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BAKOVIĆI
THE BIGEST GOLD DEPOSIT OF BOSNIA AND HERZEGOVINA

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Tectonic setting, paragenesis, structure and texture of ores, sulphide sulphur isotopic composition allign the Bakovići veiny deposit in the group of polymetallic, postmagmatic hydrothermal deposits in the Mid-Bosnian Schist Mountains area. Crude ore is rich in gold (15 g/t). Main ore mineral is gold-bearing pyrite; quartz and siderite are the main gangue minerals. Accessories are: tetrahedrite, arsenopyrite, chalcopyrite, stibnite, galena, barite, gypsum. Production between 1895-1938 gave 2.24 t of gold and 7.47 t of silver. The Bakovići deposit was the biggest producer of gold in Bosnia and Herzegovina. The deposit is related to the Late Variscan rhyolite magmatism.

Ključne riječi: Paleozojski metasediment, metarioliti, Bakovići, Zlatonosna žica pirita, Polimetalni tip, Hidrotermalan postanak, Bosna

Tektonski položaj, parageneza, struktura i tekstura rude, izotopski sastav sulfidnog sumpora svrstava žično ležište Bakovići u gurpu polimetalnih, postmagmatskih hidrotermalnih ležišta u škriljavom gorju srednje Bosne. Rovna ruda je bogata zlatom (15 g/t). Glavni rudni mineral je zlatonosan pirit; kvarc i siderit su glavni minerali jalovine. Akcesorni minerali su: tetraedrit, arsenopirit, halkopirit, antimonit, galenit, barit, gips. Proizvodnja između 1895-1938. dala je 2,24 t zlata i 7,47 t srebra. Ležište Bakovići je bilo najveći proizvođač zlata u Bosni i Hercegovini. Ležište je genetski vezano za kasnu fazu variscijskog riolitnog magmatizma.

Introduction

The Bakovići area is located on the southern slopes of Mount Citonja, southeast of Fojnica (**Fig. 1**).

The oldest rocks of this area are represented by Lower Palaeozoic crystalline phyllites, sericite-chlorite-quartz schist with subordinate metasandstones (S o f i l j et al., 1980). These rocks are invaded by Carboniferous-Permian metarhyolites (J u r k o v i ć & M a j e r, 1954). The youngest Palaeozoic series consist of Upper Permian continental-lagoonal formations.

The unconformably overlying Triassic is represented by Scythian and Middle Triassic sediments which occur in the area of Zvonigrad, Otigošće and Orašine. In the Orašine area, an occurrence of augite-labradorite andesite was registered (J u r k o - v i ć, 1954a).

The Bakovići-type occurrences are exclusively related to Palaeozoic metasediments and metarhyolites indicating older metallogenic epoch of the Middle Bosnian Schist Mountains. Along the Željeznica River stretches a strong fault zone which gave rise to subsidence of Palaeozoic formations and thrusting of Triassic formations sediments of which are not ore-bearing. Such relations point to the conclusion that the fault originated by post-ore tectonics.

Ore occurrences of the Bakovići area are located in ores stretching generally northnorthwest-southsoutheast (**Fig. 1b and 1c**). The veins are found in metarhyolites close to contact with the phyllite series (Jasenik, Jastrebac, Glavica in the Mount Citonja, Močenik on the southern slopes of Mount Berberuša, Staro Selo, west of Fojnica), or follow contact line between schists and metarhyolites lying partly either in the first or second host rock (the Baković area). The impregnation pyrite deposits found in dolomitic limestones along contact with metarhyolites (Repište, Javornjača and Šebešić) or in metarhyolite (Pod Čavaljkom) west of Fojnica, are of a less importance.

Main characteristics of the Bakovići type ore occurrences

These ore deposits were described mainly by K a t z e r, 1905, 1925, J u r k o v i ć, 1957, 1960b, 1961, R a m o v i ć et al., 1979, B o d u l i ć et al., 1979.

Repište occurs on the eastern bank of the Repište Creek (**Fig 1c**), straightly southern of the Bakovići mine and just to the Bakovići village. The ore occurrence is located in Palaeozoic dolomitized limestones. Its major minerals are siderite, pyrite and quartz and the ore contains impregnations and minute nests of tetrahedrite in siderite and a few chalcopyrite. A selected ore probe contained 5 wt% Cu, 11 g/t Ag and 4 g/t Au. The vein was explored by 20 m long adit.

Jasenik, which is located in metarhyolite, occurs 750 m southern of Bakovići in the Jasenik Creek (**Fig. 1c**). The vein is of variable in thickness and just in some places is 0,3 m thick. Major minerals are quartz and fine-grained or dense siderite. In wastes pyrite nests with a few tetrahedrite and chalcopyrite younger than pyrite can be seen. The ore is less gold-bearing than the Bakovići ore. The degree of exploration is very low.

Jastrebac is located in schists of the Bakovići area (**Fig. 1c**). The occurrence represents a vein which is 0.1 to 0.9 m thick. The nearly vertical vein stretching

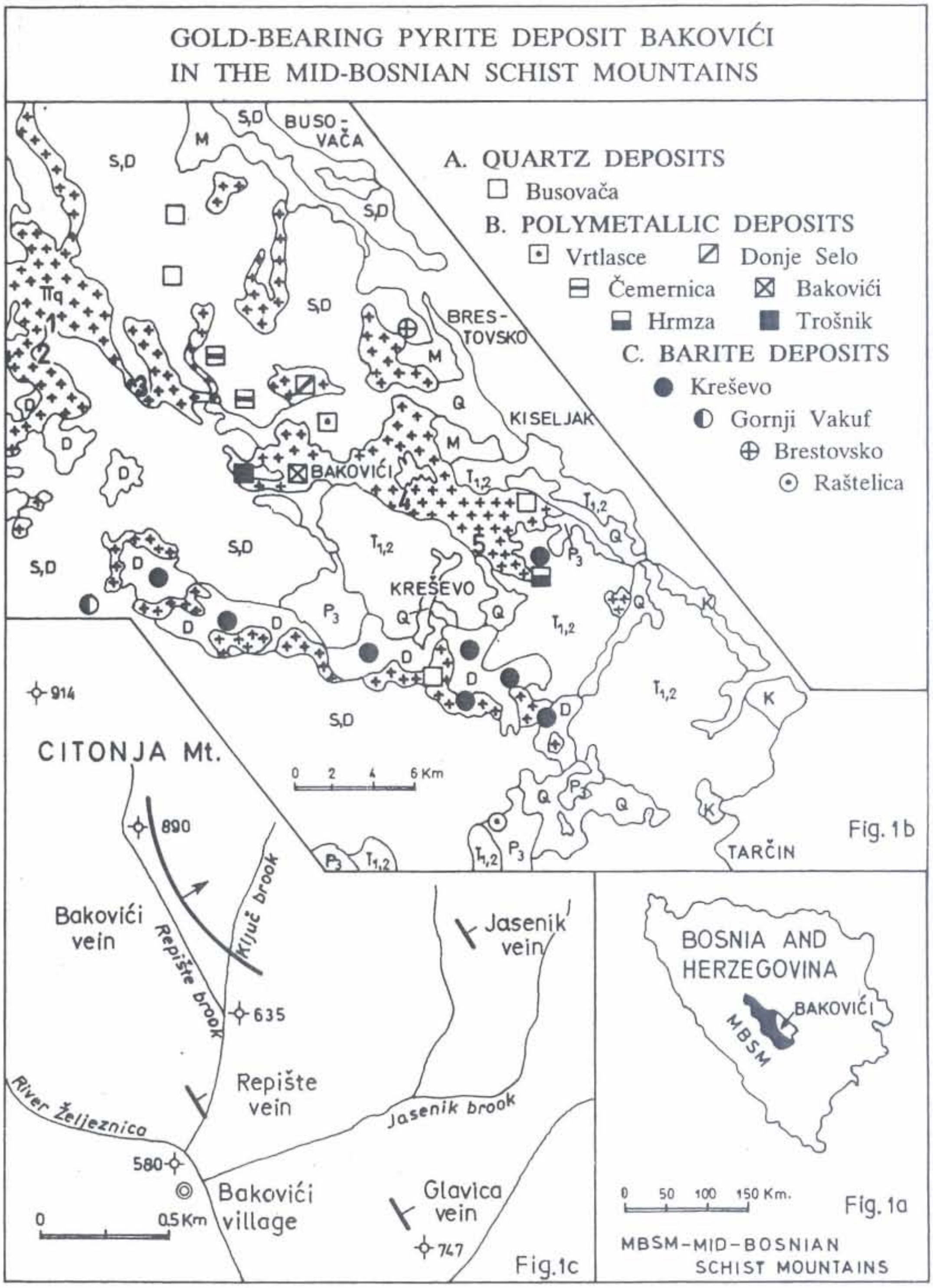

Fig. 1. GEOLOGICAL MAP OF THE BAKOVIĆI AREA

Fig. 1a

Position of the Mid-Bosnian Schist Mountains (MBSM) in the Republic Bosnia and Herzegovina.

Fig. 1b

Geological map of the MBSM (Kreševo - Kiseljak - Fojnica area) with the position of quartz deposits, polymetallic and barite deposits. Legend: Q-Quaternaire; M-Miocene; K-Cretaceous; $T_{1,2}$ -Triassic, P_3-Upper Permian; D-Devonian, S.D-Silurian/Devonian; πq- Quartzporphyre. Pyrite occurrences: 1 Šebešić 2 Javornjača 3 Staro Selo 4 Čavaljka 5 Močenik

Fig. 1c

Position of pyrite deposits in the immediate neighbourhood of the Bakovići mine.

north-south and dipping towards the east is commonly barren and filled by fault gangue or clay and quartz. Major mineral is strongly limonitized pyrite. The ore contain on average 1-5 g/t Au, locally up to 19 g/t. Both earlier and later explorations were focused to gold-bearing pyrite.

Glavica is located in metarhyolites of the northwestern flanks of Glavica, about 1 km in the southeastern extension of the Bakovići mine (**Fig. 1c**). This is a vein very variable 0.15 to 0.35 m thick and in some places it appears as a system of veinlets and fissures filled by barren clay. The vein stretching northwest- southeast is composed mostly of strongly limonitized pyrite and was explored by an adit; it showed Au variations from 3.4 to 6.8 g/t Au.

Močenik is located on the southern slopes of Berberuša Mountain, about 1 km southwest of the peak +934 m, in the upper courses of the Močenik Creek (**Fig. 1b**). The occurrence is represented by three ore veins with mutual distances of 0.7 m stretching N 35^0E and dipping towards the southeast under 45^0. The veins which are located inside sericitized and schistose metarhyolites are bounded by sharp tectonic salbands whereas their central parts are filled by fault clay. The foot parts of the clay are intensively pyritized with the width of 8-15 cm and the salbands are also slightly pyritized. Major mineral is a fine-grained pyrite. Small quantities of fluorite and realgar are noticed in the roof (in the neighbourhood are arsenic deposits Gaće, Banjak and Hrmza). The ore is gold-bearing and the selected ore gave 22.8 g/t Au in pyrite, 8 g/t Au in limonite and 4 g/t Au in the roof ore. The occurrence was explored by a shorter adit.

Pod Čavaljkom is located on the left flank of the Čavaljka Creek several hundred meters far from its mouth in the Rijekavac Creek, on the southern flanks of Mount Jasekovica, about 2 km southwest of the Višnjica village (**Fig. 1b**). This mineralization found in sericitized metarhyolites which stretches northwest-southeast and dipping towards the southwest under 50^0. Pyrite impregnations make a zone 2 m thick in which alternate thinner or thicker pyritized bands. The foot part of the mineralized zone, about 0.6 m thick, is intensively pyritized and followed by a barren bed and then by a 0.9 m thick, enriched impregnation zone in uppermost parts of which are present interlayers of massive and dense pyrite. The ore also includes dense magnetite impregnations. The mineralization was explored by adits on both sides of the river.

Javornjača is found in Mt. Javornjača about 15 km westnorthwest of Bakovići and 1 km east of the peak +1432 m (**Fig. 1b**). It occurs on contact between metarhyolite and crystalline limestone. The mineralization is of the impregnation-type in limestone and the major mineral is pyrite. The occurrence is not explored.

Šebešić occurs southern of the peak +1027 m about 1.5 km southern of the Šebešić village which is about 15 km westnorthwest of Bakovići (**Fig. 1b**). Pyrite impregnations are found in Palaeozoic limestone along its contact with metarhyolite. The pyrite is gold-bearing and the occurrence has not been explored.

Staro Selo is found about 8 km westnorthwest of Fojnica (**Fig. 1b**). The mineralization occurs south of Staro Selo village in the Jezerce Creek valley, several hundred meters from the peak +843 m. The mineralization which is located in metarhyolite is represented by pyrite impregnations with quite subordinate chalcopyrite.

The ore contained 0.14 wt% Cu, 0.50 wt% Zn, 11 g/t Ag and traces of gold. The mineralization was explored only by surfacial trenches.

The Bakovići ore deposit, which is representative for this type of gold-bearing pyrite veins, is characterized with its paragenesis, length, thickness, and ore reserves. It is the most significant representative of this area and the biggest primary gold-bearing deposit of Bosnia and Herzegovina.

Bakovići gold-bearing pyrite vein

The Bakovići deposit is located 4.5 km south of Fojnica and 0.5 km north of the Bakovići village, in the Ključ area, where the Repište and Ključ Creeks join each other (**Fig. 1b and 1c**). The ore occurrence is located within a large metarhyolite body on the southern slopes of Mount Citonja. The vein strike is NNW/23^h in its southern parts and N/24^h in its northern parts. The vein dips very steeply towards the west and is nearly perpendicular at the upper levels and under 60-70^0 towards the east and east-northeast at the lower levels. The vein is very irregular at the upper levels and more regular at its deeper parts. In the middle parts, vein is branched with a distance between the branches of about 25 m. The foot branch stretching towards the north was filled by clay. This was, in fact, a tectonic joint, about 0.5 m thick, located between metarhyolites and schists. The vein is commonly branched and represented either by network or by a system of parallel veins (**Fig. 3**). The longest vein branching was 60 m and in some places the branches were up to 2 m thick. This ore vein is characterized by sharp salbands against surrounding schists and metarhyolites. The mineralization is partly in phyllite, partly in metarhyolite or along their contact. Transition from the vein into quartz-sericite schist is not noticeable in appearance but can be traced in paragenesis exchange due to increasing quantities of quartz in metarhyolites. The vein can be continuosly traced along the strike; it is not everywhere gold- bearing but frequently barren. The barren parts are filled by fragments of schists and metarhyolites which are cemented by ore substance or clay.

The vein varies in thickness from 5 cm to 2.5 m, mostly is about 0.7 to 1 m thick. It is slightly more narrow in schists than in metarhyolites (about 2:3). Along the strike and dip, the vein is in some places thickened or narrowed and in some places it branches.

Due to the differences in mechanical characteristics, metarhyolites are more tectonized than schists as indicated by the density of jointing and slickenslides. The roof is very sharply and the foot is less sharply separated from the vein. Some parts of the vein became barren due to subsequent tectonic movements.

Historical review of the mining activity

The most important historical data can be found in the published papers and archival reports writen by Anonim (1936); Đurić (1985); Jurković (1961, 1963); Katzer (1905, 1925); Lazarević et al. (1983); Ramović (1962); Ramović et al. (1979); Simić (1951); Verbič (1971, 1983).

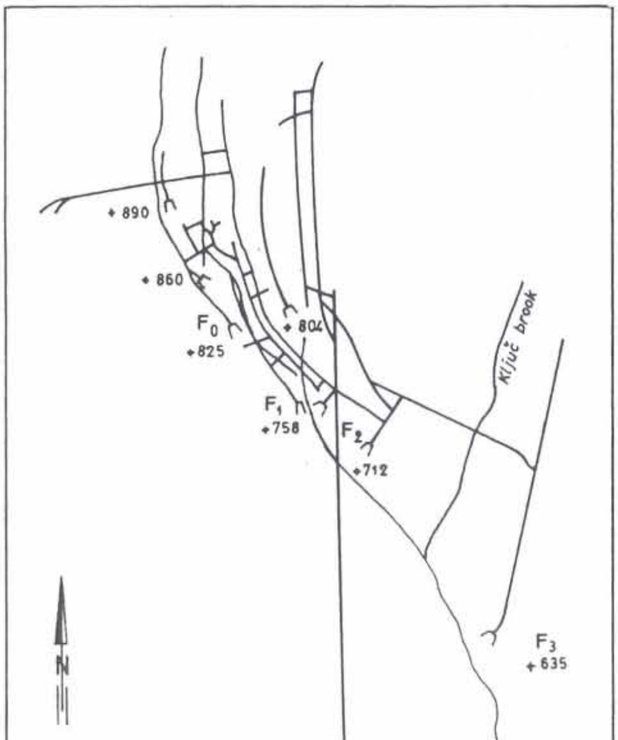

Fig. 2. SKETCH MAP OF THE UNDERGROUND MINING WORKS IN THE BAKOVIĆI GOLD MINE

First exploration works, organized by brothers Boschan from Vienna, had started in 1880. These works have proved ore outcrops about 1000 m along the strike with the average thickness of about 1-2 m. The sampled ore contained 8 to 15 g/t Au. In 1894 started a systematic exploration of the Bakovići deposit which was organized by the Company "Oberungarische Berg-und Hüttenaktiengesellschaft". Through this project four adits directed along the strike were carried out. These adits are as follows: F on +895 m, F_0 on +825 m, F_1 on +750 m and F_2 on +712 m. The southeastern part of the deposit was opened with the F_3 adit on +635 m. By these mining works, the ore vein was opened 800 m along the strike and 260 m along the dip (**Fig. 2**). Since 1895 started the mining production in the three upper horizons which lasted until 1918 (**Table 1**).

In 1934 the mining works were re-activated by "Oberungarische Berg-und Hüttenaktiengesellschaft a.d." and from 1936 the works were continued by "Trošnik Mines Ltd, London". In the period from 1934 to 1939, the main adit at the level +580 m from the Željeznica River Valley was carried out, which was 800 m long, tracing north-south. Cutting the main ore vein, the adit was simultaneously followed its richer vein branches by adits and crosscuts. By the beginning of 1935 the mining works were also focused to the exploration of the area located behind the 2-3 m wide fault zone in the northern parts of the mine, which stretched from the level of the adit F_0 up to the level of the adit F_4. During the interval 1934-1938 this company performed 4.217 m of adits and 11 drill holes (6.488 m of drilling), but did not clean up 7.235 m of earlier mining works due to the low Au content in the crude ore. In April 1936 an installation for the treatment of oxidized ore was built up.

In the first phase of the reactivated production, it was favourized the mining of gold-bearing limonite ore because it does not make difficulties in the extraction using the method of cyanization. The limonite was crushed, pulverized, mixed with the lime in containers of 40 l in volume, and afterwards the gold was extracted with NaCN. Extraction coefficient (η) raised to 82% (mainly between 75 to 77%). In the period 1936/37 19.386 t of limonite with 13,9 g/t was mined as well as 3.700 t of limonite from older wastes which contained 21.15 g/t Au. In the same period it was found the decrease of the gold-content lower of 5 g/t in the prolongation of the northern parts of the deposit and for that reason the further exploration was abandoned.

After all available gold-bearing limonite was mined, it started with the exploitation of gold-bearing pyrite because its reserves of 78.620 t from the primary zone of the deposit were proved. The total of 4.000 t of the pyrite with 13.5 g/t Au was mined. Using the cyanization method it was exploited pyrite with 16.4 g/t Au in 1936 and with 13.13 g/t Au in 1937. There are data for the gold and silver production 114.61 kg Au and 43.19 kg Ag in 1936, 144.56 kg Au and 54.20 kg Ag in 1937 and 6.01 kg Au and 3.21 kg Ag in 1938. Fineness of the obtained gold was 750. The production was ceased in 1938 due to low utilization level of the cyanization of pyrite.

In the period 1939-1940 the experiments with the treatment of pyrite were continued, but the breakout of the second world war caused the cessation of the works.

Production of crude ore from 1895 - 1938 **Table 1**

Year	t	Year	t	Year	t	Year	t
1895	260	1902	5.170	1909	?	1916	9.257
1986	2.000	1903	6.588	1910	571	1917	2.804
1897	3.760	1904	9.421	1911	3.118	1918	?
1898	240	1905	19.045	1912	6.216	1927	400
1899	431	1906	11.374	1913	7.701	1935	1.696
1900	1.700	1907	7.229	1914	4.459	1936	7.678
1901	4.570	1098	?	1915	4.005	1937	14.806
						1938	320

Evaluation for 1908, 1909 and 1918 9.850

Total 1895-1938 144.669 t

The total ore production in the Bakovići mine in the period 1895- 1938 (without data for 1908, 1909 and 1918) accounted 134.819 t (**Table 1**). The estimated production for these three years was 9.850 t and thus the total ore production was 144.669 t from which 29.500 t of gold-bearing limonite and 115.169 t of gold- bearing pyrite.

According to S i m i ć (1951) from this ore 2 tones and 240 kg of gold and 7 tones and 475 kg of silver was extracted. From the limonite ore 440 kg Au and 1.475 kg Ag and from the pyrite ore 1.800 kg Au and 6.000 kg Ag were obtained. The gold content in the ore varied from 8 to 25 g/t. The Ag:Au ratio was 3:8, 1:1, 15:1, but most commonly 3,5:1, 3:1 and 4:1. The average gold content in the ore of the whole deposit was 15 g/t.

Ore reserves in the Bakovići mine are presented on the **Table 2.** The results obtained are very close each other (from 91.000 t to 102.000 t with 1.2 t of gold and 4.2 t of silver).

Paragenesis of the Bakovići gold-bearing vein

Samples taken from old wastes and in the underground along strike and dip of the Bakovići vein enabled us, to determine by naked eyes the following primary mineral paragenesis: pyrite, quartz and siderite as predominant minerals whereas tetrahedrite, galena, stibnite, arsenopyrite, barite, and gypsum are accessories; iron hydroxides are predominant secondary minerals.

Besides these minerals, chalcopyrite, calcite, and native gold as primary minerals and goethite, lepidocrocite, hematite, covellite, chalcocite, and psilomelane as hypergene minerals, were identified under the microscope.

Pyrite is a major mineral of the Bakovići deposit and it is present from 40-50 to 75 wt% in the crude ore. In some places pyrite is almost the only mineral, in another places it is a subordinate mineral. Quartz and siderite are very common and they make 20 to 50 wt% of the ore, with very variable proportions, but quartz is more abundant than siderite. As a rule, the quartz predominates in the parts of the deposit located in metarhyolite and the siderite is more abundant in the parts located in schists. Locally, in brecciated parts of the vein very common are angular and subangular fragments of metarhyolites and schists.

Pyrite is commonly grained, xenomorphic, more rarely it builds up dense, compact masses. Such massive pyrite alternates with pyrite which is very intimately intergrown with microscopic quartz grains (**Plate I, photo 2 and Fig. 3c**). Such intergrowths (porphyroblastic and xenoblastic) indicate their simultaneous crystallization, most probably from colloid solution. Quartzose pyritic ores contain only between 42-53 wt% FeS_2, the rest is composed of gangue mineral.

Pyrite also occurs as disseminated crystals (0.1 to 1 mm in diameter) or aggregates in siderite. Its primary

Ore reserves in the Bakovići mine **Table 2.**

Kind of ore reserves	Category	Anonym 1936	Au ppm	Klepinjin 1939	Au ppm	Jurković 1963	Au ppm	Verbić 1983	Au ppm
Crude ore in the mine (mostly pyrite)	visible	57.038	15.75			40.328	14.40	33.384	13.58
	possible	85.328	16.07	76.000	15.0	16.312	13.30	45.390	11.13
	probable	62.254	16.19			9.518	15.0	-	-
Crude ore (pyrite) on the waste	visible	-	-	2.000	15.0	2.000	15.0		
Roasted cyanized pyrite on the waste	visible	-	-	1.000	7.8	1.000	7.5		
Cyanized limonite on the waste	visible	-	-	22.000	3.8	22.000	8.0	23.562	12.0
Total		204.260	16.05	99.600	12.66	91.157	12.66	102.342	12.13
Reserves of gold in kg				1.260,94		1.154,06		1.241,41	

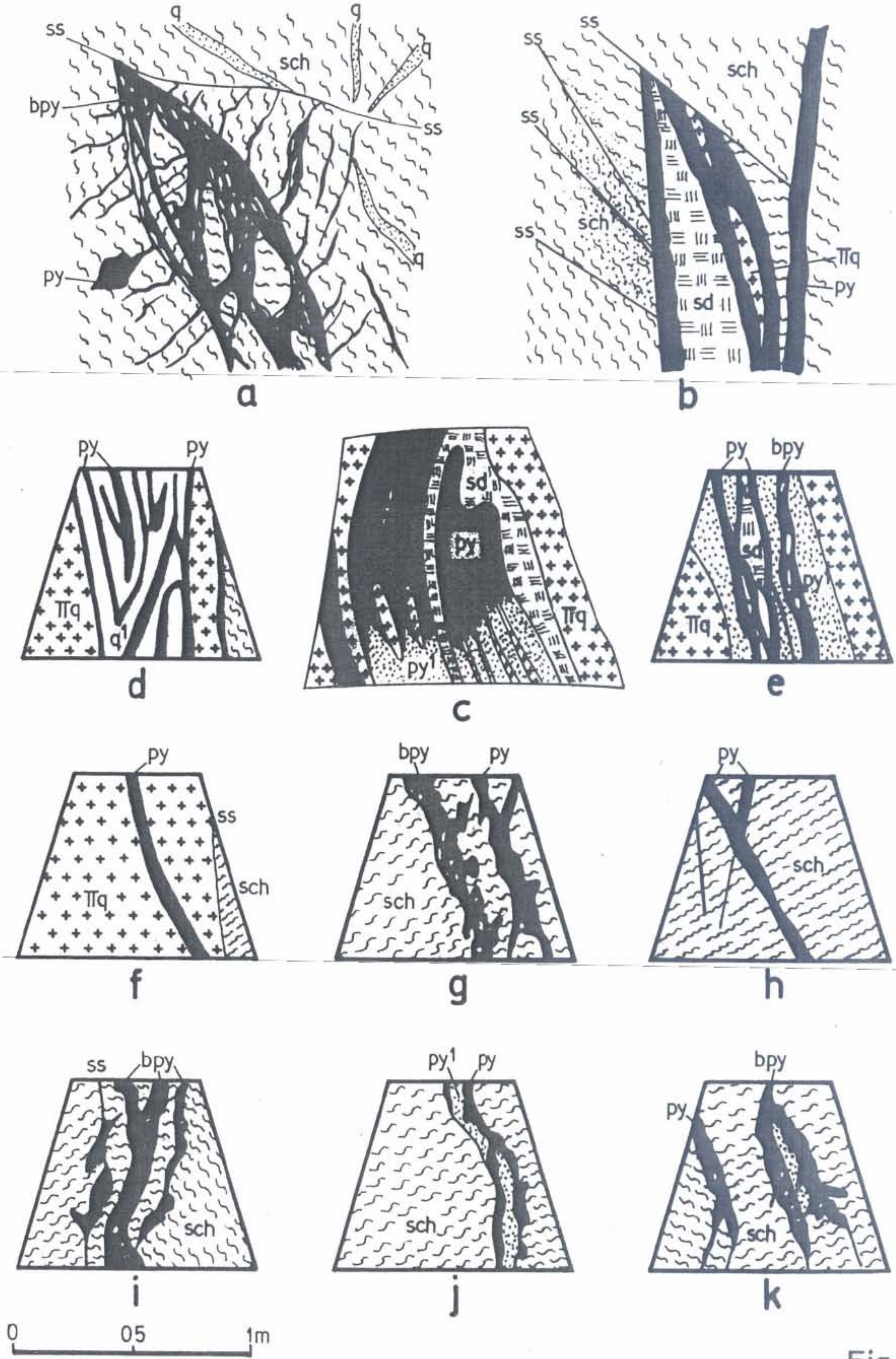

Fig.3

Fig. 3. PROFILES OF THE BAKOVICI VEIN

a, b, c - profiles come of the adit F_1+758 m, (F. Katzer, 1925), d, e, f, g, h, i, j, k - profiles come of the adit F_4+580 m, (reconstructed by author on the basis of Ramović, M. et al., 1979 data).

Legemd: sch-schist sch^1-pyritized schist πq-metarholite ss- slickenslide py-massif pyrite py^1-pyrite intimately intergrown with quartz bpy-pyrite breccia q-quartz veinlets q^1-massif quartz sd-siderite

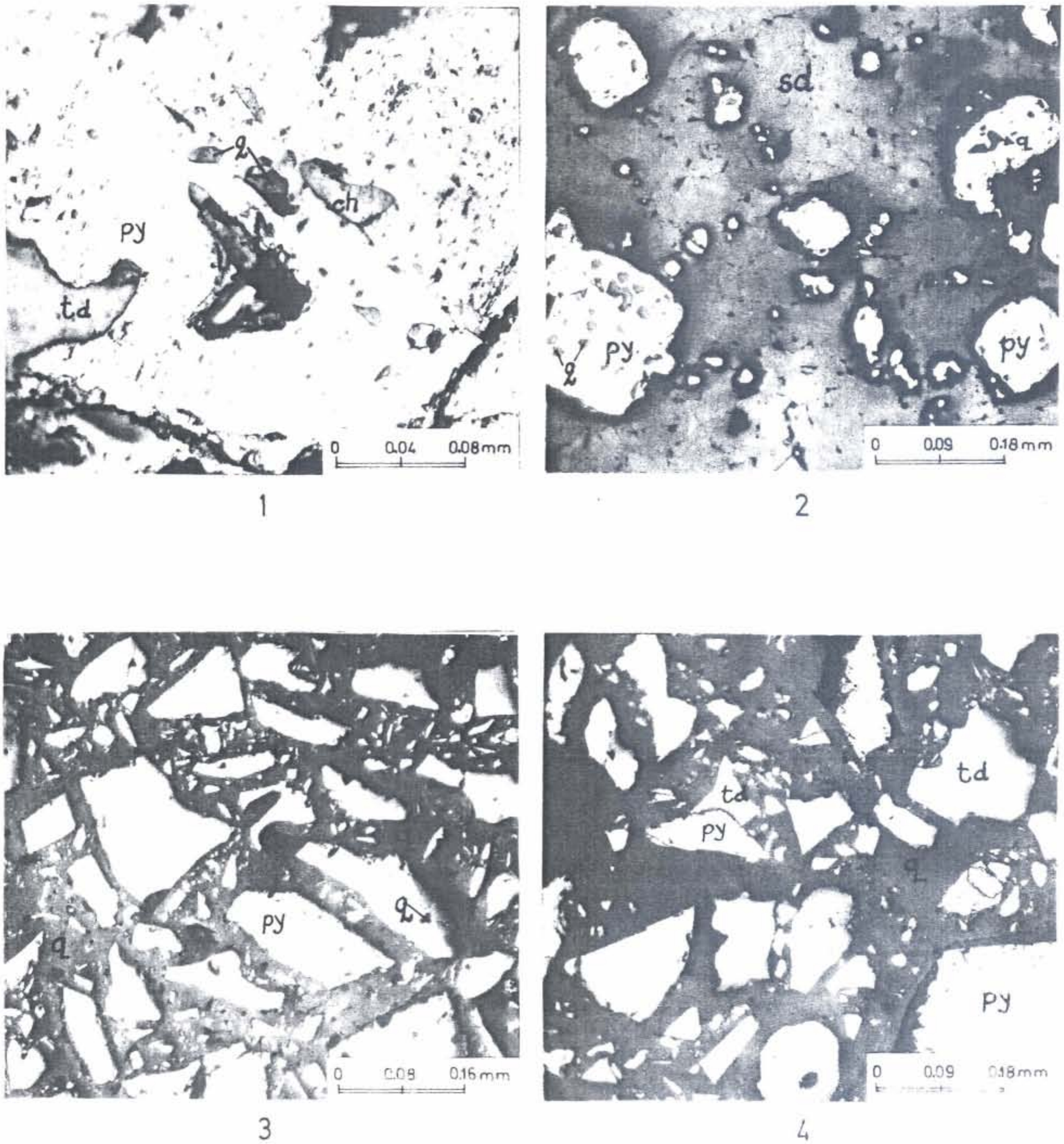

Plate I

PLATE I MICROPHOTOGRAPHS OF POLISHED SECTIONS of the ore and gangue minerals from the Bakovići ore deposit. Photos made by I. Jurković. Symbols: py-pyrite q-quartz sd-siderite td-tetrahedrite ch-chalcopyrite

hexahedral shapes are more or less corroded **(Plate I)**. A peculiar structural form of the pyrite occurrence is pyrite breccia with the size of fragments 1 to 5 mm or much less averaging 50 to 500 micrometers, which are cemented by quartz **(Plate 1 and Fig. 3)**. In some of these breccias, angular and subangular fragments of tetrahedrite are present. Some of the tetrahedrite fragments include pyrite relics indicating that the brecciation is a post-ore phenomenon. In the pores of pyrite druses occur beatifull pyrite crystals with single (210) and (100) terminal planes or their combination. Such crystals were not gold-bearing, and goldbarren also were single crystals with (201) embedded in quartz. As a rule, the pyrite associated with the siderite as gangue was more enriched in gold than the pyrite associated mostly with the quartz as gangue. A fine distribution of minute quartz crystals in pyrite did not influence the gold-bearing degree.

Drusy pores and cavities are in some places filled by minute grains either of chalcopyrite or tetrahedrite or both of them equally **(Plate I, photo 1)**. Rarely, these minute aggregates are larger than 50-100 micrometers. In the larger aggregates, tetrahedrite predominates. The tetrahedrite occurs in such a massive pyrite also in forms of fine veinlets. Because the analyses of tetrahedrite grains gave 38 g/t Au and 2.232 g/t Ag, the parts of the vein containing tetrahedrite must have contained increased quantities of gold and silver. Rare needle-like aggregates of stibnite crystals, due to increased contents of silver increased also silver content in pyrite in which stibnite occurred. The massive mode of occurrence of pyrite in the ore vein in form of thinner or thicker bands influenced the gold-bearing content. As a rule, the massive pyrite contained less and less gold by the increasing thickness of bands. The colour of pyrite was not uniform; its silverish-greyish varieties contained higher gold quantities than the typical yellowish ones.

Crystallographic measurement by goniometer on the pyrite crystals from Bakovići mine made as first K i š p a t i ć (1902). He found 9 forms (hexahedrons and dodecahedrons). Hexahedral habit (3-4 cm in diameter) distinguish only cube forms with characteristic striation lines or combinations of cubes with very narrow (210) forms. Dodecahedrons with very well developed (210) forms attain 4-5 cm in diameter. M a u r i t z (1905) measured 57 pyrite crystals from the Bakovići vein. He found 25 forms, three new among them.

The highest concentrations of gold and silver in the Bakovići deposit are connected with pyrite. Although the gold and silver concentrations in tetrahedrite are very high, and anyhow higher than in pyrite and the silver concentrations are significant in stibnite, galena and chalcopyrite, these minerals do not play an important role in the total bilance of the noble metals due to their accessory character. Their presence increases only locally gold and silver concentrations in the pyrite ore.

Spectrographic analysis of pyrite (L a z a r e v i ć et al., 1983) gave (in ppm): 18 Pb 35 Zn 10 Bi 9 Cu 4 Sn 3 Mo 3 Ga 70 Sb 14 V 3 Ni 1 Co 10 Cr 2500 Ba 8 Be 10 Ca 25 V 30 B.

Sulphur isotopic measurements on the Bakovići pyrite gave $\delta^{34}S = +4.78‰$ and $+6.76‰$. The low positive values are very similar to the ones for stibnite and sphalerite of the Čemernica deposit, for pyrite and tetrahedrite of the Trošnik mine and for realgar and orpiment of the Hrmza deposit **(Fig. 5)**.

Quartz is, besides pyrite, the most common mineral. The quartz is commonly massive, dense and milky to grayish-white in colour **(Fig. 3d)**. Often quartz is intergrown with pyrite forming porphyroblastic structure **(Fig. 3c, e, j)**. In wall-rocks of the vein there are stockwork of quartz veinlets

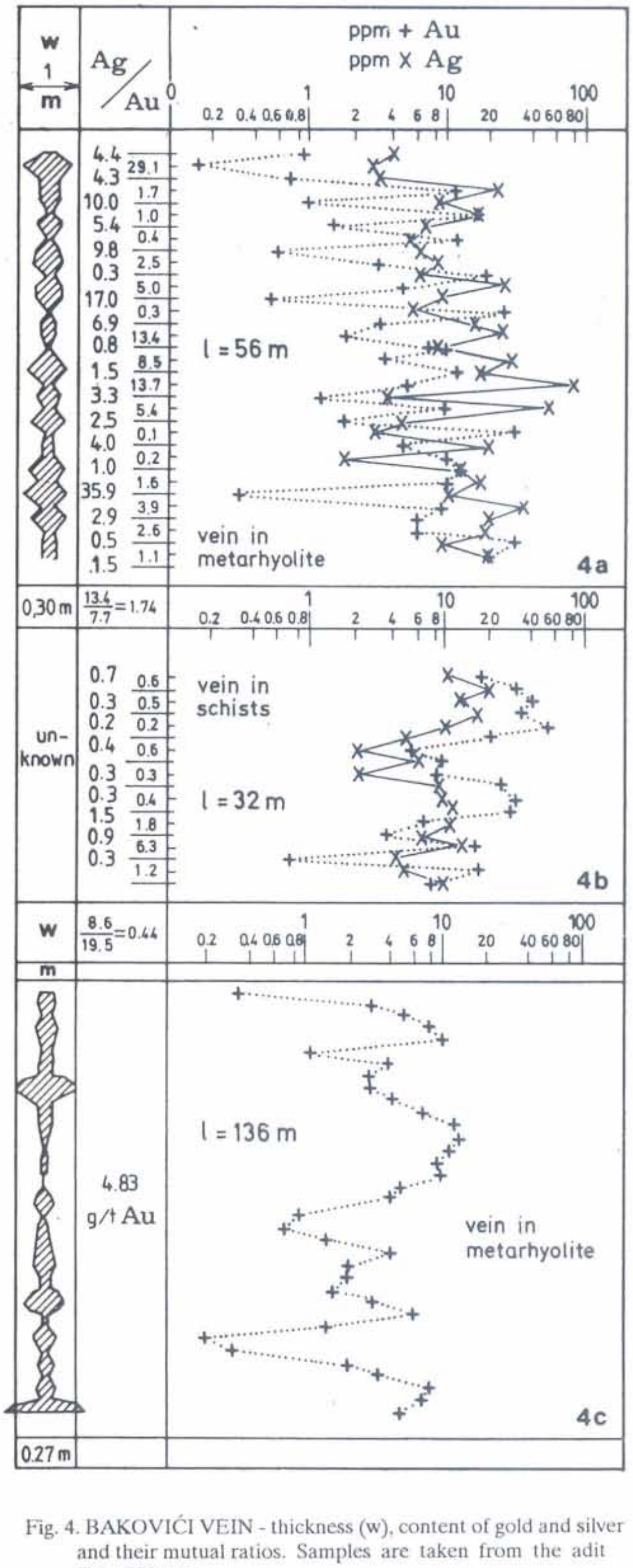

Fig. 4. BAKOVIĆI VEIN - thickness (w), content of gold and silver and their mutual ratios. Samples are taken from the adit F_4(+580 m).

(**Fig. 3a**). Essential part of the quartz as gangue is located in metarhyolite. In schists there is less quartz which occurs in form of bands in the foot and roof parts of the vein.

Siderite is a significant constituent of the deposit; it is whitish or vine-like yellowish in colour. It is younger than pyrite and quartz and replaces them. Siderite shows pronounced rhombohedral habit, unit rhombohedrons (1011) are combined with scalenohedrons (2461), angle between them amount to $49^0 23'$, There are some crystals with basal pinacoid (0001). Angles $(1011) \wedge (1011) = 70^0 01'$, (K i š p a t i ć, 1902). The siderite is most commonly impregnated with pyrite crystals and it occurs rarely in single grains associated with pyrite and quartz. If siderite builds up individual masses in the vein, than is coarser crystaline with brownish crystals (Braunspat) up to 1cm large. The chemical analysis of the siderite is as follows: 86.6 $FeCO_3$, 0.8 CaO, 2.5 MgO, and 10.1 $MnCO_3$. This chemical composition is more similar to the siderite from the polymetallic deposit Donje Selo than to the siderites from barite deposits.

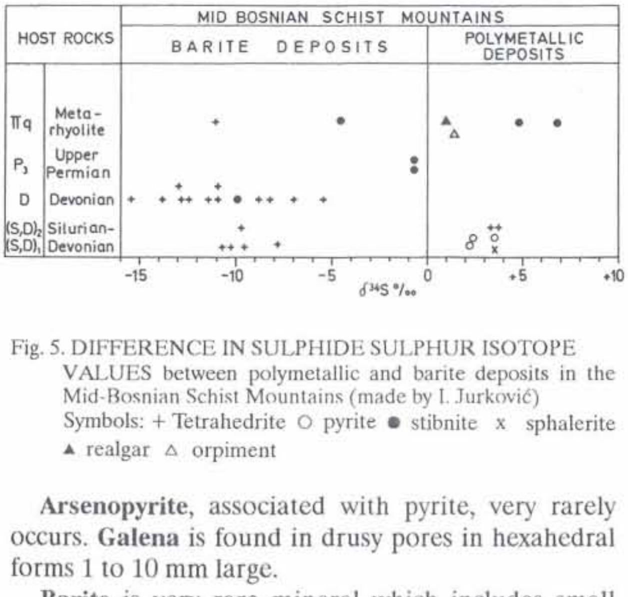

Fig. 5. DIFFERENCE IN SULPHIDE SULPHUR ISOTOPE VALUES between polymetallic and barite deposits in the Mid-Bosnian Schist Mountains (made by I. Jurković)
Symbols: + Tetrahedrite ○ pyrite ● stibnite x sphalerite ▲ realgar △ orpiment

Arsenopyrite, associated with pyrite, very rarely occurs. **Galena** is found in drusy pores in hexahedral forms 1 to 10 mm large.

Barite is very rare mineral which includes small tetrahedrite grains. The accessory character of the barite is also a common characteristic of other polymetallic types of the deposits from Middle Bosnian Schist Mountains: Vrtlasce, Donje Selo, Čemernica, and Hrmza.

Secondary (hypergene) mineral paragenesis

Limonite masses, made of **goethite** and **lepidocrocite**, with very different colloform textural features are dominant in the till 65 m deep oxidization zone of the Bakovići deposit. The limonite mostly originated by oxidization of pyrite and siderite and quite subordinately of accessory arsenopyrite, tetrahedrite, and chalcopyrite. Limonite is characterized by higher gold and silver contents relative to those in the Bakovići deposit as a whole. While in the whole deposit the gold contents varied from 8 to 25 g/t, the limonite contained over 20 g/t Au.

Quite subordinate quantities of **chalcocite** and **covellite** were noticed in tetrahedrites affected by initial phases of wheathering in very poorly developed cementation zone of the deposit. In limonite masses, **chalcedony**, **calcite**, and thin flakes of **gypsum** on siderite were found.

Chemistry of the Bakovići ore

J o h n & E i c h l e i t n e r (1901) analyzed several samples of the Bakovići pyrite ores and obtained from 42.30 to 45.40 wt% S, i.e 79.2 to 85 wt% FeS_2.

Data of several partial or partially complete chemical analyses of crude ores or composites selected during the explotation of the Bakovići deposit are presented in **Table 3**. Generally, the Ag: Au ratios decreased in the deeper parts of the mine. The most complete analysis numbered by 1 comes from "Société générale Hoboken" which was done in 1938. The calculated analysis shows that the ore contained 74 wt% pyrite, 19.8 wt% quartz and 4-5 wt% siderite. Accessory minerals are arsenopyrite (0.4 wt%), stibnite (0.06 wt%), galena (0.02 wt%) and traces of tetrahedrite and bismuthinite.

The analyses numbered by 2 to 9 come from J. Fucsko, director of the Bakovići mine (cited by K a t z - e r, 1905; B a r i ć & T r u b e lj a, 1984).

Samples Nos 10,11,15,16 come from the vein in the adit F_4; No 14 from the waste of the adit F_4, No 13 from the adit F_2 and No 12 from the adit F_2. All samples were analyzed in the laboratory of the copper mine Bor (Serbia) in 1938.

Insoluble (6.97 wt%) - sample No 9, consists of 0.10 Fe_2O_3, 0.19 SO_3, 1.87 Al_2O_3, 0.30 MnO, 0.02 CaO, 0.06 MgO, 1.71 CO_2, 0.04 wt % H_2O^+.

L a z a r e v i ć et al. (1983) analyzed a composite made from the samples of 6 wastes outside of the entrance in the adits (in total 2 tons of ores). The analysis gave (in wt%): 13.73 Al_2O_3, 25.20 R_2O_3, 11.47 Fe, 0.10 CaO, 7.03 S, 20.18 ins., 0.005 Pb, 0.030 Zn, 0.082 As, 0.033 Sb, 0.0013 Ag, 0.00208 Au.

These partial analyses show very different mutual quantitative proportions of pyrite (from 44 to 97 wt%), quartz (from 2.2 to 10.82 wt%) and siderite (from zero to several tens percents).

The most important accessory elements are present in minimal quantities: antimony (Sb) is bound to the lattice of more common tetrahedrite and rarely of stibnite; bismuth (Bi) is bound to the bismuthinite; arsenic (As) is connected mostly with arsenopyrite and to a less extent with tetrahedrite; and lead (Pb) is bound to the lattice of galena. However, the most common is Cu what is characterstic for such a paragenetic type of the deposit: traces, 0.003, 0.02, 0.04, 0.06, 0.55 and even

Partial chemical analyses of crude ore (Bakovići) Table 3

	wt%	wt%	ppm	ppm	ppm		wt%	ppm	ppm	ppm	ppm	ppm
Nos	S	Fe	Ag	Au	Ag +Au	Ag/Au	Inso-luble	Cu	As	Sb	Pb	Bi
1	39.43	36.54	51.9	14.6	-	3.55:1	19.80	tr	0.20	0.04	0.02	0.004
2	50.64	-	-	19.0	-		7.19	6.44	-	-	-	-
3	52.02	-	-		160		2.50	0.02	0.01	-	-	-
4	23.36	-	150	10.0	-	15.0:1	?	0.04	0.01	-	-	-
5	51.04	45.70	tr	13.0	-		3.59	tr	-	-	-	-
6	32.58	-	75	25	-	3.0:1	10.82	0.55	-	-	-	-
7	50.30	-	5.2	9.2	-	0.6:1	5.92	0.06	0.036	-	0.05	-
8	50.71	-	3	8	-	0.5:1	2.20	tr	-	-	-	-
9	49.39	43.33	-	-	50		6.97	0.003	0.30	-	-	-
10	22.62	20.97	6.95	0.45	-	15.4:1	-	-	-	-	-	-
11	12.28	10.32	10.7	tr	-		-	-	-	-	-	-
12	45.23	44.54	2.0	8.0	-	0.25:1	-	-	-	-	-	-
13.	42.44	45.84	16.7	23.0	-	0.73:1	-	-	-	-	-	-
14	33.22	28.34	9.85	16.15	-	0.6:1	-	-	-	-	-	-
15	31.27	33.91	9.90	14.51	-	0.7:1	-	-	-	-	-	-
16	37.69	27.82	8.40	9.30	-	0.9:1	-	-	-	-	-	-
17	13.12	10.32	5.80	0.60	-	9.7:1	-	-	-	-	-	-

6.44 wt%. Cu is the main constitutent of chalcopyrite and tetrahedrite.

Data of chemical analyses presented in **Table 3** are completely consistent with our data obtained by the detailed optical investigation of the Bakovići ores.

Distribution of gold and silver in ore

The mining works demonstrated that the gold content decreases going from the north-northwestern to south-southeastern parts of the deposit. The lowest Au content in the vein was noticed in the area east of the Ključ Creek, and it was also low in the vein behind the large fault in the northern parts of the deposit. The gold-bearing content also decreases at the depth of 30 m bellow the main adit F_4 (+580m). A minimal gold content was registered by drilling (11 drill holes) in the depth, lower than 50 m bellow the main adit F_4. In some parts of the deposit, in rich "ore shoots" some single extremely high gold contents (in g/t): 90, 116, 284, 289, 1000 were found in crude ore.

Table 3 shows extraordinary different values for gold and silver varying from 2 to 150 g/t for silver and from traces to 25 g/t for gold. Mutual ratios Ag:Au varie from 0.25:1 to 15.4:1. V e r b i č (1983) presented the silver and gold contents obtained from samples taken from seven old wastes (19.230 m^3) situated in front of the lowest adit F_4(+604 m) till the highest adit Fo (+865 m). Waste TP_1 contained (in ppm) 19.5 Au and 15.5 Ag; TP_2 31.0 Au, 16.0 Ag; TP_3 10.0 Au, 5.0 Ag; TP_{3a} 10.0 Au, 8.0 Ag; TP_4 1.0 Au, 6.0 Ag; TP_5 29.5 Au, 16.5 Ag and TP_6 6.5 Au 0.5 Ag. The average value: 20.0 Au and 13.0 Ag.

Composite of two tons from these 6 wastes (excepting the waste No TP_4 due its low content of gold) containing 20.8 g/t Au and 13.0 g/t Ag was first underwent to the gravimetric enrichment (but with unsatisfactory result) and then to the flotation enrichment. Concentration raised gold content to 90 g/t and silver content to 46.8 g/t. Utilization coefficient (μ) raised to 78% for gold and 65% for silver respectively. Further processing with NaCN raised μ to 90% (L a z a r e v i ć et al., 1983).

R a m o v i ć et al. (1979) collected from the archiv of the Bakovići mine 147 analyses concerning the contents of gold and silver in the crude ore (in situ), along the lowest, main adit F_4 (56 analyses with Au and Ag, 70 analyses with Au, 21 analyses with only Ag contents). All results were sketched on the sketch-map of underground mining works. For some sections are given also the lengths of sampled narrow channels along which ore was sampled and thus can get the idea about the thickness of the ore vein. Based on these data we prepared very illustrative diagrams (**Fig. 4a,b,c**).

Figures 4a and 4c present the vein which was located in metarhyolite and Figure 4b in phyllite. The vein sections marked as 4a and 4b contained values for Au and Ag and the vein section marked Ac only values for Au. Sketches 4a and 4c give also the lengths of sampled channels and thus the changes of the vein thickness. The sampled length of the adit in sketch 4a was 56 m (with 41 analyses), 32 m (with 48 analyses) in sketch 4b, and 136 m (with 70 analyses) in sketch 4c.

Based on these three sketches one can get a general impression that the Au and Ag values (expressed in g/t of ore) show extraordinary sudden changes on very small distances because the mutual distances of taken samples were about 1.4 m in the section 4a, 1.8 m in the section 4b and 1.9 m in the section 4c.

The vein thicknesses were also very variable: 3cm to 95 cm (average 33 cm) in the section 4a and 5 cm to 140 cm (average 26.5 cm) in the section 4c.

In the section 4a average content was 7 g/t Au and 13.4 g/t Ag with Ag:Au ratio= 1.74:1. In the section 4b average contents were 19.5 g/t Au and 8,6 g/t Ag with Ag:Au ratio= 0.44:1.0. The part 4b, although located deeply below the outcrops of the ore vein represents a classical example of the "ore shoot" i.e. the part of the ore vein extremely enriched in gold.

The part 4c represents very empoverished part of the Bakovići deposit; in its northern part, average Au content amounted only 4.83 g/t.

In 1935. in the beginning of the reactivation of the mine 41 samples were analyzed in the laboratory of the copper mine Bor. The results are presented on the **Table 4.**

During the evaluation of ore reserves of the Bakovići mine by "block method", the average content in gold (g/t) for each block has been calculated (J u r k o v i ć, 1963). The results are as follows: block I 12 g/t (back filling between adits F_2 and F_3), blocks II and III, each 15 g/t (vein in situ between adits F_2 and F_3), blocks IV-VIII (vein in situ between adits F_3 and F_4), IV 14.5 g/t, V 28.9 (ore shoot), VI 14.4, VII 14.2 g/t, VIII 6.5 g/t, blocks IX-XIII (vein 0-35 m bellow the level of the adit F_4, sampled in shafts or cores of 11 drill holes), IX 14.3 g/t, X 23.1 g/t (ore shoot), XI 13.8 g/t, XII 22.9 g/t (ore shoot), XIII 9.4 g/t.

Isotopic composition of sulphide sulphur

Isotopic analyses of sulphide and sulphosalt sulphur were carried out on mineral samples from several polymetallic deposits of the Mid-Bosnian Schist Mts: pyrite samples from the Bakovići deposit, tetrahedrite samples from the Trošnik deposit, sphalerite and stibnite samples from the Čemernica deposit and realgar and orpiment samples from the Hrmza deposit. Positions of these different paragenetic types of polymetallic MBSM deposits are presented on the **Fig. 1b**. Results of these analyses have been partly published (K u b a t et al., 1979/80) but part of them will be presented for the first time in this paper **(Fig. 5)**.

These all analyses (10) are characterized by low positive values of $\delta^{34}S$ (expressed in ‰ near to zero, in the span from 0.99 ‰ (realgar from Hrmza) to +6.78 ‰ (pyrite from Bakovići). The span of these

Contents of Au and Ag **Table 4**

Nos	ppm Ag	ppm Au	Ag/Au
342-350 (9)	7.99	12.62	0.6:1
353-377 (13)	3.13	5.78	0.5:1
381-389 (9)	1.13	5.09	0.26:1
390-399 (10)	0.87	3.19	0.27:1
342-399 (41)	3.86	8.08	0.48:1

values of 5.79 ‰ is comparatively narrow and for most of samples is in the span from 1 to 5‰. In our opinion this span indicates consistency in the source of sulphur which is probably of juvenile origin for four different paragenetic types of the polymetallic deposits which are found on the surface of 450 km^2 in the Mid-Bosnian Schist Mts.

For the scope of correlation on the same diagram **(Fig. 5)** are presented data of isotopic sulphide sulphur composition for 18 samples of Hg-tetrahedrite and 4 pyrite samples from the Kreševo- type barite deposits (located in Devonian carbonate rocks) and the Gornji Vakuf-type siderite-barite deposits (located in Silurian-Devonian metasediments) which cover the surface area of 50x15 km^2. A part of the analyses has been published (Š i f t a r, 1988, 1990; J u r k o v i ć et al., 1994) but a part of them will be published for the first time in this paper.

All isotopic data for barite deposit display exclusively distinct negative $\delta^{34}S$ values of sulphide sulphur, i.e. the dominance of lighter sulphur isotope and this is shown in the span from -0.7 to -9.86‰ for pyrite and from -5.5 to -15.4‰ for Hg- tetrahedrite (schwazite). The negative $\delta^{34}S$-values are characteristic both for pyrite and tetrahedrite disregarding stratigraphic position in which the barite deposits are located, the type of host rocks or the shape of the ore body.

These fact indicate quite different character of the sulphur origin in barite deposits relative to the ones of polymetallic types in which the Bakovići deposit is also included. However, these data simultaneously indicate common evolution for all barite deposits.

Very similar relations were established from mineral deposits in Gemerides in Slovakia (C a m b e l - J a r k o v s k y et al., 1985; Ž a k et al., 1991). Based on isotopic composition of sulphide sulphur in this area, barite-siderite deposits with Hg- tetrahedrite can be distinguished from other polymetallic deposits. Both mentioned groups of authors presumed their genetical models with which they tried to solve the difference in isotopic composition.

In our opinion the barite-type deposits and the polymetallic-type deposits of the whole Mid-Bosnian Schist Mts. are different in their genetic evolution. In the next paper which is still in progress, a genetic model for Mid-Bosnian barite deposits with Hg-tetrahedrite will be elaborated and proposed.

Parageneses of the Mid-Bosnian Schist Mountains ore deposits Table 5

Type	Host rocks		Ore deposits		Parageneses				
	Age	Type	n	form	1	2	3	4	5
A. QUARTZ DEPOSITS									
BUSOVAČA	S,D	sch	147	v l n b	q		py he mu tu ru chl		Au
B. POLYMETALLIC DEPOSITS									
VRTLASCE	S, D πq	Sch πq	3	v sw	sd q	pyrh sph	ab mu mt py cpy ga tu ru	bul sn cas mo sb rg cn	apy ll en td pol bi mc
DONJE SELO	S,D πq	Sch πq	2	v sw	sd	q sph	py	bul apy cn sb rg	cpy vl co ll mc
ČEMERNICA	S,D πq	Sch πq	12	v sw	q		sb sph cn py	apy cpy wo sd ga ba bt jm	mcn bul ss chy en td pyrh
BAKOVIĆI	S,D πq	Sch D πq	10	v i sw	py	q sd		apy sb ga td gy	Au bi
TROŠNIK	S,D πq	Sch D M πq	6	b n l	sd py	q ba td		gy mu fd cc	bi Au ss ru tu
HRMZA	πq P_3	πq L sds	4	sw n i	q		rg op fl	mpy bv sph ba sb	en tn bul cpy tu ru td mc
C. BARITE DEPOSITS									
GORNJI VAKUF	S,D S,D/P_3	Sch Sds Sh D	30	v b	sd	ba td	q py	cc do cpy	Au arg te ar str
KREŠEVO	D πq	D L M πq	103 5	b v n sw	ba	cc sd	td py	fd fl bu ga he gr	en lu sph apy ss chc cov mu ru tu tc sb
BRESTOV-SKO	amph	amph	3	v l n	ba		q mu alb mt py cpy	he ln bo td	ru tu act mo Au ml chl chc
RAŠTELICA	P_3	Sh D	3	l v n	ba		q py bo cpy	sph chc cov cc fd	

Stratigraphy: **S,D**-Silurian-Devonian **D**-Devonian **P_3**-Upper Permian **πq**-Upper Palaeozoic metarhyolite **amph**-orthoamphibolite schist
Host rocks: **Sch**-schists **L**-limestone **D**-dolomite **M**-marble **Sh**-shale **Sds**-sandstone
Forms: **v**-vein **l**-lense **n**-nest **sw**-stockwork **b**-irregular body **br**-breccia **i**-impregnation
Intensity of minerals: **1**-main mineral occurring in many or all deposits and in larger amounts **2**-present in large amounts only in a few of the deposits involved **3**-widespread, but present in small amounts **4**-occasional or very rare, mostly also sparce occcurrence **5**-widespread or occasional, but visible only under microscope
Symbols of minerals: **ab**-albite **act**-actinolite **apy**-arsenopyrite **ar**-scalenohedral calcite **arg**-argentopyrite **Au**-elemental gold **ba**-barite **bi**-bismuthinite **bo**-bornite **br**-bravoite **bt**-berthierite **bu**-bournonite **bul**-boulangerite **cas**-cassiterite **cc**-calcite **chc**-chalcocite **chl**-chlorite **chy**-chalcedony **cn**-cinnabar **co**-cobaltite **cov**-covellite **cpy**-chalcopyrite **do**-dolomite **en**-enargite **fd**-ferrodolomite **fl**-fluorite **ga**-galena **gr**-grossular **gy**-gypsum **he**-hematite **il**-ilmenite **jm**-jamestonite **ll**-loellingite **ln**-linnaeite **lu**-luzonite **mc**-marcasite **mcn**-metacinnabar **ml**-millerite **mo**-molybdenite **mpy**-gel-pyrite **mt**-magnetite **mu**-muscovite **op**-orpiment **pol**-polybasite **py**-pyrite **pyrh**-pyrrhotite **rg**-realgar **ru**-rutile **sb**-stibnite **sd**-siderite **sn**-stannite **sph**-sphalerite **ss**-sulphosalt **str**-sternbergite **td**-tetrahedrite **te**-telluride **tn**-tennantite **tu**-tourmaline **vl**-valeriite **wo**-wolframite **q**-quartz

Discussion

Based on geological, mineralogical stable isotope composition and fluid inclusion data, the vein mineralization, locally metasomatic ore bodies of the Mid-Bosnian Schist Mountains (MBSM) were formed during a period from Permian into Mesozoic. They can be divided as follows **(Fig. 1b)**.

A. Postorogenic (partly synkinematic) are **monomineralic quartz veins**, lenses, nests and irregular bodies, mostly unconformable to the schistosity of metamorphic host rocks. They are located mostly in the Kreševo-Kiseljak-Fojnica-Busovača area, i.e. in the northeastern part of the MBSM (147 localities) K a t z e r, 1925, J u r k o v i ć, 1957, Ž i v a n o v i ć, 1976). Massive, milky or semitransparent quartz is the main mineral (over 95-98 wt% SiO_2). Optically it is anomalous, often cataclazed and in some places recrystallized, without cavities. Pyrite, muscovite, chlorite, hematite, tourmaline and very rare gold are accessories. Fluid inclusion data: Th=180^0 to 280^0C with a maximum at 230^0C; Tfm confirms NaCl-Ca Cl_2 + $MgCl_2$ system of fluids. The encapsuled fluid shows high metastability and high salinity (P a l i n k a š & J u r k o v i ć, 1994) **(Table 5A)**.

B. Polymetallic ore deposits from comparatively small (Vrtlasce, Hrmza), more rarely medium sized ore occurrences (Čemernica, Bakovići), almost exclusively within Silurian-Lower Devonian schists with rare intercalations of carbonate rocks or in metarhyolites (K a t z e r, 1905, 1910, 1912, 1925; J u r k o v i ć, 1957, 1958a, 1958b, 1960b, 1962). These deposits are commonly located at contact of rhyolites with schists or carbonate rocks, inside schist or rhyolites, stretching mostly NNW-SSE, dipping ENE (40-80^0); they are structurally controlled. Hydrothermal fluids transported mineralizing material at clearly epigenetic stages and deposited them from solutions in fractures and faults, locally in brecciated zones. Ore minerals are either typical openspace fillings or coprecipitation located in silicate host rocks, or replacement bodies (Trošnik) in carbonate rocks. The deposits display very often typical well-developed bilateral symmetric wall rock alteration: muscovitization, silicification, tourmalinization, ankeritization. Sulphide sulphur isotope ratios are close to zero (δ^{34}S= from +1,0 to +6.76 ‰, on average +3.24 ‰ from 10 analyses) indicating juvenile source of sulphur. The ore deposits are closely associated in space and time with calcalkaline rhyolitic magmatic activity, which took place between the Middle Carboniferous and the Upper Permian. The deposition of ores took place at shallow depth, probably within 1 km from the surface. Small quantities of barite precipitated in late stages of mineralization represent evidence for this statement, as well as for the progressive mixing of the hydrothermal fluids with meteoric waters. In the **Table 5B** are presented the main characteristics of this polymetallic type of MBSM ore deposits. According to differences in their parageneses it is divided, in six subgroups: Vrtlasce, Donje Selo, Čemernica, Bakovići, Trošnik and Hrmza subtypes **(Fig. 1b)**. The Vrtlasce group is characterized by the highest temperature paragenesis: pyrrhotite, cassiterite, molybdenite, magnetite, marmatite and by very strong alteration of the wall- rocks: albitization, muscovitization, silicification, tourmalinization, rutilization. On the contrary, the Hrmza group represents the lowest temperature paragenesis: realgar, orpiment, melnicovite pyrite, marcasite, hexahedral fluorite, chalcedony, barite. Other subgroups of deposits (Donje Selo, Čemernica, Bakovići, Trošnik) distinguish parageneses which represent a transition between these two extremes.

Concerning the gold and silver contents the Bakovići and Trošnik deposits are the richest paragenetic types.

The main features of the MBSM polymetallic ore deposits fit very well with the general features of the Cordilleran vein types deposits, termed also postmagmatic or magmatic hydrothermal ore deposits as described by S a w k i n s (1972) and G u i l b e r t & P a r k, Jr. (1986). According to these authors the Cardilleran vein type deserve in many cases a separate classification status related to the kinds of epizonal intrusive rocks that spawn porphyries.

C Barite deposits are the youngest ones; they were formed from Upper Permian into Triassic.These deposits are the most widespread mineralization in the Mid-Bosnian Schist Mts. They are divided in four subroups:Kreševo, Gornji Vakuf, Brestovsko and Raštelica (K a t z e r, 1907, 1925, J u r k o v i ć, 1954b, 1957, 1960a, 1987, 1989, J u r k o v i ć et al. 1994, R a m o v i ć, 1976) **(Table 5C)**.

The main characteristic of barite deposits are as follows: (a) the most number of them are almost monomineralic and barite builds up over 90-95 wt% of the crude ore; deposits where siderite predominates over barite are rare (some deposits of the Gornji Vakuf subgroup); (b) mercurian tetrahedrite is the main ore mineral although rarely more abundantly present, very often as subordinate or only accessory constituent; (c) isotope compositon of sulphide sulphur of tetrahedrites and pyrites is distinctly negative **(Fig. 5)**; (d) fluid inclusion data reflect specific properties: Th between 200 and 310 °C; high salinity from 24-26 wt% NaCl equ; NaCl-$CaCl_2$ (+-$MgCl_2$) fluid system indicating strong influence of formation waters during the formation of these deposits (P a l i n k a š & J u r k o v i ć, 1994).

All these characteristics of the barite deposits contrast with those of polymetallic ore deposits and suggest a different model of their genesis.

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