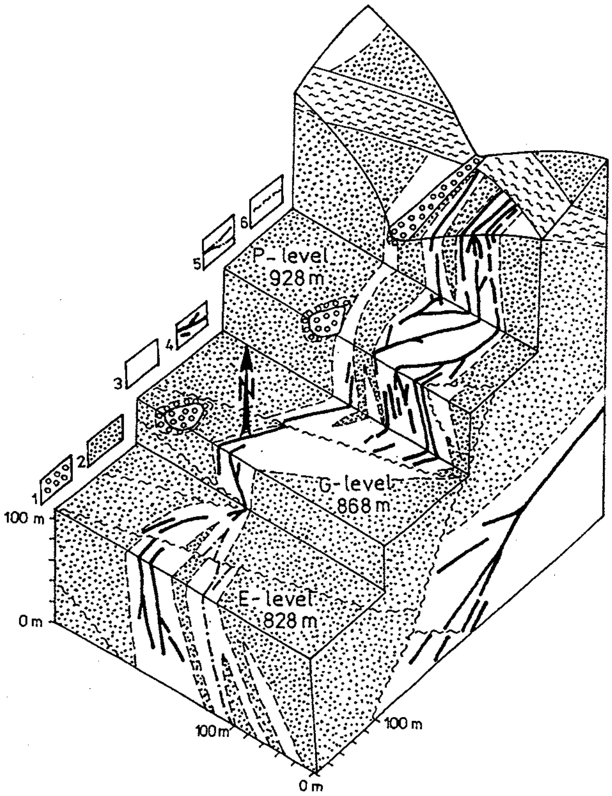

Fig. 10. Block diagram of the Jasenie-Soviansko Pb, Ag, Ba deposit (after Slavkay 1959). 1 — fluvial flood loams or gravelly loams (Holocene), 2 — biotite and two-mica gneisses with banded structure, 3 — hydrothermally altered zone, 4 — quartz veins with barite and base metal mineralization, 5 — quartz veins, 6 — fault.

Polomka village, siderite veins pass from the crystalline to Lower Triassic.

Quartz-siderite veins of the deposit Stará Boca-Pod Ištván (37) belong to the most important ones. They can be traced from the Kumštové sedlo Saddle in the ENE direction in length of about 2 km. They dip to SSE. A parallel vein system — the Kliesňava (39) deposit is almost 2 km long and explored to the depth of 150 m. Both vein structures are located in granitoids and banded biotite-two-mica gneisses. Quartz-siderite infilling is accompanied by barite and ankerite, more rarely aggregates of pyrite, chalcopyrite, tetrahedrite and hematite.

Quartz-barite-siderite-sulphide and barite-sulphide vein in Trangoška (25) has a different position (Fig. 11). It is located in quartzites, quartz, arcose or graywacke sandstones of the Lužná sequence (Scythian) or it follows their contact with coarse-grained muscovite pegmatite. It is several cm up to 1.5 m wide, with NNW-SSE direction and dip 75° to WSW. The most abundant sulphides are tetrahedrite, pyrite and galena. Smaller barite veins in Lower Triassic sandstones of N-S strike with admixture of pyrite and galena are known from the mouth of the Trangoška creek into Bystrianka.

Ba-barite. It occurs as separate veins in the Malužiná (45) deposit in Permian tholeiitic basalts and andesites with intercalations of volcanoclastic rocks of the second eruptive phase of the Malužiná sequence (Hronic Unit, Thuringian). Hydrothermal veins, lenses, stringers are confined to the N-S fractures of NNE-SSW duplexes. They dip 30–80° to W. Their length does not exceed 50 m, they are 40–180 cm thick, composed of white, gray or pinkish barite with quartz, less carbonate and rock fragments. Moreover, they contain 10–20 cm large veinlets and clusters of sulphide mineralization (pyrite, chalcopyrite, seldomly tetrahedrite). Barite bodies are genetically linked to the Permian volcanic activity (Turan 1962). Furthermore, barite is found also in siderite, galena and

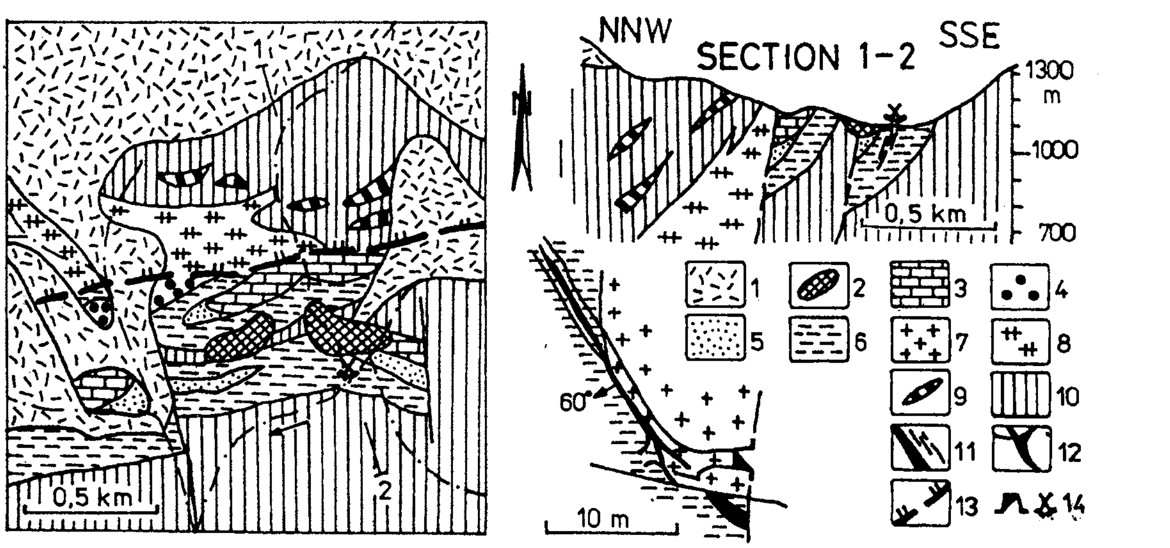

Fig. 11. Geological map of the Trangoška area (after Biely 1992), cross section and the level map of the Trangoška mine adit (compiled by Slavkay). Quarternary: 1 — periglacial block accumulations, 2 — moraine ranges. Triassic: 3 — gray limestones, 4 — rauwackes, 5 — shales and sandstones, 6 — quartzites, arkosic and graywacke sandstones. Crystalline complex: 7 — pegmatite, 8 — biotite tonalites to granodiorites (type Ďumbier), 9 — amphibolites, 10 — biotite and two mica gneisses with banded structure, 11 — ore veins (in the section 1-2), 12 — ore veins (in the level map of the adit), 13 — upthrust, 14 — adit.

less commonly stibnite veins usually as a product of the youngest mineralization stage.

Fe-hematite. Young hematite mineralization was described from many places in the Ďumbierske Tatry Mts., e.g. in the Jasenie valley, in vicinity of Magurka, Dúbrava and elsewhere (Koděra 1990) from the crystalline complex as well as from the Mesozoic cover. Tectonometamorphic processes created hematite mineralization in Alpine mylonite zones near Trangoška. It is younger than Lower Cretaceous (Zoubek 1951).

Discussion

Uranium mineralization is believed to be the oldest ore mineralization type. It was found in Variscan granite pegmatite in the Sb deposit Dúbrava. Mobilization of U from older mineralizations may be responsible for the occurrence of autunite in the Malé Železné deposit (Stankovič & Jančula 1987) as well as for the mineralization expressed by high radioactivity in the area of Malé Železné confined to the NE-SW faults and kersantite veins. According to Tréger (1975) this mineralization is younger than Permian.

Molybdenum, tungsten, pyrite-arsenopyrite and antimony (zinckenite, stibnite, tetrahedrite) mineralization was studied in detail by research of mineral parageneses, fluid inclusion, isotopes of S, H, O and coexisting sulphides in the deposits Dúbrava and Jasenie-Kyslá.

Sulphur was probably derived from several sources with later isotopic fractionation among various S-bearing components in a solution with elevated oxygen fugacity. Part of sulphur may be attributed to an endogeneous source (a metamorphic or a magmatic one). Its isotopic composition is close to zero (Fig. 12) what is typical for uncontaminated mantle sulphur. This concerns especially pyrite and arsenopyrite from the W-mineralization, galena and sphalerite. Majority of the $\delta^{34}S$ values lies within range -1 to +7 ‰. During crystallization of sulphides from hydrothermal solutions the reduced sulphur components (H_2S) prevailed over the oxidized ones

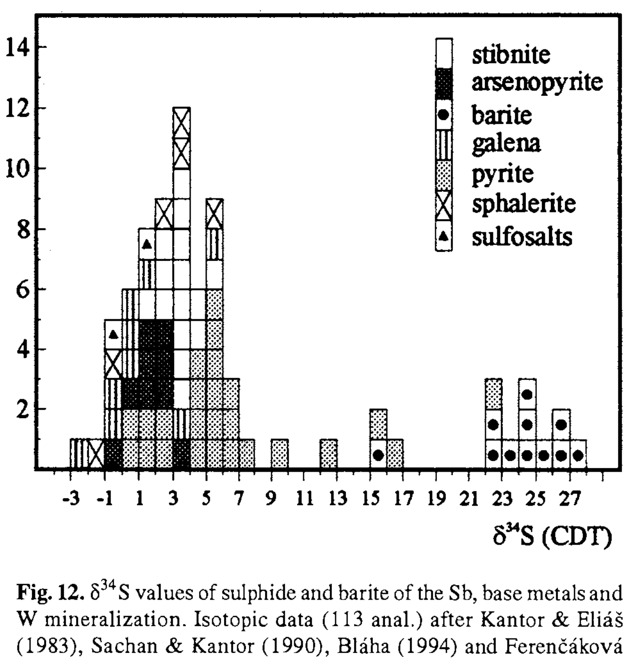

Fig. 12. $\delta^{34}S$ values of sulphide and barite of the Sb, base metals and W mineralization. Isotopic data (113 anal.) after Kantor & Eliáš (1983), Sachan & Kantor (1990), Bláha (1994) and Ferenčáková Repčok (1995).

(SO_4). Such isotopic composition of sulphur may be due to gradual fluid mixing and introduction of recycled crustal sulphur (Žák et al. 1991). Contamination of the endogeneous fluids with meteoritic fluids of shallow circulation took place in the next phase. The meteoritic fluids with free oxygen were saturated in respect to sulphates from overlying sediments with evaporites. This is suggested especially by high $\delta^{34}S$ values from pyrite from the Jasenie-Kyslá deposit. They may be elucidated by near-surface processes of sulphur reduction by sulphur reducing bacteria or by mixing of endogeneous and meteoritic waters (Kantor & Eliáš 1983). Sulphur in barite came from mixed sulphate which was produced by oxidation of H_2S by deep-seated fluids (lower $\delta^{34}S$ values) or from mobilized Permian evaporites (higher $\delta^{34}S$ values). Mixing of the two fluid types is evidenced also by fluid inclusion and oxygen isotopes studies from the deposits Dúbrava and Jasenie-Kyslá.

A comprehensive fluid inclusion study at the Dúbrava deposit (Chovan et al. 1995) showed that the earliest, higher thermal associations with scheelite, molybdenite, pyrite-arsenopyrite and gold crystallized from H_2O-$CO_2 \pm CH_4$, low saline fluids at temperatures between 300–400 °C and pressures about 200 MPa. Contemporaneous salinity increase and temperature decrease could have been caused by release of volatile components (CO_2) or by fluid boiling (Fig. 13a). The $\delta^{18}O$ values of water in equilibrium with quartz of the scheelite and arsenopyrite mineralization (+3.3 to +8.5 ‰) confirm the assumption of presence of metamorphic (or magmatic) water in high temperature CO_2-rich fluids. Arsenopyrite thermometer yielded temperatures of about 400 °C (Sachan & Chovan 1991).

Similar informations were gathered at the Jasenie-Kyslá deposit (Bláha 1994). Scheelite mineralization was formed from low saline fluids rich in CO_2, at temperature 470 °C and pressure 200 MPa. The $\delta^{18}O$ and δD values fall into the field of metamorphic water immediately next to the field of magmatic water, thus corroborating metamorphic or magmatic origin of the solutions (Bláha 1994). High temperature quartz-scheelite mineralization follows the structures of Variscan age (Sasvári & Rozložník 1993) according to the estimation of model age of granitization (Ar/K) from biotite at 330 Ma (Molák et al. 1989). The age of the final differentiation phase was determined from biotite II at 305 Ma. It probably caused also local greisenization, skarnization and formation of sulphide mineralization in marginal parts of pegmatite and aplite veins.

Precipitation of the antimony ores (Pb-Sb sulfosalts, stibnite, tetrahedrite) at the Dúbrava deposit is related to circulation of H_2O + NaCl + KCl fluids with salinity 6-24 wt. % NaCl eq. Epithermal conditions are documented by homogenization temperatures of 105–170 °C. Decrease in both salinity and homogenization temperature witnesses to mixing of endogeneous and meteoric fluids (Fig. 13b). The same is evidenced by negative $\delta^{18}O$ values of the "equilibrium water". Quartz of the last-barite stage (younger than stibnite) was formed from water solutions rich in $CaCl_2$ possibly genetically linked to the formations of Triassic evaporites (Chovan et al. 1995). We suppose that the antimony mineralization is late Variscan. It was not found in the Mesozoic rocks. However, its recrystallization during Alpine tectonometamorphic cycle is probable. Slavkay (1971) argues that the stibnite veins of the Lomnistá deposit are confined to the Alpine structural elements.

Galena mineralization is located mostly in the crystalline rocks of the Nízke Tatry Mts. but it penetrates together with

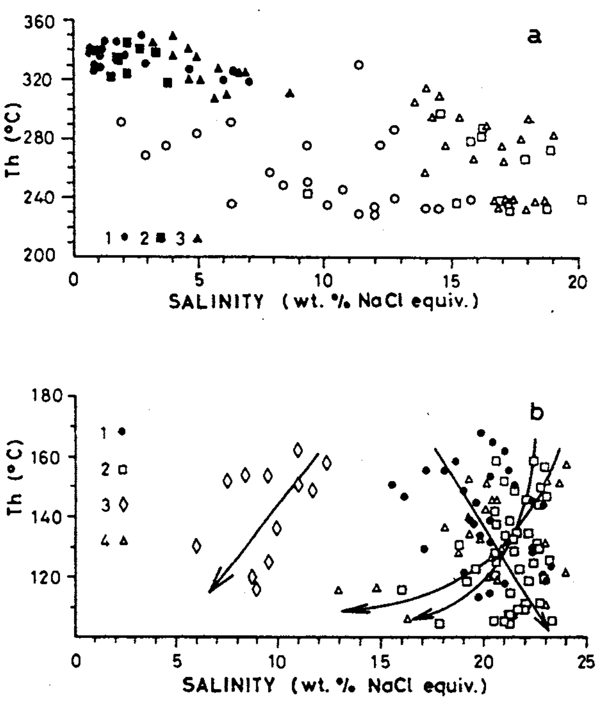

Fig. 13. Correlation between homogenization temperatures and salinities of ore-forming fluids from the Dúbrava deposit (adapted after Chovan et al. 1995). **a** — microthermometry data for quartz from 1-scheelite, 2-molybdenite, 3-arsenopyrite stages. The solid symbols denote CO_2- rich inclusions, the open symbols represent aqueous inclusions. **b** — microthermometry data for quartz from 1-sphalerite and Pb-Sb sulphosalts, 2-stibnite, 3-tetrahedrite and 4-barite (salinity—wt.% $CaCl_2$ equiv.) stages.

siderite and barite mineralization into the Mesozoic. Model ages determined by isotopical studies of lead (Kantor & Rybár 1964; Černyšev et al. 1984) can be divided into two groups. The first one with ages 320-300 Ma includes galenas from the deposits Trangoška, Jasenie-Soviansko and Dve Vody. The second one with ages 270-240 Ma encompasses analyses from the deposits Lom and Ždiar-Dve Vody where contamination by lead from ambient rocks may be assumed. The mineralization is Variscan or post Variscan, possibly related to intrusions of younger Permian granites. Alpine metallogenesis could initiate regeneration of older ore accumulations or remobilization of ore elements of various ages (Černyšev et al. 1984).

Siderite mineralization in the area of Jasenie, sometimes with quartz and remobilized scheelite is younger than the Variscan scheelite ores. Alpine age of the mineralized structures was confirmed by Ar/K dating of sericite from an E-W plane with model age of 110 Ma and younger Alpine mylonite zone with age 81.9-78.4 Ma (Sasvári & Rozložník 1993). According to Rozložník (1990) its formation is connected to regional distribution of shear zones. The elements Fe, Mg, Mn, Ti, Cu, Co, Ni were derived from mantle and mobilized from fragments of basic and ultrabasic rocks that were subducted under the internal zones of the Western Carpathians in Cretaceous. Mineral composition of the siderite and sulphide hydrothermal mineralization of the Nízke Tatry Mts. (Vyšná Boca, Trangoška) and the Spišsko-gemerské rudohorie Mts. is similar. Several authors point at its relationship to Variscan (Ilavský 1986) or Alpine (Cretaceous) (Varček 1976) magmatism or recently to the Variscan metamorphic processes (Grecula et al. 1991 and others). They do not exclude even Cretaceous-Alpine mobilization.

Barite at the Malužiná deposit is genetically linked to the Permian volcanic activity. Barite veins at the sulphide deposits are thought to represent the youngest mineralization stage. They originated from fluids possible genetically related to the formation of the Triassic evaporites. Hematite mineralization is Alpine.

Most of the known types of the hydrothermal mineralization in the Ďumbierske Tatry may be genetically linked to the evolution of metamorphic or magmatic rocks of the Variscan basement. Certain mineralization types were recrystallized or they originated by mobilization during the Alpine metallogenetical cycle and they are localized in Mesozoic rocks.

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