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GEOLOGY AND GEOCHEMISTRY OF THE MINERALIZATION FROM THE GORNJI VAKUF AREA, BOSNIA

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In the Gornji Vakuf area, which is built up of Palaeozoic sediments and metarhyolites, the authors investigated 47 ore occurrences by geological and different geochemical methods. They distinguish: (a) alluvial, diluvial and fluvio-glacial placers; (b) epigenetic hydrothermal barite-siderite-tetrahedrite veins located in the Silurian-Devonian schist complex and Upper Permian, and almost monomineralic barite (± tetrahedrite) veins, breccias and bodies in the Middle Devonian carbonate complex; (c) post-kinematic monomineralic metamorphogenic quartz deposits interlaying the schists.

The hydrothermal deposits have common characteristics as follows: location exclusively in Palaeozoic strata, epigenetic character; simple, monotonous paragenesis (barite ± siderite as main nonmetallic minerals and Hg-tetrahedrite as preponderant ore mineral); siderite characterized by high CaO, MgO and low MnO content; all tetrahedrites are Hg, Ag, Au, Bi-bearing; barite with average content of 2.9 wt% of $SrSO_4$.

The stable isotope study revealed: $\delta\,^{34}S = +15.0‰$ in barites, $-10.1‰$ in tetrahedrites, $\delta\,^{18}O = -9.6‰$ and $\delta\,^{13}C = -3.7‰$ in siderites. The microthermometric measurements gave: $T_h = +200\,°C$ in barites.

The very close similarity of all above mentioned results with those found in the minerals of the Kreševo area deposits, urged the authors to assign also the Gornji Vakuf area deposits to the post-Variscan tectonic event.

Ključne riječi: Zlatonosni nanosi, Epigenetska hidrotermalna barit (± siderit) ležišta, Hg-tetraedrit, Stabilni izotopi, Sadržaj Sr u baritu, Post-variscijska tektonika, Paleozoik, Bosna.

U području Gornjeg Vakufa koje je izgrađeno od paleozojskih sedimenata i metariolita, autori su istražili 47 rudnih pojava geološkim i različitim geokemijskim metodama. Razlikuju: (a) aluvijalne, diluvijalne i fluvioglacijalne zlatonosne nanose; (b) epigenetske, hidrotermalne žice u silursko-devonskim škriljavcima i u gornjopermskim sedimentima te gotovo monomineralne baritne (± tetraedrit) žice, breče i nepravilna tijela u srednjodevonskim vapnenjacima; (c) postkinematska metamorfogena monomineralna kvarcna ležišta u škriljavcima.

Hidrotermalna ležišta imaju niz zajedničkih karakteristika: isključivi smještaj u paleozoiku, epigenetski karakter, jednostavnu, monotonu paragenezu (barit ± siderit kao glavne nerudne minerale i Hg-tetraedrit kao dominantan rudni mineral), siderit karakteriziran s visokim CaO, MgO i niskim MnO, svi su tetraedriti s Hg, Au, Ag i Bi, barit sa srednjim 2.9 wt% $SrSO_4$.

Studij stabilnih izotopa je dao: $\delta\,^{34}S = +15.0‰$ u baritu, $-10.1‰$ u tetraedritu, $\delta\,^{18}O = -9.6‰$ i $\delta\,^{13}C = -3.7‰$ u sideritu. Mikrotermometrijska mjerenja dala su: $T_h = +200\,°C$ u baritu.

Vrlo bliska sličnost svih gore navedenih parametara s onima nađenim u ležištima Kreševa utjecala je na autore da pripišu rudnim ležištima područja Gornjeg Vakufa post-variscijski karakter postanka.

Introduction

The Gornji Vakuf (Uskoplje) area, with the surface of almost 340 km², is located in the middle parts of the southwestern Middle Bosnian Schist Mountains (MBSM). Orographically, Mt. Vranica with the Nadkrstac Peak (2110 m) is characteristic. This is the area of upper courses of the Bistrica, Desna, Dragučina and Vrbas river basins (Fig. 1a, b).

Geology

Fig. 1b presents a simplified geological map of the area based on data of the geological map, sheet Prozor (Sofilj & Živanović, 1979) and its explanatory text (Sofilj et al. 1980). The location and classification of ore occurrences is given in this paper by Jurković.

The oldest are *Silurian-Devonian metamorphic rocks* of the greenschist formation. Its older members are represented by chlorite-sericite schists and sericite-chlorite-quartz schists which, in the area of Dobrošin, Berač, Maškara, Lisina, Grača and in the Rika and Blazinka valleys, are interlayered by metasandstones and in the area of Gromilica by quartzites. Younger members of the formation, represented mostly by slates, predominate in the area of the Cvrče village and in the Desna valley, nearby Krugljača over dark siltstones, sandy sericite-chlorite schists and schistose sandstones. Limestone and dolomite lenses are rare. These higher parts of the formation, in some places, laterally grade in Lower Devonian limestones.

In Mt. Vranica area Silurian-Devonian formations are tectonically covered by *Devonian limestones* with subordinate dolomites which are rarely found within the rhyolite masses of the area Rosin and Mt. Smiljevača. *Lower Devonian* platy limestones are noticed only in the Suvodol canyon. The *Middle Devonian* is represented by zoogenic

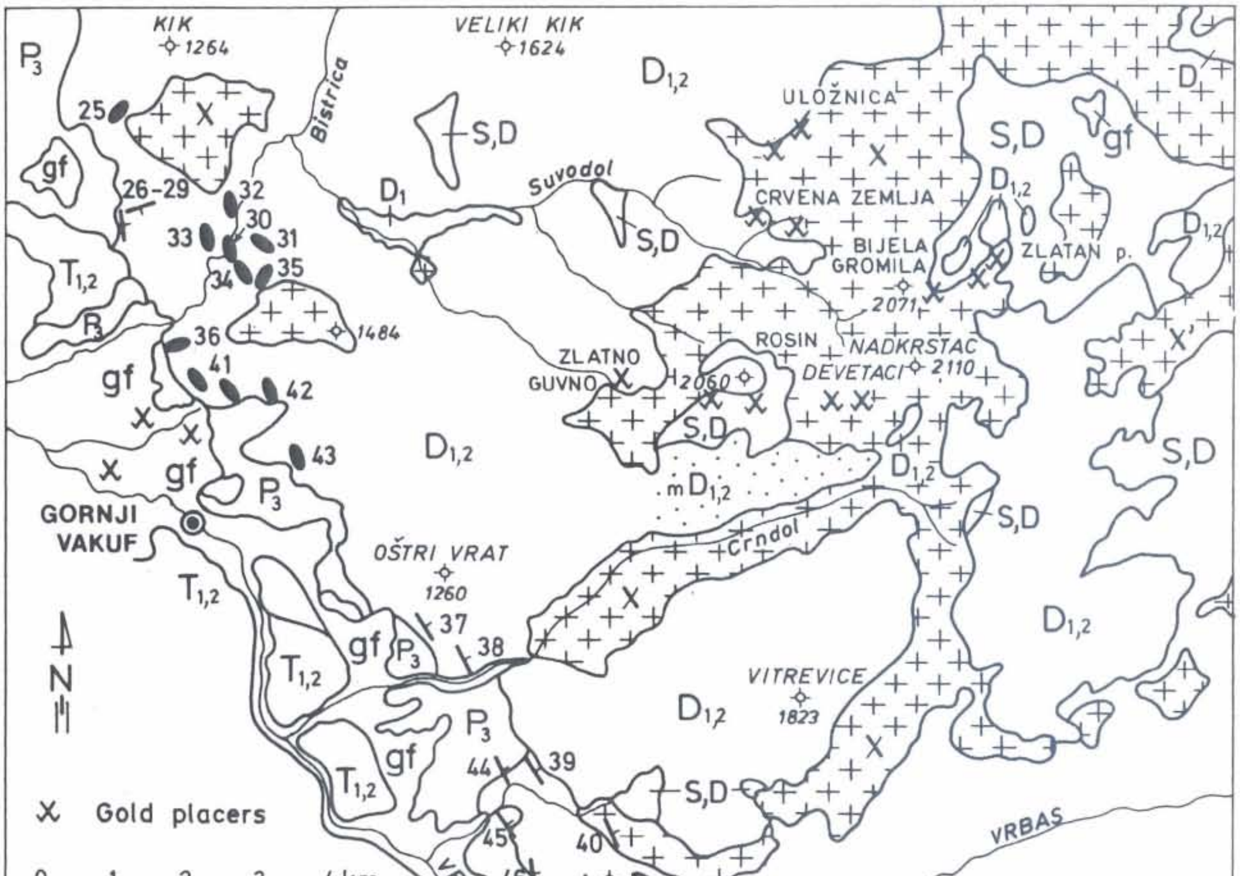


Fig. 1. **a** — Position of the Mid-Bosnian Schist Mountains (MBSM) inside the Republic Bosnia and Herzegovina
b — Simplified geological map of the Gornji Vakuf area from the sheet Prozor made by Sofilj & Živanović (1979). Positions of the 47 ore occurrences, their parageneses, stretching and dip by Jurković (this paper).

Legend: S, D — Upper Silurian-Lower Devonian schist complex; D_1 — Lower Devonian; $D_{1,2}$ (D) — Middle Devonian carbonate complex; $mD_{1,2}$ — marbleized limestones; X — rhyolite; X' — metarhyolite; nq — quarzkeratophyre; P_3 — Upper Permian sediments; $T_{1,2}$ — Lower and Middle Triassic; gf — fluvioglacial placers; **Ore occurrences:** Nos 1—17 (in the Fig. 1b) siderite ± barite + tetrahedrite in $(S, D)_1$; Nos 18—24 ba ± si + td in $(S, D)_2$; Nos 25—40 ba ± td in $D_{1,2}$; Nos 41—43 ba ± td in $P_3/D_{1,2}$ thrust/fault zone; Nos 44—46 si ± ba + td in $P_3/(S, D)_1$ thrust/fault zone; No 47 metamorphogenic quartz deposit.

limestones and subordinate dolomites which are found in the area of the Mts. Močike, Krstac, Dobruška, Rog and Goletica. These rocks are massive and rarely bedded. Carboniferous rocks have not been registered in the area of the map-sheet Prozor, but Živanović (1979) presumes that younger parts of the Silurian-Devonian series may belong to the Lower Carboniferous and, metalogenetically, this hypothesis can be accepted by the present authors.

Shallow subvolcanic *rhyolite intrusions and extrusions* are widespread. Petrologically, they represent branches of leucocratic aplite-granite magma (Jurković & Majer, 1954). The rhyolites were mostly transformed into metarhyolites by regional metamorphism which probably took place in the Carboniferous-Middle Permian as supported by contact-metamorphosed marbles found along the contact with Devonian limestones. Much more rare are rhyolites enriched in sodium which are in some places covered by Upper Permian formations. However, some of them could be related to Triassic magmatic activity.

Upper Permian formations are unconformably underlain by older Palaeozoic formation. Lower parts of the Upper Permian consist of reddish breccias, quartz conglomerates, porous limestones (± gypsum) and the higher parts consist of coloured fine-grained subgraywackes, subarcoses and siltstones ± gypsum-anhydrites. The highest parts grade into the Lower Triassic. The present authors are inclined to the opinion that a detailed differentiated correlative analysis between these Permian formations and corresponding formations from Austria and Slovenia may indicate the existence of the Middle Permian as indicated by Ramovš et al. (1987) for the Permian and Permotriassic of the southeastern Bosnia.

The *Lower Triassic* is represented by the Saisian schistose siltstones and limestones which grade in *Middle Triassic* limestones, dolomites, and volcanic-sedimentary formations. The *Upper Triassic* consists mostly of limestones and dolomites.

Palaeozoic rocks were deformed during the Variscan orogeny and these structures were affected by younger Alpine tectonic events.

Ore occurrences

In the area of Gornji Vakuf the following genetical types of ore occurrences are found: A. Sedimentary gold deposits: 1. Quaternary accumulations; 2. Diluvial terraces; 3. Uppermost Pleistocene (Wuerm) glacial formations. B. Hydrothermal ore deposits: 1. siderite-barite-tetrahedrite occurrences of the Maškara type located in metapelites and metapsammites of lower parts of the Silurian-Devonian; 2. barite-siderite-tetrahedrite of the Cvrče—Borova Ravan-type located in metaclastic rocks of higher parts of the Silurian-Devonian; 3. monomineralic barite occurrences (± tetrahedrite) of the Sabeljine Pećine-type located in Middle Devonian limestone, partly dolomitized; 4. barite-siderite-tetrahedrite occurrences of the Mračaj-type located along the Voljevac fault zone (tectonic contact between the Upper Permian and Early Palaeozoic). C. Metamorphogenic quartz deposits of the Šeferovići-type.

A. Sedimentary deposits

1. Quaternary gold-bearing fluvial deposits. Relict old gold washing places found in the Alluvium between the villages Blatuša and Bistrica, northwest of Gornji Vakuf, have been described by Walter (1887). According to his opinion the gold comes from Mt. Vranica. Foullon (1892) washed up minute microscopic gold flakes and some fine gold grains from Quaternary accumulations in the area of the villages Blatuša and Krupa, in the Crnodol Creek, Vrbas river and the mouth of Desna to Vrbas. According to his opinion the gold comes from gold-bearing tetrahedrite and limonitized iron ores from Mt. Vranica so that Palaeozoic schists may represent source rocks. Ruecker (1896) checked the gold-bearing of old washing places Blatuša and Bistrica and found out variations in Au content from 0.5 to 2.1 (the average 0.65) g per 1 m^3 sand in 1891 and the average for 1982 was $0.45/m^3$. He considered that schists, rhyolites and the Werfenian beds represent its source rocks. Poech (1900) described gold washing of ancient Romans in the River Vrbas area whereas Katzer (1902, 1925) was of the opinion that alluvial deposits were washed up by earlier mining activity and thus unconvinient for a new exploitation.

Radusinović (1960) examined 11 samples of Alluvial deposits from upper courses of the River Vrbas basin and he found increased quantities of scheelite, garnet and Mn-oxides in the Crnodol and Dobrošin Creeks, garnet and Mn-oxides in upper courses of the River Vrbas, and barite in the Desna, Crnodol, Dobrošin, Pridolci Creeks genetically related to barite deposits of this area. This also holds for increased quantities of chalcopyrite and siderite in the River Vrbas basin nearby Boljevac. Extensive occurrences of pyrite in heavy concentrates is connected wih pyrite impregnations found in schists and partly with quartz occurrences.

On the basis of our own investigations of the whole Mid-Bosnian Ore Mountains the numerous gold-bearing tetrahedrite deposits and the pyritized contact zones between rhyolites and older rocks are the most important source of all secondary gold deposits.

2. Gold-bearing Diluvial terraces from the area of Krupa and Oglavak, north of Gornji Vakuf were washed up by Romans. Ruecker (1896) washed up again the terraces and found that they are gold-bearing only in their middle parts nearby Krupa.

3. Glacial deposits. Conrad (1870) first and Mojsisovics et al. (1880) noticed Diluvial glacial deposits. Walter (1887) described in details old Roman and Illirian mining works of Mt. Vranica and he thought that gold was washed up from strongly weathered, reddish, ferruginous rhyolites and phyllites from their contact area. Foullon (1892) and Ruecker (1896) in their descriptions mainly used previous Walter's data. Katzer (1902, 1925) was the first to present the idea on glaciers. Sofilj et al. (1980) are of the opinion that the Vranica glaciers were generated during the Pleistocene (Wuerm).

A large glacial amphiteater-like valley located in the spring-area of Zlatan (Golden) Creek, between the Mts. Bijela Gromila (2071 m) and Smiljevača Kosa (1924 m) was explored by Jurković (1951). Numerous Roman dumps, heaps and shafts indicate gold exploitation. In the eastern parts of the Bijela Gromila—Nadkrstac Ridge (2017 m) relics of Roman etages are found in rhyolites and their glacial materials (drifts). In Mt. Rosin (2060 m) large number of Roman dumps and trenches are found along contact between rhyolites and phyllites. Large elongated open pit was noticed between rhyolites and schists in the area east of Rosin towards Devetak (2080 m) on the southern slopes of which great number of old Roman works are located along the same contact. In the area of Crvena Zemlja a large amphitheatre is found with a waste, 100 × 50 × 30 m in size. In yellow-reddish loan larger and smaller blocks and debris of propylitized rhyolites, metarhyolites, schists and slags are embedded. Twofold Roman water-mains with the hight altitude of 8 m is carried into rock and it was used for etage mining works and open pits in the area of Crvena Zemlja.

B. Hydrothermal ore deposits

(1) Siderite-barite-tetrahedrite of the Maškara-type (Nos 1 to 17 on the Fig 1b).

Seventeen out of 46 registered ore occurrences of the broader area of Gornji Vakuf are located in lower parts of the Silurian-Devonian complex (Table 1). Ore occurrences are found in the southeastern part of the area of Gornji Vakuf (Fig. 1b).

Illyrians and Romans were exclusively mined limonite from the oxydized zone of siderite and cinnabar, silver, and gold from weathered tetrahedrite, but they did not mined barite and fresh tetrahedrite. During the Austrian-Hungarian Monarchy (1878—1917) Cu-enriched tetrahedrite was explored due to its copper, gold, silver and mercury content. After 1918, more intensive exploration of barite deposits was carried out with a particular emphasize to the monomineralic barites found in carbonate rocks.

The Maškara-type mineralization processes took place inside the system of shorter and larger, more shallow and deeper, narrow and wider open tensional fissures and joints. Length, height and thickness dimensions of the system vary not only from place to place but also within the same deposit. There are all possible gradation from the fissures, a few centimeter wide, which can be traced along strike from a few meters up to several

Table 1

Ore occurrences in the lower level of the Silurian—Devonian complex (S,D)$_1$

No	Locality	Host rocks Type	Dip	Ore occurrences Alt.	Dip	h	l	w	Minerals			
1	Berać	phy sds	45/50^0	+1250 +1200	E and NNW	shw	sht	0.1 1.0	**si** **ba**	q	td	py
2	Šeferovići Jabučnica	phy	0/30^0	+ 925	75/35^0	shw	sht	th	**si**	py	td	
3	Šeferovići Duboki potok	phy	15/55^0	+ 900	240/30^0	shw	sht	th	**si**	q	td	py
4	Šeferovići Groblje	phy	11/28^0	+ 935	75/45^0	shw	sht	th	**si**	td		
5	Vrbas-vein	phy	dist. zone	+ 800	135/80^0	shw	sht	0.1 0.7	**si** **td**	q		
6	Maškara	phy	60/30^0	+ 930 + 821	75/40—60^0	109	200 350	0.1 1.0	**si** **ba** **td**	q py	cc ch	do
7	Rad vein	phy	NE	+1000	SE	shw	sht	0.2	**si**	td	ba	
8	Saski Rad	phy	45/50^0	+1070	90/40^0	15	sht	0.3	**ba** **td**	si	q	
9	Desna vein	phy	dist. zone	+ 850	165/var.	shw	sht	0.1	**ba** **si**	td		
10	Daganj potok	phy	NE/st.	+1100	105/40^0	50	sht	0.1 0.2	**si**	q	td	
11	Valice selo	phy	NE/st.	+1100	ENE/st.	shw	sht	0.1	**si**	q	td	
12	Valice Mlinovi	phy	SE/50^0	+1100	ENE/st.	shw	sht	0.1	**si**	td		
13	Laznice	phy	NE/50^0	+1200	ENE/st.	long fissure		0.1 3.0		fault gouge ba	cc	Mn
14	Crkvice	phy	NW	+ 950	ENE/st.	shw	sht	0.0 1.0		fault gouge si	ank	td
15	Kulentaš	phy	16/38^0	+1100	E/st.	shw	sht	0.2	**si** **td**			
16	Ladina Voda	phy	32/68^0	+1320	NE	shw	sht	th	**ba** **si**	td		
17	Kašli Brdo	phy	32/68^0	+1250	75/48^0	shw	sht	th	**ba** **si**	td		

Legend (Tables 1, 2, 3, 4 and 7)

(S, D)$_1$ — Lower level of the Upper Silurian — Lower Devonian complex
(S, D)$_2$ — higher level of the same complex
D$_{1,2}$ — Middle Devonian carbonate complex
P$_3$ — Upper Permian sediments
P$_3$/D$_{1,2}$ and P$_3$/(S, D)$_1$ — thrust-fault zone, phy — phyllite, sch — schist, sds — sandstone, alv. — alevrolite, lm — limestone, si — siderite, ba — barite, td — tetrahedrite, q — quartz, cc — calcite, do — dolomite, py — pyrite, ch — chalcopyrite, ank — ankerite, Mn-Mn — oxides, shw — shallow, sht — short, th — thin, h — height, l — length, w — width, Alt. — altitude, st. — steep.

hundred meters, and along the dip for more than hundred meters to the joints, a few centimetre to more than 1 m wide. These were filled in some places for several times and then repeatedly opened and sheared (Table 1).

The system of mineralized fissures and joints stretches mostly northnorthwest-southsoutheast and dips towards the eastnortheast with very variable angles. Generally, this strike is very similar to the strike of the Voljevac fault zone. The most significant tetrahedrite occurrence of the MBSM is related to this system (Fig. 1b no 6). Several, not yet sufficiently explored ore veins (Rad, Saski Rad, Kašli Brdo) can be traced towards the southeast along its extension. A similar jointing system, about 3.5 km long, is found between the Rivers Desna and Vrbas in the neighbourhood of the villages Valice and Crkvice. The same mineral paragenesis is found in subordinate and mainly smaller veins stretching in north-south direction which dip towards the east.

Both systems of veins are disturbed by post-ore faults stretching in northeast-southwest direction with the dip towards the southeast. The faults are filled mostly by fragments of schists and subordinate metarhyolites and fault gouge. If partly mineralized, faults are filled by fine-grained quartz or barite with some tetrahedrite. Faulted blocks are shifted along these faults mostly towards the southeast and rarely towards the northwest.

Coarse-grained and massive veins originated along gradually opening joints. If salbands were immovable then the veins with symmetric texture were generated, and vice versa, the movement of one salband gives rise to assymmetric texture. Shearing salband movement could give rise to multiple pressing and crushing of schists but also to the inset of broken plates of country rocks inside the vein and thus to its branching. (Fig. 2). This

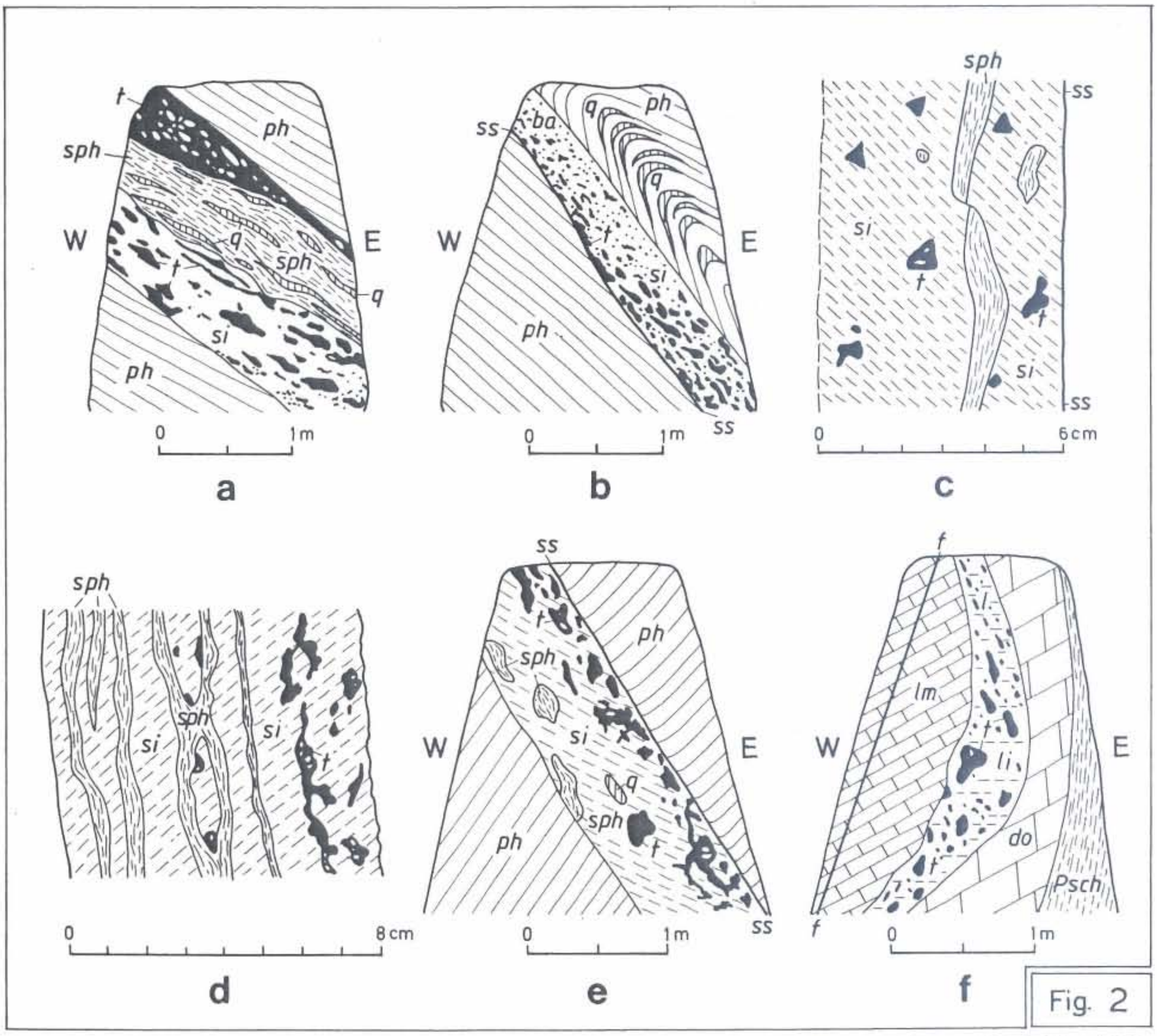


Fig. 2. Ore vein profiles **a, b** — Maškara vein (No 6); **c** — Draganj (No 10); **d** — Kulentaš (No 15); **e** — Mračaj (No 46) in phyllite; **f** — Mračaj (No 46) in P_3; Legend: ph — phyllite; sph — sericitized and silicified phyllite; Psch — Permian schist; lm — Permian limestone; do — Permian dolomite; si — siderite; ba — barite; t — tetrahedrite; q — quartz; f — fault; ss — slickenslide. Profiles made by E. Komatitsch (in Katzer, 1907).

frequently happens with thicker or their thickened parts. Phyllitic ore breccias originated by the cementation of angular schists in some places can be found. Schist fragments and plates within the vein are enriched in quartz (silicification) along the bedding plane or in the shadow zones. Drusy space of the lenticularly widened parts of the veins are commonly covered by well developed drusy minerals of a young mineralization phase. Fig. 2 illustrates representative sections of ore veins.

The Maškara ore deposit is a typical representative of this genetical type.

The Maškara vein (No 6 on the Fig. 1b). In the area between the Desna Creek, in the north, and the Maškara Creek, in the south, the vein was exploited along strike totally for 500 m and along dip for 150 m and, vertically, 109 m, respectively. At separate deep levels the strikes and dips vary and, in some places, the vein branches and again connect in one single vein. Its thickness irregularly varies from 0.1 to 1 m, and it averages 0.2—0.3 m. Two swellings up to 1 m were noticed in its northern flank and its middle parts across all five mined depth levels. The vein is the thickest in the levels II and III and it wedges below the level V by decreasing quantity of tetrahedrite (Fig 3).

The vein fills a tectonic joint in phyllites, in some places silicified and thus empoverished in ore. The vein is cut by faults stretching northeast-southwest and deviating mostly towards the southeast and rarely towards the northwest.

The vein is mined at five levels and its length is about 200 m in first two levels, 300 m in the fourth one and 350 m in the fifth one. Due to the high economic criteria during Austrian-Hungarian time of exploitation (minimum 2—4 wt% of Cu), the exploitable length of the vein was only 100 m.

The barite-siderite Maškara vein contains very significant quantities of Hg-Sb-tetrahedrite. Quartz is an important subordinate constituent evenly distributed in the vein, whereas calcite occurs locally, in its siderite-containing parts. All other minerals are accessory constituents.

Koch (1897; 1899), Katzer (1907; 1925), Kišpatić (1909) and Vesely (1921) described minerals of the Maškara vein and other occurrences. Jurković (1956; 1960) gave first detailed microscopic analyses of transparent and opaque minerals and quantitative optical data for tetrahedrite and its four-stage mineral succession.

The succession is as follows: **Phase I:** very small quantities of pyrite I, quartz I, chalcopyrite and first part of tetrahedrite crystallization; in **Phase II** (the main phase) crystallized siderite, barite-type IV and calcite II (rhombohedral) and the continued crystallization of tetrahedrite; **Phase III** very small quantities of quartz II, barite-type III, argentopyrite, sternbergite, Au-Ag-tellurides, and in **Phase IV** (drusy phase): accessory scalenohedral calcite, dolomite, quartz III, and pyrite II.

Mineral microscopic features: **Pyrite I** is the oldest member of the paragenesis. It is found on schist salbands and as partly corroded grains in barite and quartz II, and as worm-like and relict forms in tetrahedrite. It is more common in the incline of the level II and in adjacent rhyolite apophyse. **Pyrite II** occurs as minute and automorphic crystals grown together with drusy calcite being the youngest mineral of the paragenesis.

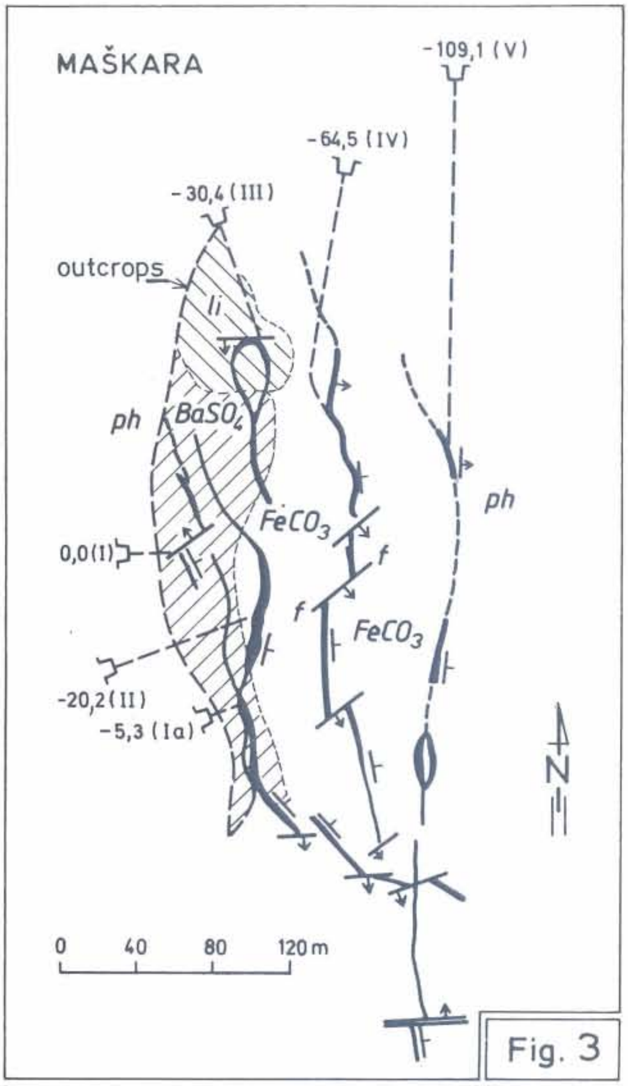


Fig. 3. Maškara vein (No 6 in Fig. 1b) Underground mining works. Legend: ph — phyllite; f — fault; li — limonitizied siderite; I—V — levels. Sketch presented in Katzer (1907).

Hg-Sb-tetrahedrite is major and, quantitavelly, the only ore mineral. Single automorphic crystals, smaller grain aggregates, smaller or larger nest-like and discoid-lensoid interlayers are found in barite or siderite.

Parts of the vein enriched in tetrahedrite are characterized by interrupted or continuous compact corticuated tetrahedrite, particularly along salbands. There are indications for two tetrahedrite generations. Gold and silver, originated during weathering, occur as minute masses and veinlets inside tetrahedrite. The average content of tetrahedrite amounted 9—15 vol. %, and 10—16 wt%, respectively, in barite crude ore and 20—60 vol. %, and 15—65 wt%, respectively, in siderite crude ore, which is 2.5 to 4 times more. The average crude ore of the mined 8.000 t during the 1896—1917 period contained 25 wt% of tetrahedrite. **Chalcopyrite,** which is very rare, is commonly accompanied by tetrahedrite; it was found accompanied by pyrite in the incline of the level V in a metarhyolite apophyse. **Sternbergite** and **argentopyrite** of microscopic dimensions are accessories mainly found in fissures and cataclases in tetrahedrite. **Au-Ag-telluride,** in form of minute grains and rarely as smaller masses, was found in tetrahedrite. **Native gold** was noticed only in some tetrahedrite grains in form of ovoid minute grains or microveinlets.

Quartz I is xenomorphic, optically anomal and cataclased with incipient recrystallization effects. It is replaced partly by siderite and calcite, rarely by barite and is preserved in worm-like relict grains. **Quartz II** is a vein mineral which replaces, in form of microveinlets and small nests, the major nonmetallic minerals and schist salbands. It is whiteish, dense and fine-grained. **Quartz III** is a drusy mineral which occurs as 3—4 mm long needlelike yellowish transparent crystals.

Calcite I (the type II) is rhombohedral, dense, coarser crystalline and is younger or synchronous with siderite I; it is most common between the levels IV and V. **Calcite II** (the type III) is scalenohedral and occurs in druses or in cataclastic parts of siderite.

Siderite I is a main nonmetallic mineral of the Maškara mineral deposit. It occurs as a coarse-grained xenomorphic aggregate and in druses as a rhombohedral crystal. The siderite is yellowish-gray in colour which grades during oxydation processes in a redbrownish colour, i. e. the siderite grades into strongly haematitized »brown-spar«. The quantitative chemical analysis of the E-91/1 sample gave 7.48 wt% of Fe_2O_3 and under microscope a dense network of microscopic and submicroscopic haematite grains can be noticed. **Siderite II** is thin-platy in crystal habitus and fills interstices between barite I crystals. The siderite with some quartz and between the levels IV and V with larger calcite masses, makes up middle and lower part of the Maškara vein. The chemical composition of siderite I is presented in Table 6.

Dolomite, which is rare and found only in the level IV, occurs in coarser rhombohedral crystals.

Barite I, which is in habitus of the type IV, is coarse-grained or thick-platy and columnar, milk-whiteish in colour. Due to stress effects it is deformed as shown in undulose extinction, pressure twins, and incipient recrystallization. **Barite II,** which is in habitus of the type VI, is thin-platy or fine-grained, transparent to semitransparent and grown up over siderite I or tetrahedrite. The barite occurs in upper parts of the Maškara vein, about 20—30 m below the outcrops. Only in the utmost north-northwestern parts of the vein prevails limonite originated by the oxydation of siderite. A transition between siderite and barite gangue is between the levels Ia and I in southern parts of the vein and the levels II and III in its middle parts. Siderite completely limonitized to the depth of 30—40 m reaches the surface in utmost north-northwestern parts of the vein.

Ore occurrences of Šeferovići (Nos 2, 3 and 4), Vrbas vein (5), Rad (7), Daganj Creek (10), Valice (11 and 12) and Kulentaš (15) are sideritic in composition but with single minute crystals or grains, nest-like aggregates and rarely interrupted lensoid interlayers of tetrahedrite. The occurrences, in a rule, contain noticeable quantities of quartz, particularly in Šeferovići (3), Vrbas (5), Daganj (10), and Valice (11). The increased quantity of quartz is commonly accompanied by higher pyrite and decreased tetrahedrite contents. The barite-tetrahedrite occurrences with predominant siderite over barite, as examplified by Maškara (6) and Desna (9) are, as a rule, the most optimal for tetrahedrite crystallization.

Barite occurrences with subordinate siderite, as examplified by Saski Rad (8), Ladina Voda (16), and Kašli Brdo (17) are characterized by decreased quantities of tetrahedrite. The Lazine (13) and Crkvice (14) ore occurrences represent an open jointing system which is only partly filled by ore minerals inside fault gouge.

(2) *Ore occurrences connected with stratigraphycally higher parts of the Silurian-Devonian complex of metaclastic rocks*

In Table 2 are included basic geometrical data for seven ore occurrences located 2.5—3 km south of Maškara, in the area of Cvrče (19, 20) and Borova Ravan (21, 22, 23). The mineralization is of the vein-type and it stretches in northwest-southeast and northnorthwest-southsoutheast direction dipping towards the northeast. The ore occurrences are located in metaclastic rocks of higher parts of the Silurian-Devonian complex. Živanović (1979) claims that these rocks may belong to the Lower Carboniferous.

All ore occurrences of this group are presented in Table 2. Here, barite predominates over siderite with subordinate Hg-tetrahedrite. Based on preliminary investigations these are smaller ore occurrences. Microphysiography, structure and texture of the ores, are same, like in the ores described in preceding chapter.

(3) *Ore occurrences from Middle Devonian Carbonate Rocks (Table 3, nos 25—40)*

(a) In the Bistrica river basin, north of Gornji Vakuf the Vučja Kosa and Grnica barite occurrences are found and barite pebbles and debris on the southwestern slopes of Vučja Kosa (25) also are present.

The Grnica barite veins (26—29) are located in Middle Devonian limestones of the Mt. Vučja Kosa. There four barite veins were explored by trenches and shafts and the reserves were estima-

Table 2

Ore occurrences in the upper level of the Silurian / Devonian complex $(S,D)_2$

No	Locality	Host rocks		Ore occurrences					Minerals			
		Type	Dip	Alt.	Dip	h	l	w				
18	Djamuš brdo	sds		+1250	ENE	shw	sht	0.05 0.25	**ba**	si	q	td
19	Cvrče selo	sch sds	NE/st	+1200	60/30°	shw	sht	0.05 0.10	**si**	ba	q	td
20	Cvrče / Zaganj	sch sds	W	+1150	NE/25°	shw	sht	0.10 0.40	**ba** **td**	si		
21	Borova Ravan Guvnanica	sds sch		+1100		only ore blocks			**ba**	si	td	
22	Borova Ravan Bosnjačica	sds alv sch		+1000	75/45°	shw	sht	0.06 0.10	**ba**	si	td	
23	Borova Ravan	sds sch	stretch E—W	+1000		shw	sht	th	**ba**	si	td	
24	Ričica brook	phy sds		+1350 +1400		ore blocks			**ba** si	td		

ted to 40.000—50.000 t (Jurković, 1958; Vasiljević & Zec, 1961). Barite is the only major mineral and thus the veins are nearly monomineralic. Geometry of veins is presented in Table 3 and Fig. 4, and chemical composition in Table 5. The crude ore had the averages 95.38 wt% $BaSO_4$ in the veins 1 and 2 and 91.38 wt% $BaSO_4$ in the veins 3 and 4.

(b) The Sabeljine Pećine barite occurrences (nos 30—36) are found on both sides of the Bistrica River about 4 km far from the Gornji Vakuf—Rostovo—Travnik road; the area consists of Middle Devonian limestones dolomitized in the zone of mineralization (Fig. 1b)

The barite occurs mostly as logs, smaller and irregular bodies and thinner and shorter veins. The largest ore body (no 31) was 66 m long, 12 to 22 m thick (the average was 15 m), and 10 to 17 m high (the average was 12 m). Its vertical and horizontal projection is presented in Fig. 5. Geometry of other ore occurrences is presented in Table 3. They have been described by Jurković (1956; 1958a), Jeremić (1959, 1963); Vasiljević & Zec (1961) and Ramović (1976).

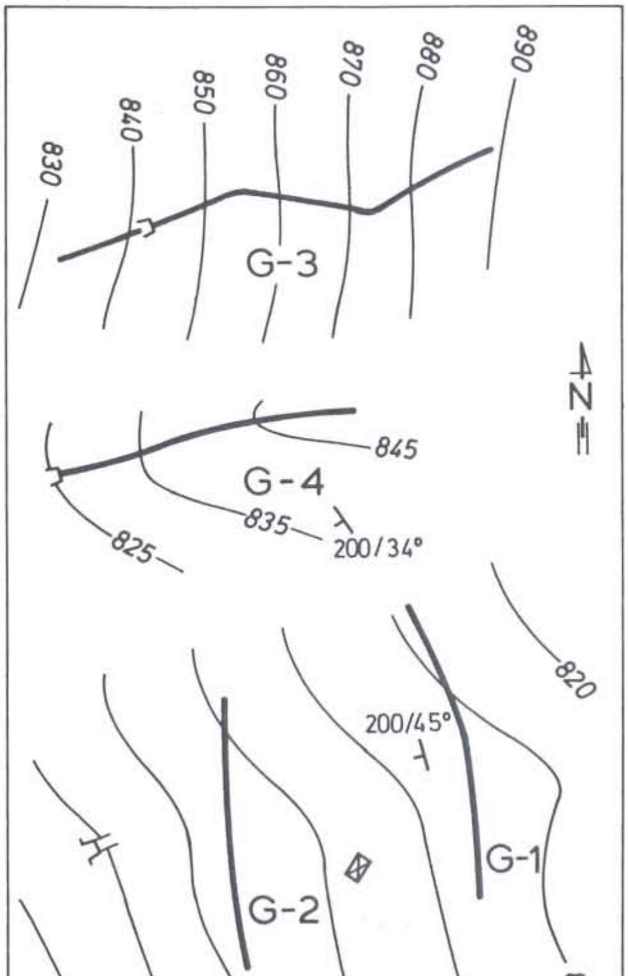


Fig. 4. Grnica barite veins G_1—G_4 (No 25—29 in Fig. 1b). Made by Vasiljević & Zec (1961).

The occurrences were intensively exploited; the Sabeljine Pećine II (31) body gave more than 15.000 t barite of high quality (94.47 wt% of $BaSO_4$). The ore quality and mineral paragenesis are presented in Table 5.

(c) In the area southeast of Gornji Vakuf are found ore occurrences numbered by 37—40. Some of them have been mentioned by Jurković (1956; 1958a), Ramović (1976) and Katzer (1907; 1926).

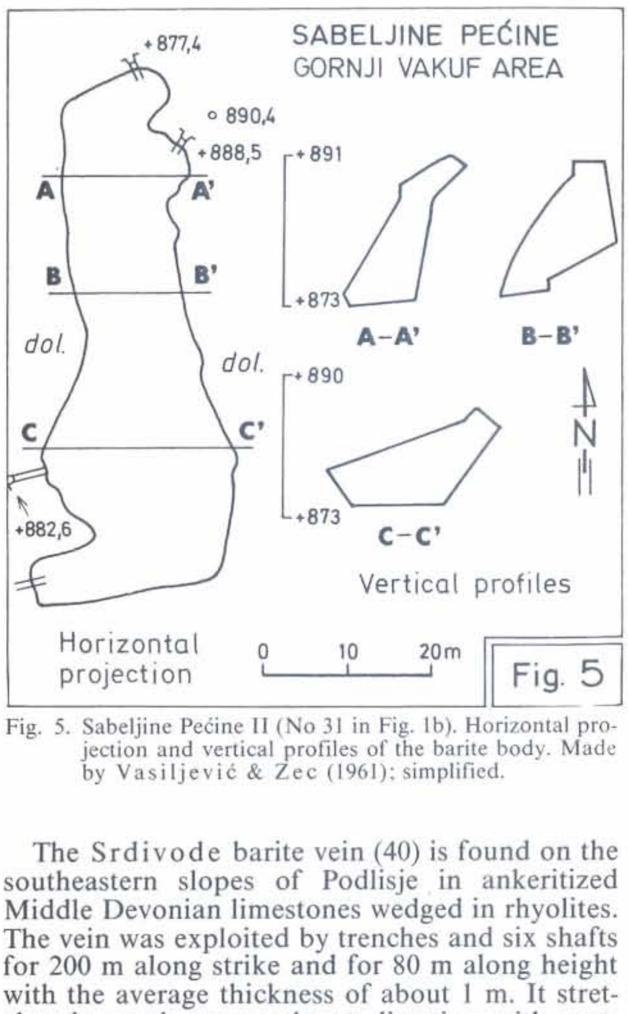


Fig. 5. Sabeljine Pećine II (No 31 in Fig. 1b). Horizontal projection and vertical profiles of the barite body. Made by Vasiljević & Zec (1961); simplified.

The Srdivode barite vein (40) is found on the southeastern slopes of Podlisje in ankeritized Middle Devonian limestones wedged in rhyolites. The vein was exploited by trenches and six shafts for 200 m along strike and for 80 m along height with the average thickness of about 1 m. It stretches in northwest-southeast direction with east-west deviation and dips steeply (85°) towards the northeast. The reserves were estimated by Vasiljević & Zec (1961) to 28.000 t averaging 92.63 wt% $BaSO_4$.

Geometry of barite bodies is presented in Table 3 and their chemical composition in Table 5.

Features of Barite Occurrences from Middle Devonian Limestones

Barite occurrences located in Middle Devonian limestones are mostly irregularly shaped logs or irregularly thickened veins (particularly in the area of Sabeljine Pećine). Typical veins with significant lengths are known only in the area of Grnica and Srdivode. Larger logs are surrounded by the network of very thin veinlets, nests and barite or barite-quartz covers; brecciated masses are also noticed. Contacts between barite and limestone are mainly sharp. In the zone of mineralization limestones are commonly more or less dolomitized and ankeritized, respectively.

Table 3

Ore occurrences in the Middle Devonian limestones (±dolomitized) ($D_{1,2}$)

No	Locality	Host rocks: Type	Host rocks: Dip	Ore occurrences: Alt. m	Ore occurrences: Dip	h	l in m	w	Minerals
25	Vučja Kosa	lm	270/70°	+1100	ESE/st			0.5 1.2	**ba** cc q si td py
26	Grnica 1	lm	200/45°	+ 813 + 804	75/60°	9	70	0.6	**ba** cc q td py
27	Grnica 2	lm	200/45°	+ 792 + 780	85/75°	12	65	2.5	**ba** cc q td py
28	Grnica 3	lm	200/34°	+ 890 + 832	160/75°	58	120	1.0	**ba** cc q si td py
29	Grnica 4	lm	200/34°	+ 850 + 825	165/80°	25	80	0.8	**ba** cc q si td py
30	Sabeljine Pećine I	lm	260/70°	+ 870	stretch. N—S		lens-sized vein		**ba** cc q td py
31	Sabeljine Pećine II	lm	260/70°	+ 890 + 871	255/30-65°	10 17	66	12 22	**ba** cc q td py
32	Sabeljine Pećine III	lm	260/70°	+ 700	stretch. N—S		8	0.3 0.8	**ba** cc q td py
33	Sabeljine Pećine IV	lm	260/70°	+ 900	stretch. N—S			0.1	**ba** cc q td py
34	Sabeljine Pećine V	lm	260/70°	+ 900	NE		small lenses		**ba** cc q td py
35	Sabeljine Pećine VI	lm	260/70°	+ 900	NW		lense-shaped bodies		**ba** cc q td py
36	Bistrica	lm	240/40°	+ 720	stretc. E—W		50	0.5	**ba** cc q td
37	Lisina	lm	235/40°	+ 900	stretch. NNW-SSE			0.1 0.4	**ba** q td
38	Crnodol	lm	285/40°	+ 900	stretch. NNW-SSE		veins		**ba** q cc td
39	Seoci	lm	330/40°	+1015	NE	shw	sht	th	**ba si** td
40	Srdivode	lm	330/40°	+ 950	45/85°	80	200	0.3 1.5	**ba** si td cc py

Table 4

Ore occurrences in the thrust fault zone between $P_3/D_{1,2}$ (Nos 41—43) and $P_3/(S,D)_1$ (Nos 44—46)

No	Locality	Ore occurrences: Dip	Alt.	Dip/Str.	h	l	w	Minerals
41	Krupa I, II	SW/40°	+ 750	stretch. NNW—SSE			0.1 1.0	**ba** cc q td
42	Drin	SW/40°	+1100 + 900	stretch. NNW—SSE			0.1 1.0	**ba** cc q td
43	Vrse	SW/40°	+ 900	stretch. NNW—SSE			0.1 1.0	**ba** cc q td
44	Lanište	330/40°	+1020	NE		torn off parts of vein		**ba si** td py
45	Dobrošin	225/st	+ 900	NE		torn off parts of vein		**ba** si td
46	Mračaj	225/st	+ 922 + 840		82	70 200	0.1 1.6	**si ba td** q

Barite veins and bodies stretch in various direction but, generally, with the northnorthwest-southsoutheast trend. Barite is the only major mineral in all barite bodies of that type; the averages in the most significant bodies (Grnica, Sabeljine Pećine and Srdivode) vary from 91.83 to 95.38 wt%. Consequently, these are monomineralic barite deposits. Other minerals: calcite, quartz, haematite+limonite, Hg-Sb-tetrahedrite, pyrite, and siderite (ankerite) are quite rare. In the oxydation zone tetrahedrite was weathered in hypergenic chalcocite, covellite, azurite, malachite, cinnabar, goethite and lepidocrocite; and pyrite and siderite in Fe-hydroxides.

Table 5

Chemical composition of barite crude ore from Devonian rocks

Symbol	Ore deposits	Number of analyses	$BaSO_4$ wt%	Fe_2O_3 wt%	CaO wt%	SiO_2 wt%
26—27	Grnica 1 and 2	4	91.14—97.55 av. 95.38	0.13—0.65 av. 0.34	0.18—0.75 av. 0.46	0.0—5.04 av. 1.26
28—29	Grnica 3 and 4	2	90.40—93.96 av. 91.83	0.28—1.18 av. 0.87	2.43—2.45 av. 2.44	0.50—1.21 av. 0.85
31	Sabeljine Pećine II	17	78.30—98.38 av. 94.47	0.05—1.20 av. 0.41	0.0—4.03 av. 1.69	0.0—2.32 av. 0.77
40	Srdivode	6	91.10—94.32 av. 92.63	1.18—3.30 av. 1.99	0.05—1.43 av. 0.68	0.45—2.90 av. 1.90

References: Vasiljević & Zec (1961)

(4) Ore Occurrences inside the Voljevac Fault Zone ($P_3/D_{1,2}$); P_3/S, D)

The Voljevac Fault Zone, stretching in the northwest-southeast direction, is characterized by tectonic contact between Permian formations (sandstones, shales, limestones, and conglomerates) and Middle Devonian limestones. Along the fault zone significant barite veins: Krupa I, II, Drin, and Vrse (Nos 41—43) are found. Only parts enriched in barite were mined and the ores mixed with limestones were abandoned (Table 4).

The Lanište barite vein (No 44) is located west of the village Seoci. The vein, which is made mostly of barite with quartz-siderite as subordinate minerals, is found along contact between Permian porous limestones and phyllites. In a similar position is the Dobrošin barite vein (No 45) in which tetrahedrite nests occur.

The Mračaj vein (No 46), next to the Maškara vein (No 6), represents the most significant tetrahedrite-bearing occurrence of the MBSM. The old Mračaj mine was located east of Mračaj about 7 km southeast of Gornji Vakuf.

Illyrians, Romans and Saxsons were mined shallow oxydized parts inside Upper Permian limestones. In the Austrian-Hungarian time exploration works were carried out in the primary zone which was partially exploited until 1917 when the Maškara mine was closed. The mine was opened with two adits, the upper one (901 m) was ore-bearing and the lower one (860 m) was barren. Katzer (1925) was of the opinion that the ore-bearing part of the deposit represents a broken part of the nappe of an unknown root or was thinned or abraded along the Voljevac Fault Zone. The mining activity, renewed in 1925, succeeded to detect part of »the broken root with the vein« at the lower level (860 m) which was significantly dislocated in southeast direction along the northwest-southeast trending fault (R/II in Fig. 6). The mining works followd the vein for 29 m along the incline up to the altitude of 840 m and also behind the eastern fault towards the north. These works proved new 3000 t ore. In the period 1928/32 385 t ore with 3 t native mercury was produced (Eschke, 1929) and the additional activity carried out in 1939/40 gave 1000 t crude ore with 8.5 t native mercury. Some intensive works were organized in 1959/61 (Vasiljević & Zec, 1961) when detailed cleaning of the underground mining works gave better inside in the position and quality of the ore deposit (Fig. 6).

The Mračaj mine is located inside the Voljevac Fault Zone in which, along contact with Silurian-Devonian phyllites, separate blocks of limestones are wedged in Groeden sandstones and conglomerates. The ore vein and adjacent rocks, generally, stretch in the northnorthwest-southsoutheast direction but with the opposite dips — the vein towards the northeast and surrounding rocks towards the southsouthwest. The vein and adjacent rocks are intersected by younger joints stretching in the northwest-southeast direction and dipping steeply (60—85°) towards the northeast. The joints are filled by joint clays (fault gouge), phyllite debris and kaolinized metarhyolites. These faults joints gave rise to doubled wrapping of the ore vein and block with sediments in the northnortheastern strike with the dip towards the eastsoutheast between the fractures R_I and R_{II} and

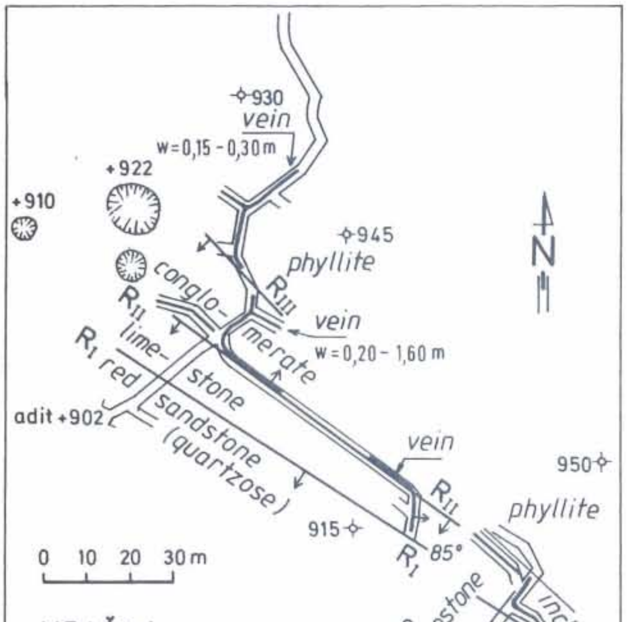


Fig. 6. Mračaj vein (No 46 in Fig. 1b). Underground mining works. R — faults; w — width of the vein. Made by Jurković (1951); Vasiljević & Zec (1961).

steplike subsidence towards the southwest. The entire block is displaced towards the southeast. The ore vein is located in phyllites, in its northeastern parts and in limestones, dolomitized limestones, sandstones and conglomerates, in its southwestern parts. An apophyse of kaolinized and sericitized metarhyolite is wedged in along the fault zone R_{II}.

The Mračaj vein has a vertical range of 82 m and is 70 to 200 m long and 0.1 to 1.6 m thick (clustered from 0.2 to 0.5 m, in some places up to 0.7 m) in Permian sediments, whereas its thickness is 0.2—0.3 m in phyllites, where it contains enough joint clays. In the phyllite zone the vein wedges towards the north.

The mineral paragenesis is very simple. Major nonmetallic minerals are barite and predominant siderite which is 2 to 2.5 times enriched in tetrahedrite than the barite. Chalcopyrite is an accessory mineral. The vein includes phyllite fragments and in some places an orebearing breccias was generated. The average tetrahedrite content was 3.7 wt% in barite, 13.7 wt% in barite-siderite, and 29.4 wt% in siderite crude ore. The average crude ore contained 15.8 to 23 wt% tetrahedrite with 6.02—7.72 wt% Cu, 0.40—0.82 wt% Hg, and 3.19—3.93 wt% Sb.

General Paragenetic Features of Hydrothermal Mineralization of the Gornji Vakuf area

Katzer (1907, 1925) emphasized a very important fact that ore occurrences of the same paragenetic kind occur in all rock types and in all stratigraphical levels of the area of Gornji Vakuf. He noticed the vertical distribution of barite and siderite in the Maškara mine.

Detailed correlative analysis of all explored occurrences (Jurković 1956, 1958b, 1959, 1960) and this paper showed that the quantitative relations between separate minerals (siderite, barite and Hg-tetrahedrite) and the participation of subordinate constituents (quartz, calcite, and pyrite) depend on host rocks of a separate ore occurrence and on the position in the stratigraphic column.

Quantitative Proportions of the Major Minerals

In barite-siderite occurrences in which siderite predominates over barite, and with quartz as a subordinate constituent, Hg-tetrahedrite has an optimum participation. Typical representatives of the Maškara and Mračaj veins contain 25—65 wt% tetrahedrite in the siderite crude ore and 10—15 wt% in the barite crude ore. The Saski Rad, Desna, and Kašli Brdo occurrences, in which barite predominates over siderite, suddenly decreases the Hg-tetrahedrite content. The similar empoverishment in tetrahedrite takes place in the occurrences which contain more quartz on account of barite (Šeferovići, Rad, Daganj, Valice). The occurrences found in limestones or dolomitized limestones (Sabeljine Pećine) are characterized by almost monomineralic barite bodies with a few weight percentage of tetrahedrite. The optimum participation of barite is in Middle Devonian carbonate rocks. Such occurrences average 90—95 wt% barite and accessory siderite is hardly noticeable (Grnica 3, 4, Srdivode). The optimum siderite participation is connected with the deposits located in metaclastic rocks, particularly in the ones from lower parts of the Silurian-Devonian complex.

Distribution Zonation of the Genetic Types

Concerning a vertical zonation, in higher levels of the ore occurrences located in metamorphic rocks barite predominate over subordinate tetrahedrite, whereas in lower parts is present siderite with plenty of tetrahedrite (± quartz). The typical representative is the Maškara vein in which a horizontal zonation, with predominant barite in the norther flank and predominant siderite in the southern flank, was noticed.

A vertical zonation inside the geological column was noticed between the occurrences of lower and higher levels of the Silurian-Devonian complex. In the lower level siderite with subordinate barite and quartz and quartz with pyrite are common, whereas in the higher level barite with subordinate siderite or without it are common. It is significant the difference between paragenetic types in clastic rocks of the Silurian-Devonian complex, characterized by polymineralic parageneses, as distinguished from the Middle Devonian complex characterized by almost monomineralic barite occurrences.

The spatial distribution of the Gornji Vakuf ore-bearing area is brought about by differences in geology. In its northwestern parts consisting of Middle Devonian limestones monomineralic barite occurrences are abundant. By contrast, the southeastern parts of the area, made up of Silurian-Devonian metaclastic rocks, are characterized by barite-siderite-tetrahedrite polymineralic paragenesis.

C. Metamorphogenic deposits

The Šeferovići-type metamorphogenic quartz deposits (no 47 in Fig. 1b) occur in strongly tectonically disturbed phyllites along the southeastern margin of the village Šeferovići (Katzer, 1907, 1925). The paragenesis consists of colourless or milky, optically anomalous quartz with abundant pyrite aggregates (Jurković 1956). This type of quartz occurrences are synorogenic or post-orogenic (Jurković et al., 1993).

Geochemical Data on Ore-Forming Minerals of the Gornji Vakuf Area

Chemical analyses on barite and Hg-tetrahedrite, isotopic analyses of sulphate sulphur in barites, sulphide sulphur in Hg-tetrahedrite and pyrite, and oxygen and carbon isotope composition of siderite from the Maškara and Trošnik were carried out.

All analytical data obtained for the Mid-Bosnian Schist Mountains (MBSM) were correlated with corresponding data for other ore-bearing Hg-tetrahedrite data from »The western Graywacke Zone« in Austria (Brixlegg, Kitzbuehel) and for

Hg-tetrahedrite deposits from »Rudnanske rudne pole« included in Spišsko—Gemersko—Rudohorie in Slovakia. Both in Tirol and Rudnany the Hg-tetrahedrite deposits are also located in Devonian to Permian rocks.

A. Quantitative chemical analyses

1. Siderite. A fresh light yellowishbrown, coarse-crystalline »siderite-spar« from the barite-siderite-Hg-tetrahedrite Maškara vein and, for the scope of correlation, a siderite sample from the barite-siderite Trošnik deposit, with pyrite and tetrahedrite (from the area of Fojnica inside the MBSM metallogenic zone) were analyzed. The results are presented in Table 6, together with the average analysis of siderite from the Rudňany area in Slovakia (Cambel & Jarkovský et al., 1985). P-T conditions of crystallization can be estimated by the $MgCO_3$ content of siderite. A significantly higher $MgCO_3$ content in the Trošnik siderite is due to higher temperature paragenesis of Trošnik (Jurković, 1959) in which significant quantities of gold-bearing pyrite and tetrahedrite, which is also gold-bearing, contains minimum mercury in the tetrahedrite lattice. Similar paragenesis and $MgCO_3$ content are in the Rudňany veins. In the Maškara vein the $MgCO_3$ content is significantly lower, what should correspond to the paragenesis in which tetrahedrite with high Hg-content is the only ore mineral. Comparatively higher $CaCO_3$ and lower $MnCO_3$ contents, genetically, link the Maškara and Trošnik deposits whereas in the Rudnány area $CaCO_3$ and $MnCO_3$ values are distinctly lower.

Table 6

Analyses of siderites

Maškara 4a(013)			Trošnik 007			Rudnany	
Components			Components			Components	
wt%		mol %	wt%		mol %		wt%
81.23	$FeCO_3$	75.13	74.39	$FeCO_3$	70.38	$FeCO_3$	83.38
9.52	$CaCO_3$	10.18	12.89	$CaCO_3$	14.13	$CaCO_3$	0.69
6.59	$MgCO_3$	12.22	10.03	$MgCO_3$	13.03	$MgCO_3$	11.32
2.66	$MnCO_3$	2.47	2.69	$MnCO_3$	2.52	$MnCO_3$	4.61

2. Strontium in Barite. Sr-content was analyzed in 13 samples of barite using the emission spectral method with Ba as the internal standard. The method used has been described by Šiftar (1974). Controlling analyses were carried out by the precipitation method from a homogeneous solution, barium was precipitated as Ba-chromate, strontium as $SrCO_3$ and afterwards as sulphate as described by Gordon et al. (1959). Data obtained are presented in Table 7. The results for the Gornji Vakuf area were compared with the ones from whole MBSM area. Sr-content in barites from

Table 7

Strontium contents in barites from Gornji Vakuf area

No	Symbol	Ore deposit	Host rocks		wt% $SrSO_4$ single	average	References
1	26—27	Grnica 3,4	$D_{1,2}$	lm	2.54		Vasiljević & Zec (1961)
2	30	Sabeljine Pećine I	$D_{1,2}$	lm	1.60		
3	31	Sabeljine Pećine II	$D_{1,2}$	lm	5.90	3.00	this paper
4	40	Srdivode	$D_{1,2}$	lm	1.80		
5	18	Djamuš Brdo E-79/2	$(S,D)_2$	sds/sch	2.70		
6	20	Cvrče—Zaganj	$(S,D)_2$	sds/sch	2.20	2.47	this paper
7	21	Borova Ravan	$(S,D)_2$	sds/sch	2.50		
8	6	Maškara 2	$(S,D)_1$	sch	3.60		
9	6	Maškara 5	$(S,D)_1$	sch	3.80		
10	6	Maškara VII	$(S,D)_1$	sch	3.40	3.23	this paper
11	6	Maškara VIII	$(S,D)_1$	sch	3.70		
12	6	Maškara IX	$(S,D)_1$	sch	1.90		
13	6	Maškara E—16/2	$(S,D)_1$	sch	3.00		
1—13	GV	Gornji Vakuf area	Lower Palaeozoic		1.60 5.90	2.90	this paper
1—24	RA	Raštelica, MBSM	P_3		2.10 9.70	4.49	Šiftar (1990)
1—86	MBSM	Mid—Bosnian Schists Mountains	Palaeozoic		0.40 8.80	4.22	Šiftar (1988)
1—76	RUD	Rudňany, Droždiak vein	P/C/D		0.35 3.00	1.25	Cambel—Jarkovsky et al. (1985)
1—23	RUD	Rudňany, Zlatnik vein	P/C/D		0.90 1.80	1.24	
	BRI	Brixlegg, Austria	D_1		4.99 9.98	7.50	Weber (1986)
	BRI	Brixlegg, Austria	D_1		0.40 5.03	2.14	Frimmel & Papesch (1990)
	KI	Kitzbühel, Austria	D_1/P		1.24 2.40	1.82	Pak (1978); Schroll & Pak (1990)

Brixlegg and Kitzbuehel (Tirol) area are given for the scope of correlation.

Barite samples located in Middle Devonian carbonate rocks have $SrSO_4$ contents between 1.8 and 5.9 wt%; the vein types (Grnica 3 and 4 and Srdivode) display narrow variation interval (1.8—2.5 wt%) and the irregular barite bodies the wider one (1.6—5.9 wt% $SrSO_4$). Barite samples from the deposits from higher parts of the Silurian-Devonian complex show $SrSO_4$ variations in the narrow space from 2.2—2.7 wt%. Barite samples from the Maškara-type deposit from the lowest stratigraphic level show uniform $SrSO_4$ content from 3.0 to 3.8 wt% (except one sample). The average values for all three deposit types are very close indicating the uniform metallogeny for the Gornji Vakuf area as a whole.

Comparing the average content of 2.9 wt% $SrSO_4$ with the average content of 4.22 wt% $SrSO_4$ for the entire MBSM area and with the values from 11 MBSM separate ore areas, then it can be seen the Sr-content from the Gornji Vakuf area is the lowest when correlated with other 10 ore areas. Barite deposits located nearer to large rhyolite massifs have higher Sr-contents but such deposits have some features of higher temperature occurrences.

Barite from the veins in the Rudňany area have considerably lower values of $SrSO_4$ contents, in average 1.25 wt% (Cambel & Jarkovsky et al., 1985). On the contrary, barite deposits with Hg-tetrahedrite, located in the Lower Devonian Schwaz dolomites from Brixlegg in Tyrol have very high values ranging from 4.99 to 9.98 wt% $SrSO_4$, whereas barite, almost sulphidefree, located inside Lower-Middle Devonian Spielberg dolomites and partially in the karstified Permian rocks show very low contents of $SrSO_4$ (1.24—2.40 wt%).

3. Tetrahedrites. Table 8 presents variation intervals of some elements in 10 samples of tetrahedrite crystals and almost pure grain-aggregates of tetrahedrite. The correlation of tetrahedrites from the areas of Gornji Vakuf, Brixlegg and Rudňany shows that they represent typical Hg-tetrahedrites (schwazites). The variation intervals for Hg are very great in all the three areas, but the averages are the highest in the Rudňany veins and the lowest in the Brixlegg deposits whereas the average of the Gornji Vakuf area (4.12 wt%) is in the between. Cambel & Jarkovsky et al. (1985) proved that the Hg-content of tetrahedrites decreases going to central parts of the area in relation to external parts and from upper parts of the vein towards its lower parts. The content of Hg in tetrahedrite lattice decreases by increasing P-T-conditions of the deposit formation. Published chemical analyses (Katzer, 1907, 1925; Jurković, 1959, 1969, 1986) support this hypothesis, because the Hg-contents are, in average, lower in tetrahedrites from the areas of Kreševo and Fojnica with higher temperature parageneses.

Tetrahedrites from the Gornji Vakuf area have higher Fe values than other two areas, lower Zn and Ag contents relative to Brixlegg and very similar ones relative to Rudňany. It is important to emphasize that the Brixlegg tetrahedrites contain Mn but does not Bi. In the Gornji Vakuf, deposits are gold-bearing as the other ones in the MBSM which is not the case with the Brixlegg and Rudňany deposits.

B. Isotope Data

In stable isotope measurement the standard as follows were used:

NBS-127 (dec. = 20.05)

20.12 $\delta^{34}S_{C,D}$ 21.782 $^{32}S/^{34}S$ 0.23 std

NBS-122 (dec. = 0.08)

0.13 $\delta^{34}S_{C,D}$ 22.217 $^{32}S/^{34}S$ 0.29 std

Analyses were carried out in the Institute »Jože Štefan«, Ljubljana, Slovenia.

Isotope Analyses of Sulphate Sulphur in Barites

Two samples from the deposits in Middle Devonian limestones, two from lower parts and three from higher parts of the Silurian-Devonian metamorphic complex were analysed and data obtained are presented in Table 9 together with correlative data for all 11 ore-bearing areas from the MBSM, for the Raštelica area, and for the Rudňany and Kitzbuehel areas.

Data presented in Table 9 demonstrate dictinct differences of barites from different stratigraphic levels and between deposits located in clastic and

Table 8

Analyses of Hg-tetrahedrites (wt %)

	Gornji Vakuf, Bosnia		Rudňany, Slovakia		Brixlegg, Austria		References
	10 analyses	av.	41 analyses	av.	numerous	av.	
S	20.4 —25.9	23.43	22.2—26.0	24.08		25.8	for Gornji Vakuf:
Fe	1.1 — 8.1	4.50	0.2— 5.8	2.59	2.5— 3.0	2.6	Katzer (1907, 1925)
Cu	36.2 —41.8	38.91	34.6—46.0	39.20	37.0— 38.0	37.5	Jurković (1960)
Zn	0.3 — 4.2	0.96	0.1— 4.0	0.79	4.0— 6.0	5.4	and this paper
Hg	1.5 —16.0	4.12	0.0—19.8	9.70	0.0—15.0	1.8	
As	2.1 — 5.8	4.18	2.3— 7.4	4.87	5.0— 6.5	6.2	for Rudňany:
Sb	16.8 —27.4	21.68	14.6—23.9	18.84	15.0—21.0	18.6	Cambel—Jarkovsky
Bi	0.03— 0.33	0.24	0.0— 2.3	0.71	0.0— 0.0	0.0	et. al (1985)
Ag	0.08— 0.21	0.14	0.0— 0.4	0.12	0.5— 0.6	0.5	for Brixlegg:
Au	20—50 g/t		ø		ø		Lukas (1971)
Mn	ø	0.0	ø	0.0		0.5	Gstrein (1983)
Total		98.20		100.87		98.71	

carbonate rocks of the Gornji Vakuf area. Based on 56 barite samples from the ore areas of the MBSM the average $\delta^{34}S$ value is +11.07‰ which corresponds to the isotopic value of sulphates from Permian seas (Claypool et al., 1980). The value is close to the barites from Middle Devonian limestones of the Gornji Vakuf area but is significantly lower than in the ones found in the Silurian-Devonian metamorphic rocks. The average value of isotopic sulphate sulphur for the Gornji Vakuf area is for about 4 promiles higher than the average value for the whole MBSM. In the Raštelica ore bodies, which represents a stratified Upper Permian deposit, the average $\delta^{34}S$ value is + 6.28‰.

The Rudňany barites have the identical average value of isotopic sulphate sulphur as the ones from the Gornji Vakuf area (Cambell & Jarkovsky et al. 1985). The Brixlegg barites with Hg-tetrahedrites have the average isotopic composition of +23.5‰ which is typical for Devonian marine sulphates (Schulz, 1972; Schroll & Pak, 1980; Weber, 1986). The Kitzbuehel barites, located both in Middle and Lower Devonian dolomites and Permian karstified sediments, which are nearly without sulphides, have the average sulphate sulphur in barites of +8.15‰. According to Mostler (1982), Schroll & Pak (1980) and Weber (1986) this is typical for the Permian.

The $\delta^{34}S$ value for sulphate sulphur of Slovenian mercury-bearing barite deposits containing cinnabar and galena which are represented by the Litija one, located in Carboniferous-Permian sediments, and the Pleše one, located in Permo-Carboniferous and partly in Triassic sediments, have much higher values: from +16.52 to 19.28‰ (Drovenik et al., 1976) and +17 to +25‰ (Ozerova et al., 1973) respectively.

Isotope Analyses of Sulphide Sulphur in Hg-Tetrahedrites

Six tetrahedrite samples from the ore deposits located in the $D_{1,2}$, $(S, D)_2$ and $(S, D)_1$ stratigraphic units were analysed and the results are presented in Table 10.

The average $\delta^{34}S$ value for 6 samples is −10.13‰ which is very close to the average $\delta^{34}S$ of −10.49‰ obtained on 18 tetrahedrite analyses carried out to date for six ore areas of the MBSM (Kreševo, Duboki Vaganj, Inač—Kostajnica, Mt. Zec, Deževica and Gornji Vakuf). All analyzed

Table 9

Isotopic values of sulphate sulphur in barites

No	Symbol	Ore deposits	Host rocks	$\delta^{34}S$‰	Average values	References
1	30	Sabeljine Pećine 1	$D_{1,2}$	+10.86	+11.92	this paper
2	31	Sabeljine Pećine 2	$D_{1,2}$	+12.99		
3	6	Maškara VIII	$(S,D)_1$	+13.31	+14.96	this paper
4	6	Maškara IX	$(S,D)_1$	+16.07		
5	18	Djamuš Brdo E—78/2	$(S,D)_2$	+18.48	+17.19	this paper
6	20	Cvrče—Zaganj	$(S,D)_2$	+17.21		
7	22	Borova Ravan	$(S,D)_2$	+15.89		
1—7	GV	Gornji Vakuf area	Palaeozoic	+10.86 to +18.48	+14.97	this paper
1—56	MBSM	Mid Bosnian Schist Mountains	Palaeozoic	+ 1.0 to +18.48	+11.07	Palinkaš & Jurković (1993)
1—17	RA	Raštelica	P_3	− 0.9 to +11.70	+ 6.28	Šiftar (1990)
1—4	LI	Litija—Pleše, Slovenia	T_1/P/C	+17.0 to +25.0	+21.0	Ozerova et al. (1973)
1—4	LI	Litija—Pleše, Slovenia	T_1/P/C	+16.52 to +19.28	+17.90	Drovenik et al. (1976);
1—10	RUD	Rudňany, Slovakia Droždiak vein	P/C/D	+14.1 to +18.2	+16.00	Cambel—Jarkovsky et al. (1985)
1—6	RUD	Rudňany, Slovakia Zlatnik vein	P/C/D	+ 9.8 to +15.0	+13.60	
1—2	BRI	Brixlegg, Austria	D_1	+23.1 +23.9	+23.50	Mostler et al. (1982); Schulz (1972);
1—4	Ki	Kitzbühel, Austria	$D_{1,2}$/P	+ 7.5 + 8.8	+ 8.15	Schroll & Pak (1980)

Legend: Symbol = number of the ore occurrences in the text and on the fig. 1 b.

Table 10

Isotopic values of sulphide sulphur in tetrahedrites

No	Symbol	Ore deposits (area)	Host rocks	$\delta^{34}S$‰	from-up to	References
1	31	Sabeljine Pećine 2	$D_{1,2}$	−12.82		this paper
2	6	Maškara DT 4	$(S,D)_1$	− 7.91		Kubat et al. (1979/80)
3	6	Maškara, crystals	$(S,D)_1$	−10.81		this paper
4	8	Saski Rad III, E-41	$(S,D)_1$	− 9.50		this paper
5	18	Djamuš Brdo E-78	$(S,D)_2$	−10.69		this paper
6	20	Cvrče—Zaganj E-91	$(S,D)_2$	− 9.68		this paper
1—6	GV	Gornji Vakuf (area)	Palaeozoic	−10.13	− 7.91 −12.82	this paper
7—24		Mid-Bosnian Schist Mountains (MBSM)	Palaeozoic	−10.49	− 5.50 −15.40	Palinkaš & Jurković (1993)
1—14		Rudňany veins	Palaeozoic	− 4.44	− 0.70 − 9.40	Cambel—Jarkovsky et al. (1985)

tetrahedrites are characterized by negative values due to a significant participation of the light sulphur isotope above the normal for troilite. For the scope of correlation the average values for 14 isotopic analyses of sulphide sulphur from the Rudňany Hg-tetrahedrite samples were given. This average value is much lower, but all samples have negative values. Cambel & Jarkovsky et al., (1985) explain this phenomenon by contamination of sulphur with lighter isotopic cmposition from surrounding sedimentary rocks from higher parts of veins. This is due the fact that the lighter isotope proportion in the Rudňany area decreases in lower parts of the deposit and thus its composition is close to the one of primary igneous origin. The same authors do not exclude effects of thermodinamic processes during the mineralization as one of controlling factor for the lightening of isotopic composition.

It was noticed that tetrahedrites from the Gornji Vakuf deposits, located in stratigraphically higher levels, have increasing proportions of lighter sulphur isotope which can be explained by contamination with sulphur from surrounding sedimentary rocks, particularly those enriched in organic matter. This problem was considered in detail elsewhere (Jurković et al., 1993).

Isotopic Analyses of Sulphide Sulphur in Pyrite

In Table 11 are presented isotopic compositions for pyrites from the Maškara deposit and correlative data for pyrites from other three deposits from the MBSM. Positive values of the sulphur isotopic composition in the Maškara deposit and coexisting distinctly negative values for tetrahedrites may be explained by a difference in the sulphur origin in the Maškara deposit. Cambel & Jarkovský et al. (1985) also noticed the difference in isotopic composition of coexisting sulphides in the Rudňany veins. Chalcopyrite and tetrahedrite are characterized by negative and cinnabar by positive values. According to their presumption this is brought about either by a difference in the sulphur source or kinematic processes which influenced the equilibrium between isotopes.

Oxygen and Carbon Isotopic Composition of Siderites

Table 12 includes $\delta^{18}O_{PDB}$ and $\delta^{13}C_{PDB}$ values for two siderites from the Maškara deposit and for the scope of correlation for siderites from the Rudňany, Vareš and Ljubija areas and neocalcite from the Kreševo area.

Carbon isotopic composition of the Maškara siderite, sample E—91/1 with $\delta^{13}C = -5.55$‰ is close to the values for volcanogenic and endogenic CO_2, respectively (Deines & Gold, 1973; Faure, 1977, Hoefs, 1989, Ohmoto, 1986). The second sample, E—9/3 with $\delta^{13}C = -1.81$‰ shows a stronger influence of sedimentary organogenic carbon.

In correlation with other siderites, the Maškara siderite and Kreševo neocalcite are similar to the Rudňany and Kitzbuehel siderites and their carbon isotopic composition indicates primary, endogenic carbon origin influenced more or less by carbon of organogenic-sedimentary origin from host rocks. The Vareš and Ljubija siderites are distinctly influenced by carbon of organogenic-sedimentary origin.

The differences in carbon isotopic composition of the two Maškara siderite may be due different generations (siderite I and II). According to Rye & Ohmoto (1974) late-stage siderite commonly shows greater share of the heavy carbon isotope.

Table 11

Isotopic values of sulphide sulphur in pyrites

no	Symbol	Ore deposit	Host rocks	$\delta^{34}S$‰	Mineral	References
1	26	Maškara 5a	$(S,D)_1$	+6.61	pyrite	this paper
2	IOK	Točak Brook (potok)	$D_{1,2}$	−9.86	pyrite	this paper
3	RA	Raštelica	P_3	−0.70	pyrite	Šiftar (1990)
4	LJE	Ljetovik	P_3	−4.61	pyrite	this paper

Table 12

Isotopic values of oxygen and carbon in siderites

No	Symbol	Ore deposits	Host rocks	Mineral	$\delta^{18}O$‰	$\delta^{13}C$‰	References
1	6	Maškara E-91/1	$(S,D)_1$	siderite	− 8.82	−5.55	this paper
2	6	Maškara E-9/3	$(S,D)_1$	siderite	−10.33	−1.81	this paper
3	MBSM	Jelica, Kreševo	$D_{1,2}$	calcite	− 7.10	−2.45	Palinkaš & Jurković (1993)
4	V	Vareš, Bosnia	T_2	siderite	− 6.50	−1.20	Schroll et al. (1986)
5	L	Ljubija, NW Bosnia	C_2	siderite	− 9.60	−0.90	Schroll et al. (1986)
6	RUD	Rudňany, Slovakia	(P,D)	siderite	−11.0	−3.7	Cambel—Jarkovsky et al. (1985)
7	KI	Kitzbühel, Austria	D	siderite	−12.5	−8.1	Schroll et al. (1986)

Oxygen isotopic composition in the Maškara siderite is similar to the one of the Ljubija siderite, but higher than in the Rudňany siderites, and lower relative to the Vareš and Kreševo siderites, respectively.

Fluid Inclusion Study in Barite from Sabeljine Pećine
(made by L. Palinkaš)

Milky, and semitransparent samples of the barite from the Sabeljine Pećine deposit, located in Middle-Devonian limestones, contain numerous, small fluid inclusions (1—15 μm in diameter) with irregular shape, only occasionally mimicking crystal forms. Uniform degree of feel of the two phase inclusions (L+V) and their random spacing suggest primary origin although some inclusion trails warn on existence of the secondary ones as well. A few performable homogenization runs reached temperature (T_h) of 200 °C. Cryometric study failed due to poor transparency of the studied material.

Discussion

Age of many European hydrothermal deposits of U, W, Sn, Au, Pb, Zn, CaF_2 and $BaSO_4$ of the Palaeozoic complexes and the overlying Permo-Mesozoic and Tertiary sedimentary cover were last decades matter of dispute. There are many different opinions on their genesis. Both types of the deposits were related to the Variscan metamorphism and the Variscan granites or to the post-Variscan tectonic events (Baumann, 1979; Walther, 1982).

Based on systematic mapping of the crustal fluids using fluid inclusion analysis Behr & Gerler (1987) and Behr et al. (1987) could differentiate two distinct fluid systems which enabled them to assign many of the ore deposits in the Federal Republic Germany to the Variscan or to the post-Variscan tectonic events.

The first group of fluids is related to the Variscan compression tectonics and metamorphism ending in the Early Permian. The second system is related to the fault tectonics, uplift and sedimentation of the Variscan molasse stage and it is present from the Late Permian up in the Tertiary.

In the same decade Marshall & Giligan (1987) recognized a new class of metamorphogenic mineral deposits, opening simultaneously the role of fluids in regional and metamorphic processes. Two end member models can occur in field: the prograde devolatilization and retrograde leaching model (Pohl, 1992). The first model involves liberation of aqueous, low-salinity fluids with variable amounts of CO_2, CH_4, N_2 during prograde metamorphism by devolatilization reactions, whereas the second model stresses the introduction of water from outside the hot metamorphic rock body during the retrograde cooling phase of the system. Pohl (1993) investigating the hydrothermal, epigenetic ore deposits in the Eastern Alps classified them on the basis of their fluids in one of above mentioned metamorphogenic ore groups.

The genesis of polymetallic deposits, on the one hand, and Hg-tetrahedrite-bearing barite deposits, situated in the MBSM, on the other hand, has been for long time the subject of contraversial discussion. Both types of the deposits were related to the Triassic metallogeny (Janković, 1987), Early Permian continental rifting (Palinkaš, 1990) and Hercynian metallogeny from the Middle Carboniferous to the Lower Permian for the polymetallic deposits, and to the Late Permian for the tetrahedrite-barite deposits (Jurković, 1991).

Recently, Palinkaš & Jurković (1993) distingusihed the following genetic types of ore depo-

PLATE I Microphotographs of thin and polished sections of the ore and gangue minerals in the ore deposits of the Gornji Vakuf area; Photos made by I. Jurković.

Phot. 1 Maškara deposit No 6), thin section. Coarse-grained strongly oxidized siderite (si) fills interstices of the idiomorphic barite (ba) crystals, + Nicols

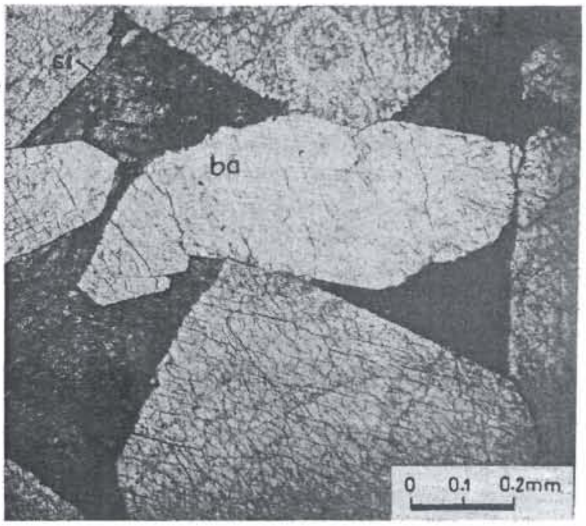
Phot. 2. Maškara deposit (No 6), thin section. Idiomorphic quartz (q) crystals in siderite (si), characterized by distinct rhombohedral cleavage, + Nicols

Phot. 3. Maškara deposit (No 6), thin section. Barite (ba) replaces idiomorphic quartz (q) crystal. In the left lower corner tetrahedral section of the bigger tetrahedrite crystal (black), + Nicols.

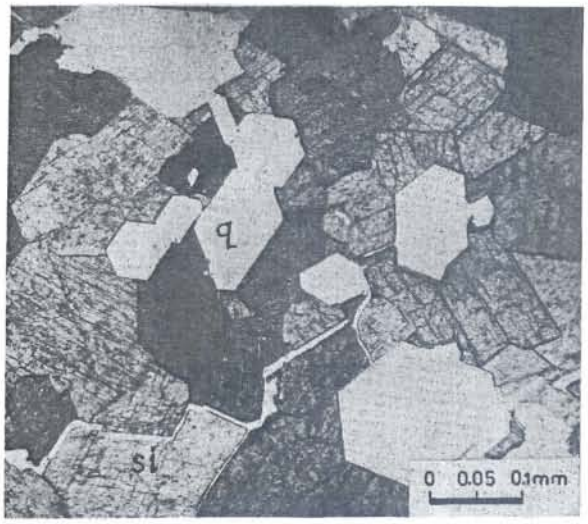
Phot. 4. Maškara deposit (No 6). Polished section. Small irregular mass of gold (Au) in tetrahedrite (td), caught by weathering

Phot. 5. Đamuš Brdo (No18). Polished section, in cedar oil. Ag-Fe-sulphide (su) and Ag-Au telluride (te) replace tetrahedrite (td) caught by weathering in chalcocite, covellite, cinnabar, goethite, lepidocrocite, malachite, azurite etc.

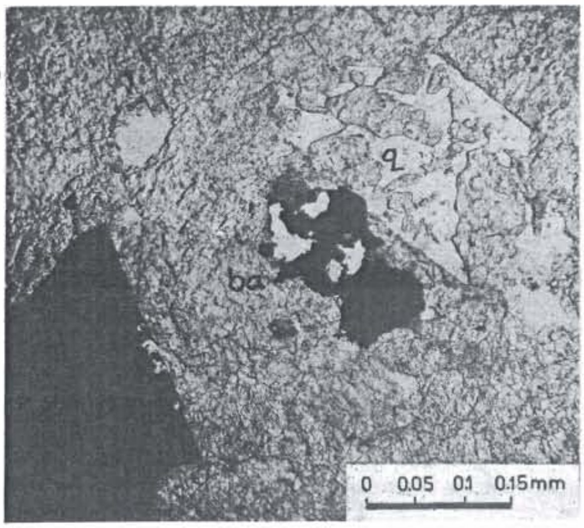
Phot. 6. Ladina Voda (No 16). Thin section. Haematitization (he, black) of coarse-grained siderite (brown-spar) (si) along cleavage planes effected by regional metamorphism, + Nicols



Phot. 1



Phot. 2



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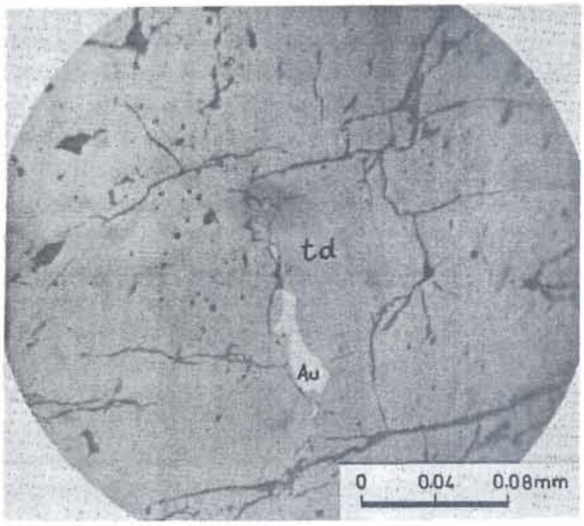

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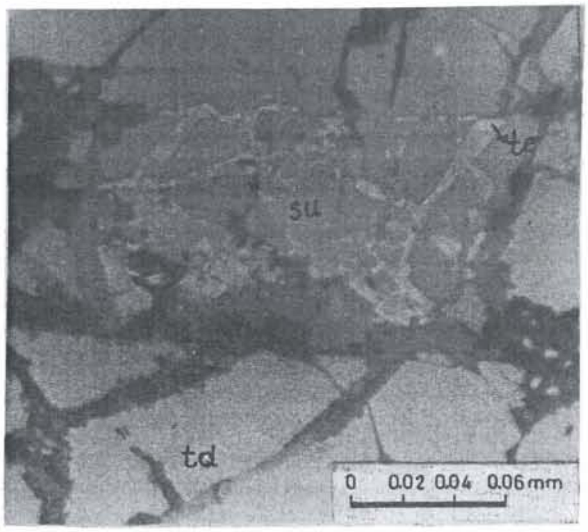

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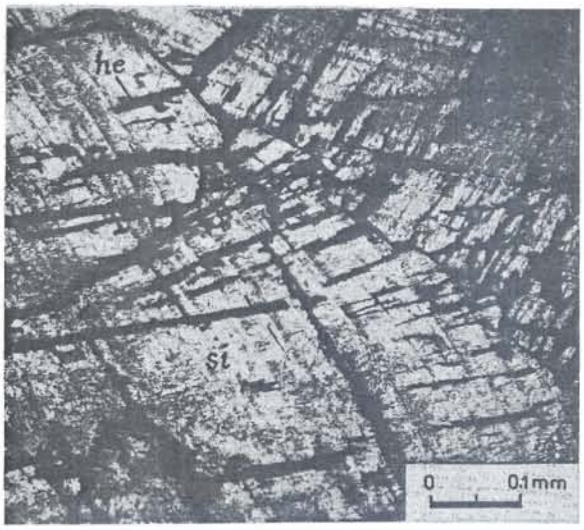

Phot. 6

PLATE I

sits: (a) postkinematic metamorphogenic quartz deposits; (b) hydrothermal polymetallic ore deposits related to Permian rhyolite volcanism and (c) post-Variscan tetrahedrite-barite deposits generated by mixing of fluids.

The presented results of the investigations from 47 ore occurrences situated in the Palaeozoic strata of the Gornji Vakuf area, clearly proved almost identical or very similar geological and geochemical characteristics of the mineralization in both areas, the Kreševo area and the Gornji Vakuf area. The common characteristics are as follows:

- location exclusively in Palaeozoic strata;
- the epigenetic character of hydrothermal veins, breccias and replacement bodies;
- very simple and similar paragenesis: barite or barite + siderite are the main nonmetallic minerals, Hg-tetrahedrite is the preponderant main ore mineral;
- the average strontium content of barites varies in very narrow range: from 2.9 to 4.2 wt% $SrSO_4$;
- high CaO and MgO, low content in MnO in siderites;
- all tetrahedrites characteristically contain Hg, Au, Ag, and Bi. Certain differences in As, Fe and Zn can be interpreted by the different positions with regard to the fault systems and deep of the erosional level;
- the average values of the stable isotopes (sulphur, oxygen and carbon) in minerals from the Gornji Vakuf area (GV) and from the other MBSM areas are similar: $\delta^{34}S$ in barites = +15.0‰ (GV) and +11.0‰ (MBSM); $\delta^{34}S$ in tetrahedrites: −10.1‰ (GV) and −10.4‰ (MBSM); $\delta^{18}O$ in siderites: −9.6‰ (GV) and −7.9‰ (MBSM); $\delta^{13}C$ in carbonates: −3.7‰ (GV) and −0.9‰ (MBSM).

The above cited results represent evidence that the Gornji Vakuf ore deposits area belongs to the unique metallogenic province of the Mid-Bosnian Schist Mountains.

The Gornji Vakuf ore deposits are related to the fault tectonics, uplift and circulation of the modified deep basinal, highly saline brines which originated in gypsum and anhydrite bearing Middle and Upper Permian strata. The source of barium is probably related to the leaching from the enormous masses of rhyolites (containing from 300 to 3000 ppm of barium) and the widespread Variscan molasse complex. For that reason, we assign these deposits to the post-Variscan type in terms of Behr & Gerler (1987).

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