BAKOVICI
THE BIGGEST GOLD DEPOSIT OF BOSNIA AND HERZEGOVINA

Ivan JURKOVIC
Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, HR-10000 Zagreb, Pierottovu 6, Croatia

Abstract

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 metasediments (Sofilj et al., 1980). These rocks are invaded by Carboniferous-Permian metarhyolites (Jurkovic & Majer, 1954). The youngest Palaeozoic series consist of Upper Permian continental-lagoonal formations.

The unconformably overlying Triassic is represented by Seythian 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 (Jurkovic, 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 north-northwest-south-southeast (Fig. 1b and 1c). The veins are found in metarhyolites close to contact with the phyllite series (Jasenik, Jastrebc, Glavica in the Mount Citonja, Močenik on the southern slopes of Mount Beriberuša, Staro Selo, west of Fojnica), or follow contact line between schists and metarhyolites lying partly either in the first or second host rock (the Bakovići area). The impregnation pyrite deposits found in dolomitized limestones along contact with metarhyolites (Repiste, Javornjaca and Sebešić) 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. Tz, 1905, 1925, Jurkovic, 1957, 1960b, 1961, Ramovic et al., 1979, Bodulj et al., 1979.

Repiste occurs on the eastern bank of the Repiste 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. 1e). The vein is of variable 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.

Jastrebec 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...
A. QUARTZ DEPOSITS
- Busovača

B. POLYMETALLIC DEPOSITS
- Vrtlacce
- Donje Selo
- Čemernica
- Bakovići
- Hrmza
- Trošnik

C. BARITE DEPOSITS
- Kreševl
- Gornji Vakuf
- Brestovsko
- Raštelica

Fig. 1. GEOLOGICAL MAP OF THE BAKOVIĆI AREA

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

Geological map of the MBSM (Kreševl - Kiseliak - Fojnica area) with the position of quartz deposits, polymetallic and barite deposits. Legend: Q - Quaternary; M - Miocene; K - Cretaceous; T1,2 - Triassic, P3 - Upper Permian; D - Devonian, S.D - Silurian/Devonian; xq - Quartzporphyre. Pyrite occurrences: 1 Šebešić 2 Javornjača 3 Staro Selo 4 Čavaljka 5 Mošćenik

Fig. 1a

Fig. 1b

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°E and dipping towards the southeast under 45°. 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 Čavljikom is located on the left flank of the Čavljik Creek several hundred meters far from its mouth in the Rijekavac Creek, on the southern flanks of Mount Jasekovića, about 2 km southwest of the Višnjačka village (Fig. 1b). This mineralization found in sericitized metarhyolites which stretches northwest-southeast and dipping towards the southwest under 50°. 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. The mineralization was explored only by surficial 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 Repšte 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° in its southern parts and N/24° in its northern parts. The vein dips very steeply towards the west and is nearly perpendicular at the upper levels and under 60° 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 continuously 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 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 written by Anonym (1936); Duric (1985); Jurkovic (1961, 1963); Kutzer (1905, 1925); Lazarevic et al. (1983); Ramovic (1962); Ramovic et al. (1979); Simic (1951); Verbic (1971, 1983).

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 Bakovic 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, F0 on +825 m, F1 on +750 m and F2 on +712 m. The southeastern part of the deposit was opened with the F3 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 I).

In 1934 the mining works were re-activated by "Oberungarische Berg-und Hüttenaktiengesellschaft a.d." and from 1936 the works were continued by "TroSnik Mines Ltd, London". In the period from 1934 to 1939, the main adit at the level +580 m from the Zeljcznica 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 F0 up to the level of the adit F4. 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 favored 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 Au 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

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

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 Simić (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).

### Production of crude ore from 1895 - 1938 (Table 1)

| Year | 1895 | 1902 | 1903 | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | Total 1895-1938 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|----------------|
| t    | 280  | 3,120| 6,508| 9,621| 19,042| 23,184| 23,486| 5,000| 14,693| 20,118| 3,118| 5,712| 9,701| 14,005| 14,806|
| t    | 1936 | 1895 |
| t    | 1937 | 1938 |

### Ore reserves in the Bakovići mine (Table 2)

<table>
<thead>
<tr>
<th>Kind of ore reserves</th>
<th>Category</th>
<th>Anonymous</th>
<th>Au ppm</th>
<th>Klepinji 1939</th>
<th>Au ppm</th>
<th>Jurković</th>
<th>Au ppm</th>
<th>Verbić</th>
<th>Au ppm</th>
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<tr>
<td>Crude ore in the mine</td>
<td>visible</td>
<td>48,038</td>
<td>15.75</td>
<td>76,000</td>
<td>15.0</td>
<td>40,328</td>
<td>14.40</td>
<td>33,384</td>
<td>13.58</td>
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<tr>
<td>(mostly pyrite)</td>
<td>possible</td>
<td>85,328</td>
<td>16.07</td>
<td></td>
<td></td>
<td>16,312</td>
<td>13.30</td>
<td>45,390</td>
<td>11.13</td>
</tr>
<tr>
<td></td>
<td>probable</td>
<td>62,254</td>
<td>16.19</td>
<td></td>
<td></td>
<td>9,518</td>
<td>15.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crude ore (pyrite)</td>
<td>visible</td>
<td>-</td>
<td>-</td>
<td>2,000</td>
<td>15.0</td>
<td>2,000</td>
<td>15.0</td>
<td>-</td>
<td>-</td>
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<tr>
<td>on the waste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roasted cyanized</td>
<td>visible</td>
<td>-</td>
<td>-</td>
<td>22,000</td>
<td>3.8</td>
<td>22,000</td>
<td>8.0</td>
<td>23,562</td>
<td>12.0</td>
</tr>
<tr>
<td>pyrite on the waste</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanized limonite</td>
<td>visible</td>
<td>-</td>
<td>-</td>
<td>22,000</td>
<td>3.8</td>
<td>22,000</td>
<td>8.0</td>
<td>23,562</td>
<td>12.0</td>
</tr>
<tr>
<td>on the waste</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>204,260</td>
<td>16.05</td>
<td>99,600</td>
<td>12.66</td>
<td>91,157</td>
<td>12.66</td>
<td>102,342</td>
<td>12.13</td>
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<tr>
<td>Reserves of gold in kg</td>
<td></td>
<td>1,260.94</td>
<td>1,154.06</td>
<td>1,241.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 3. PROFILES OF THE BAKOVIĆ VEIN

a, b, c - profiles come of the adit F1+758 m, (F. Katzer, 1925), d, e, f, g, h, i, j, k - profiles come of the adit F4+580 m, (reconstructed by author on the basis of Ramović, M. et al., 1979 data).

Legend: sch-schist, schl-pyritized schist, ssq-metarholite, ss-slickenslide, py-massif, pyr-pyrite, pyr1-pyrite intimately intergrown with quartz, bpy-pyrite breccia, q-quartz veinlets, qq-massif, sd-siderite.
hexahedral shapes are more or less corroded (Plate 1). 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 beautiful 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 č (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 balance 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 č 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 δ34S = +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
Barite is also a common characteristic of other polymetallic types of the deposits from Middle Bosnian Schist Mountains: Vrtlase, Donje Selo, Cemernica, and Hrmza. However, the most common is Cu what is characteristic for such a paragenetic type of the deposit: traces, 0.003, 0.02, 0.04, 0.06, 0.55 and even 11.47 Fe, 0.10 MgO, 0.19 SO\textsubscript{3}, 1.87 Al\textsubscript{2}O\textsubscript{3}, 0.005 Pb, 0.030 Zn, 0.082 As, 0.033 Sb, 0.0013 Ag, 0.00208 Au.

Quite subordinate quantities of chalcopyrite and covellite were noticed in tetrahedrites affected by initial phases of weathering 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

**John & Eichleitner (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\textsubscript{2}.

Data of several partial or partially complete chemical analyses of crude ores or composites selected during the exploitation 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. Fussko, director of the Bakovići mine (cited by Katzer, 1905; Barič & Trubeši, 1984).

Samples Nos 10, 11, 15, 16 come from the vein in the adit F\textsubscript{1}; No 14 from the waste of the adit F\textsubscript{4}, No 13 from the adit F\textsubscript{2} and No 12 from the adit F\textsubscript{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 0.01 Fe\textsubscript{2}O\textsubscript{3}, 0.19 SO\textsubscript{3}, 1.87 Al\textsubscript{2}O\textsubscript{3}, 0.30 MnO, 0.02 CaO, 0.06 MgO, 1.71 CO\textsubscript{2}, 0.04 wt % H\textsubscript{2}O\textsuperscript{+}.

Lažarević 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\textsubscript{2}O\textsubscript{3}, 25.20 R\textsubscript{2}O\textsubscript{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 characteristic for such a paragenetic type of the deposit: traces, 0.003, 0.02, 0.04, 0.06, 0.55 and even 11.47 Fe.

**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°23’. There are some crystals with basal pinacoid (0001). Angles (1011) × (1011) = 70°01’, (K i š p a t i č, 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 crystalline with brownish crystals (Branspat) up to 1 cm large. The chemical analysis of the siderite is as follows: 86.6 FeCO\textsubscript{3}, 0.8 CaO, 2.5 MgO, and 10.1 MnCO\textsubscript{3}. This chemical composition is more similar to the siderite from the polymetallic deposit Donje Selo than to the siderites from barite deposits.

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: Vrtlase, Donje Selo, Cemernica, 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 oxidation zone of the Bakovići deposit. The limonite mostly originated by oxidation 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.

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 characteristic for such a paragenetic type of the deposit: traces, 0.003, 0.02, 0.04, 0.06, 0.55 and even 11.47 Fe.
Cu is the main constituent of chalcopyrite Au, 6.0 Ag; TPs 29.5 Au, 16.5 Ag and TP6 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 TP4 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% (Lazarévić et al., 1983).

Ramović 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 F4 (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 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
several polymetallic deposits of the Mid-Bosnian sulphur were carried out on mineral samples from between the deposit and sampled in shafts or cores of 11 drill holes), IX 14.3, but part of them will be presented for the first time in this paper.

The vein thicknesses were also very variable: 3 cm 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 empowered part of the Baković deposit; in its northern part, average Au content amounted only 4.85 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 Baković 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 F2 and F3), blocks II and III, each 15 g/t (vein in situ between adits F2 and F3), blocks IV-VIII (vein in situ between adits F3 and F4), 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 below the level of the adit F4, 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 sulphosalts sulphur were carried out on mineral samples from several polymetallic deposits of the Mid-Bosnian Schist Mts: pyrite samples from the Baković deposit, tetrahedrite samples from the Trčnik deposit, sphalerite and stibnite samples from the Cemerinka 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; 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 -13.4‰ 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 Baković 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 (Cam 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.

### Table 4

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<th>Nos</th>
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<td>342-399 (41)</td>
<td>3.86</td>
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Parageneses of the Mid-Bosnian Schist Mountains ore deposits

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### A. QUARTZ DEPOSITS

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### B. POLYMETALLIC DEPOSITS

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### C. BARITE DEPOSITS

| GORNJI | S,D | πq | D | πq | P3 | S,D/P3 | Sch | Sds | Sh | D | 30 | v | b | sd | ba | td | q | py | cc | do | cpy | Au | arg | te | ar | str |
| VAKUF  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| KREŠEVO | D | D | L | M | πq | 103 | 5 | b | v | n | sw | ba | cc | sd | td | py | fl | bu | ga | he | gr | en | lu | sph | apy | ss | che | cov | mu | ru | tu | tc | sb |
| BRESTOPSKO | 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 |

Stratigraphy: S,D-Silurian-Devonian D-Devonian P3-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 scarce occurrence 5-widespread or occasional, but visible only under microscope

Discussion

Based on geological, mineralogical stable isotope composition and fluid inclusions data, the vein mineralization, locally metasomatic ore deposits 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 Krešovo-Kiseljak-Gojna-Busovaca area, i.e. in the northeastern part of the MBSM (147 localities) Kat z e r, 1925, J u r k o v i ć, 1957, Z i v a n o v i ć, 1976). Massive, milky or semitransparent quartz is the main mineral (over 95-98 wt% SiO₂). Optically it is anomalous, often cataclased and in some places recrystallized, without cavities. Pyrite, muscovite, chlorite, hematite, tourmaline and very rare gold are accessories. Fluid inclusion data: Tm=180° C to 280°C with a maximum at 230°C; TfT confirms NaCl-CaCl₂ + MgCl₂ system of fluids. The encapsulated 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. Poly metallic ore deposits from comparatively small (Vrlasce, Hrmza), more rarely medium sized ore occurrences (Čemernica, Baković) 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 NW-SSE, dipping ENE (40-80°); 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 open space fillings or coprecipitation located in silicate host rocks, or replacement bodies (Trošnjk) in carbonate rocks. The deposits display very often typical well-developed bilateral symmetric wall rock alteration: muscovitization, silicification, tourmalinization, ankeritization. Sulphide sulphur sulphur ratios are close to zero (δ³⁴S= 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 rhylotitic 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: Vrlasce, Donje Selo, Čemernica, Bakovići, Trošnik and Hrmza subtypes (Fig. 1b). The Vrlasce 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, melonicovite 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 Cordilleran 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 subgroups: Krešovo, Gornji Vakuf, Brestovsko and Raštelica (K a t z e r, 1907, 1925, J u r k o v i ć, 1954b, 1957, 1960, 1987, 1989, J u r k o v i ć et al. 1994, R a m o v i ć et al. 1976) (Table 5C).

The main characteristic of barite deposits is 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 composition of sulphide sulphur of tetrahedrites and pyrites is distinctly negative (Fig. 5); (d) fluid inclusion data reflect specific properties: Tm between 200 and 310°C; high salinity from 24-26 wt% NaCl equ; NaCl-CaCl₂ (-MgCl₂) 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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