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MINERAL PROCESSING

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THREE TYPES OF ORE MINERALIZATION AT THE VRSHNIK ORE BODY, BUCHIM COPPER MINE, REPUBLIC OF MACEDONIA

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ABSTRACT

The ore body Vrsnik as a constitutional part of the Buchim ore deposit is the most complex and completely zoned of all four of them. There strictly were distinguished three main ore types: oxide, sulfide and mixed. The oxide ore, that is of major interest within this paper, mainly was developed in shallow or near surface parts, i.e. in the first 20 m from the surface to depth (E660/675), than mixed oxide-sulfide or so-called cementation zone that stretches up to 50m in depth, while below elevation 630 m continues sulfide primary (hypogene) ore. Total quantity of oxide and mixed ore is 5 Mt with an average content of 0,342 % Cu and it represents an important copper raw material for copper leaching facility within the Buchim mine. Total ore reserves within the Vrsnik ore body were calculated at approximately 14 Mt with an average content of 0,305 % Cu.

Keywords: Vrshnik ore body, oxide ore, leaching, cathode copper.

INTRODUCTION

In recent years, an increased interest in hydrometallurgical process of leaching of oxide copper ores occurred. In 2011. with leaching (heap leaching and in-situ leaching) were produced 3,4 Mt copper, which is 22% of world production [1]. The biggest heap leaching of copper ore is taking place in Chile, Peru and southeastern United States. The percentage of extraction of the useful component in the process of leaching of oxide copper ores ranges from 60% up to 70%. Within the ore body Vrsnik were certified ore reserves in amount of 13,6 Mt of ore of which about 5,4 Mt oxide ore with presence of copper oxide of 20-40% and 8,2 Mt sulphide ore [2]. During 2011 the ore body Vrsnik began the exploitation of oxide ore and the establishment of disposal sites for heap leaching located below the main dump no. 1, where until the mid 2015 have been exploited 4,92 Mt oxide ore with 0,342% Cu and 0,25 g/t Au. This oxide ore is the main raw material for heap leaching installation within the Buchim Mine, which increases the profitability of the ore body Vrshnik.

Within the Buchim Mine is applied heap leaching process. Leaching of copper ores is carried on: 1). primary dump no. 1 and 2). oxide ore disposal sites. The technology used in extraction of the cathode copper from the Buchim deposit is based on the use of 0.5% aqueous solution of sulfuric acid, called leaching solution, which is added to the surface of the dumps. Passing through the ore within the dump, the solution dissolves copper and flows out at its lower part. This solution that is rich in copper and is called a productive and it is transported into technological facility, where it is further processed to obtain cathode copper. The facility has an annual capacity of 2 000 t of copper. The production cycle is 365 days a year. With this production capacity copper leaching from the oxide ore dumps would last at least for another 6 years.

GENERAL FEATURES OF THE BUCHIM DEPOSIT

The Cu-Au Buchim deposit had about 170 Mt ore reserves with an average concentration of 0,240% Cu, 0,25 g/t Au and 1g/t Ag. Since 1979, 124 Mt of sulfide ore and 5 Mt of oxide ore have been exploited. The deposit represents a magmatic complex that consists of three proven finger-like porphyry ore bodies (Central Section or Central Ore Body, Vrshnik and Bunardzik). The ore body Chukar, which was supergene mineralization [3] in its nature has been exploited already (Figure 1). According to new findings in the southeastern part of the ore body Chukar there are significant amounts of ore reserves of primary sulfide mineralization. Central Ore Body porphyry mineralization is cut in one part by the Vrshnik intrusive, which means that the Central Intrusion is older than the Vrshnik one (Figure 2).

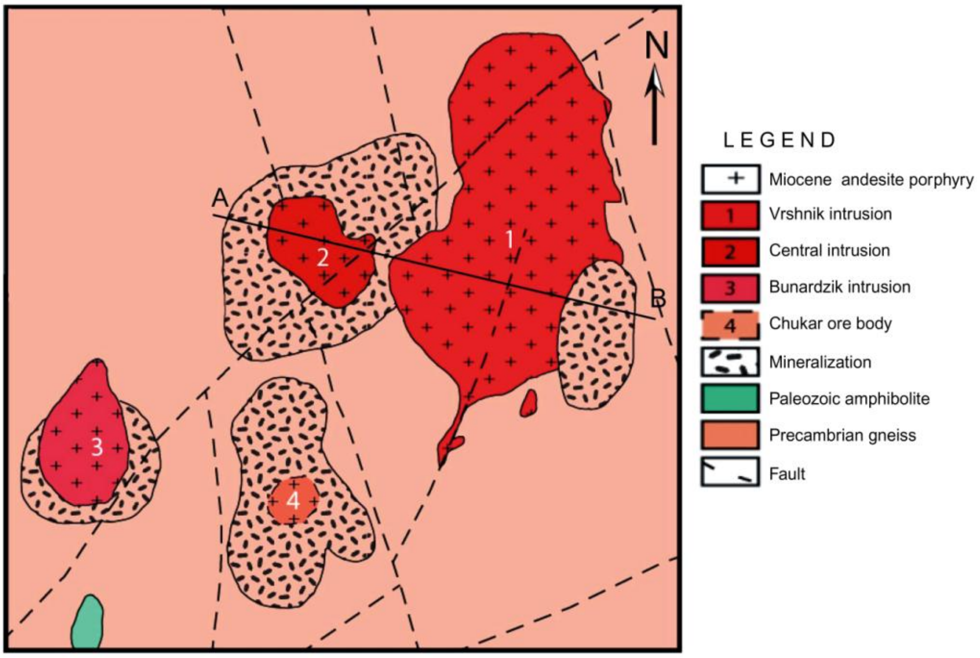

Figure 1. Geological map of the Buchim deposit (modified by [4], with position of the cross section A – B).

The Central Ore Body has been intruded into a mass of different Precambrian gneiss, which contain a small amount of lenses of Precambrian schists. Copper mineralization is primary and is located within the gneiss. It is known that gneiss phenocrysts within the magmatic stock contain pyrite veins that have been cut off from the magmatic intrusion (Figure 2C). Present magmatic rocks are a continuation of the previous magmatic and hydrothermal activities. The Central Ore Body is of cylindrical shape with a diameter of 500 m and a vertical extension of 500 m and envelopes andesite intrusion (Figure 2). The most important ore mineral is chalcopyrite followed by pyrite, magnetite, hematite, cubanite, valleriite, native gold, bornite and other minerals [4]. The Bunardzik ore body has the same mineralization as the Central Ore Body, but it id poorly mineralized in comparison to it [3].

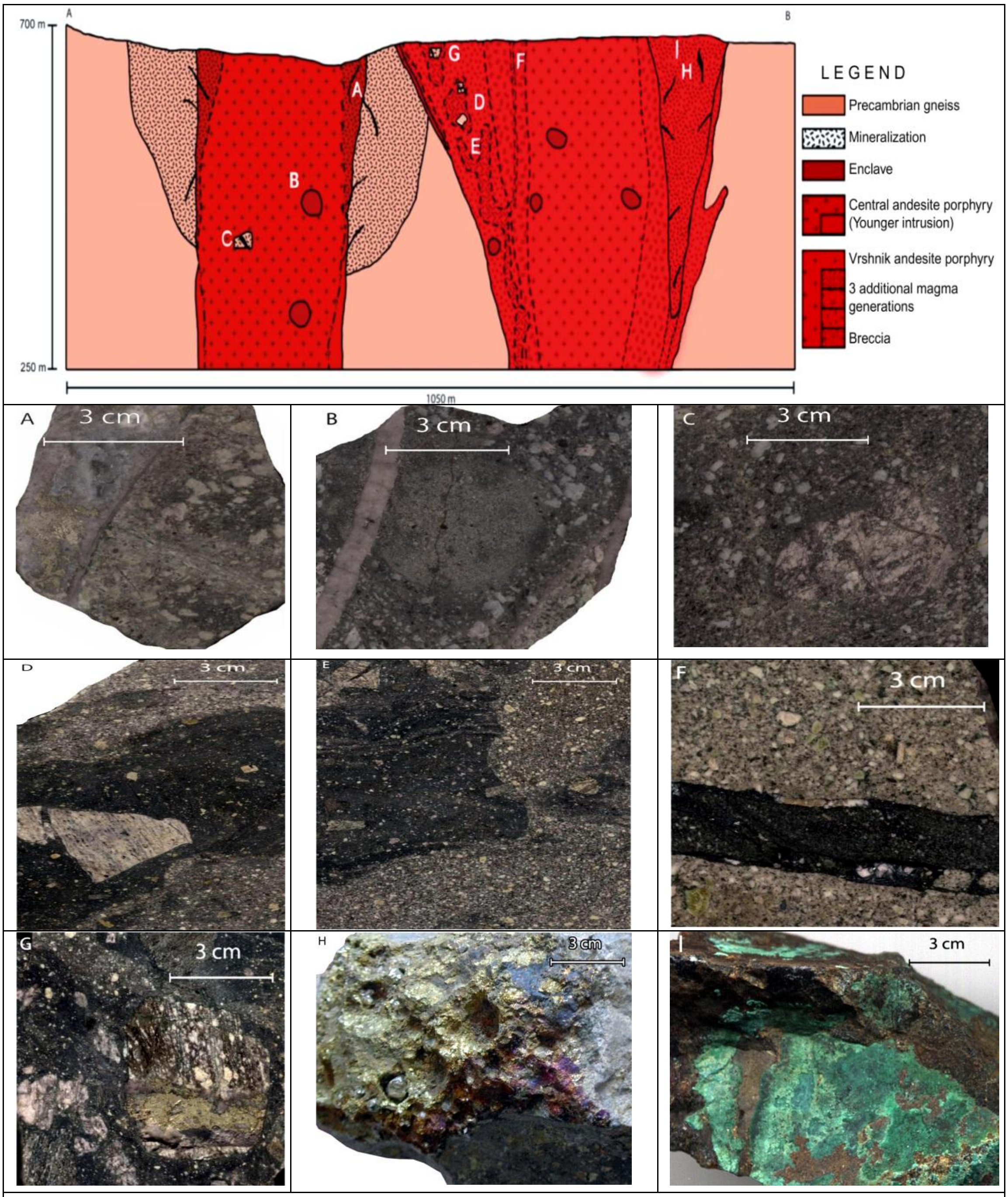

Figure 2. Geological cross-section through the Buchim ore deposit (Position of section line A-B given at Figure 1). (A) Cross-section of quartz vein at the contact of the central andesite with gneiss; (B) enclave in central intrusive; (C) gneiss fragment with porphyry structure in Central intrusive; (D) gneiss fragments are almost always placed along the dark magma; (E) mixed structure of Vrshnik's intrusions; (F) dark fine-grained magma intruded into a fragile medium-grained magma; (G) a fragment of gneiss with pyrite vein in a mixed zone; (H) pyrite-chalcopyrite vein, thick 5 cm, with presence of chalcocite, part of Vrshnik andesite E630; (I) malachite in oxide zone of the Vrshnik ore body, E675 [5].

The mineralization of the Bunardzik ore body is also located within the Precambrian gneiss of the Circum-Rhodope unit. The Bunardzik ore body unlike Central Ore Body, forms of sickle-like shape and is located within the gneiss around the southern andesite intrusions [3]. This ore body have dimensions of 300 x 100 m at surface and reaching 300 m in depth [3]. The Solway company began its exploitation back in 2014.

The Vrsnik ore body that is located east of Central Ore Body is with an oval shape. Unlike the two previously mentioned mineralizations, mineralization Vrsnik is only partially penetrated into the host rocks (gneiss). The main part is deposited in the intrusive. The ore body reaches depth of about 80 m, while at the the surface is long 300 m and wide 200 m [3]. The various parameters indicate the ore body with small dimensions, but explorations at depth not completed yet. However, Solway company began exploiting the ore body in 2011 and it is at the final stage of exploitation.

GEOLOGICAL FEATURES OF THE VRSHNIK ORE BODY

More than three decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis [3] [4]. Based on data of detailed geological exploration of copper mineralization it was determined that the Buchim deposit consists of four ore bodies: Central, Bunardzik, Vrsnik and Cukar (Figure 1), spread over an area of 10 km^2 [3]. In the ore body "Vrshnik" were allocated three andesite phases [3]. The opinion of several geologists is that andesite breakthrough within the Vrshnik ore body is cross-cut by small and sterile andesite apophyses, which results in uneven mineralization. Andesite breakthrough in the ore body Vrsnik is the largest compared to the other within the deposit and reaches 0.5 km² in area. In the southeastern parts of the Vrshnik ore body occur serpentinite, but they are of small dimensions (1-10 m), which commonly occur along fault zones [3] (Figure 3).

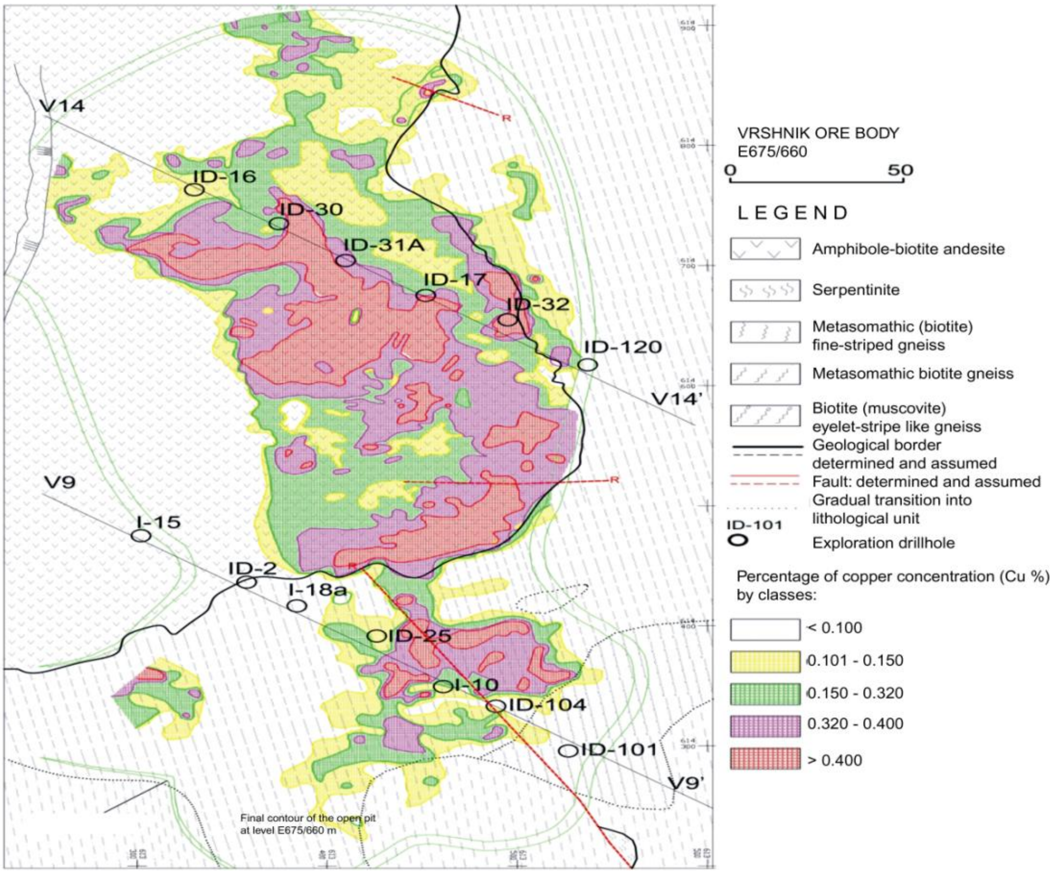

Figure 3. Geochemical map of Cu distribution within the Vrshnik ore body, level E 675/660 m.

The secondary enrichment mineralization is located in the Precambrian rocks while the primary and seconadry mineralizations are located within the andesite. Mineralization witin the Vrshnik ore body has been divided into zones (Figure 4 and 5 [2]):

1. Oxide zone (oxidation zone): a) Sub-zone of oxide ore; b) Sub-zone of ore leaching; c) Sub-zone of rich oxide ore where the content of Cu is over 1% Cu, this oxide ore contains oxide copper up to 40%, and at the moment it has been leached. At level E675 / 660 m are excavated up to 2.1 Mt of oxide ore (Figure 3).
2. Cemented zone or zone of secondary sulfide enrichment. Oxide - cementation zone in the southern parts of the Vrshnik ore body is located in muscovite finely stratified gneiss and ends at level 600. At depth occur poor sulfide mineralization <0,1% Cu (Figure 4).
3. Area of primary ore. Figure 5 shows that oxidation-cementation zone in the northern part of the Vrshnik ore body ends at level 630 m and at depth continues into the primary sulfide mineralization which is not fully explored.

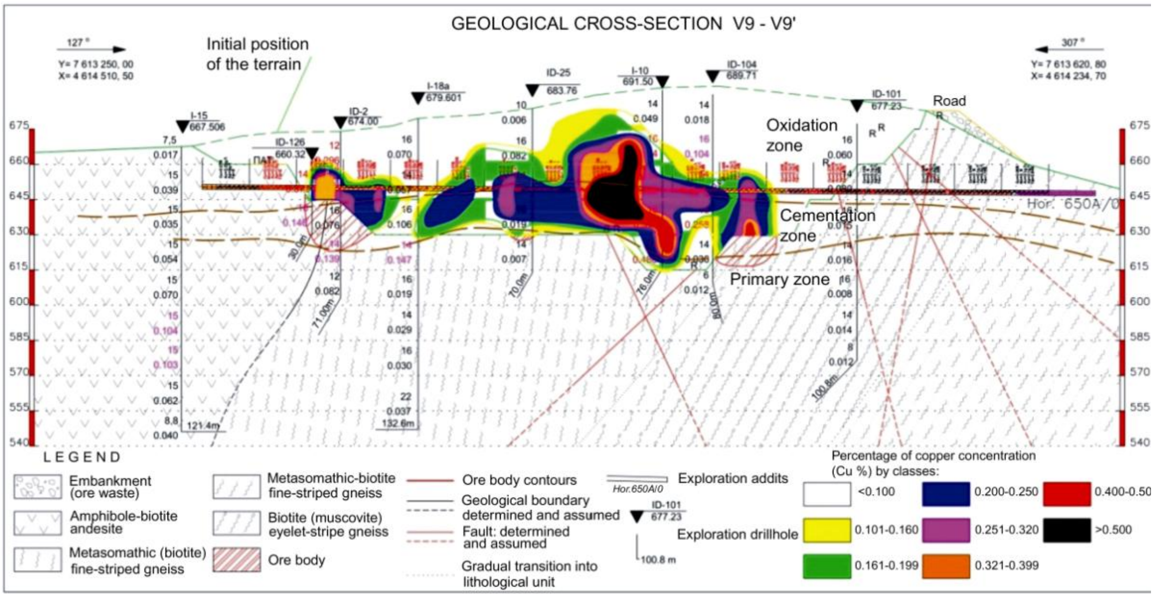

Figure 4. Geochemical cross-section V9-V9' of Cu distribution.

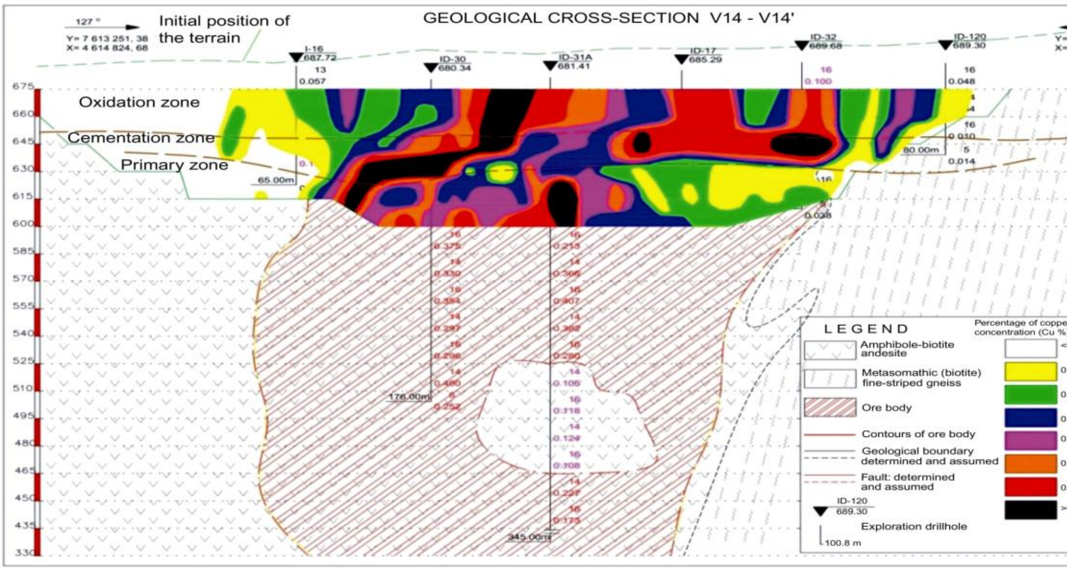

Figure 5. Geochemical cross-section V14-V14' of Cu distribution.

MINERAL COMPOSITION

The Vrshinik ore body microscopically in more details was studied by [6] and [7]. Those studies and exploitation of the Vrshnik ore body contributed into better understanding of minerals from zone of cementation as well as the sulfide minerals from the primary ores. In the part which refers to the study of primary sulfide mineralization have been established similar associations of minerals, such as in Central Ore Body and Binardzik ore body, while in the oxidation-cementation zone were determined minerals corresponding to those in the Chukar II ore body. With all the microscopic studies conducted so far for the Vrshnik ore body were found following metallic minerals pyrite, chalcocite, chalcopyrite, pyrrhotite, magnetite, Fe-hydroxides, covellite, ilmenite, sphene martite, hematite, limonite, cubanite, valeeriite, sphalerite, galena, molybdenite, enargite, anglesite, malachite, cassiterite, bornite, etc., most of which have character of a mineralogical occurrence [3].

Unlike in other ore bodies in the Vrsnik ore body particularly distinctive is an appearance of widely disseminating supergene chalcocite and the mineralization is deposited in andesite and partly in gneiss [3].

From the presented an outline of the ore minerals can be concluded that within the Buchim Mine is determined complex and diverse mineral composition, whose minerals indisputably build complex paragenetic relationships.

Here we will accent only the main types of ore parageneses:

- High-temperature oxide ore paragenesis (magnetite, titanomagnetite, rutile, specularite, sphene)
- High-temperature sulfide ore paragenesis (pyrrhotite, pyrite-I, chalcopyrite- I, nuggets)
- Medium-temperature sulfide ore paragenesis (pyrite-II, chalcopyrite-II, nuggets, molybdenite, cubanite, bizmutin, friedrichite, galenobismutite, emplektite, laitakarite)
- Medium to low-sulfide ore paragenesis (luzonite, tetrahedrite, galena, sphalerite, pyrite - III, chalcopyrite - III, enargite, bornite, chalcocite, cosalite)
- Medium to low temperature oxide paragenesis ore (hematite, martite)
- Low temperature petrogene paragenesis (quartz, calcite, chalcedony)
- Supergene paragenesis: oxidation (limonite, tenorite, native copper, malachite, azurite) and cementation (chalcocite, covellite, bornite).

QUALITATIVE-QUANTITATIVE FEATURES OF THE VRSHNIK ORE BODY MINERALIZATION

From the results obtained for the Vrshnik ore body, especially the exploration drilling by 50 x 50 m and 50 x 33 m grid, was possible to categorize ore reserves into so-called B and C_1 categories. By synthesizing the exploration results following amounts of ore and the degree of geological reserves has been confirmed (Table 1; [2])

Table 1. Geological ore reserves within the Vrshnik ore body.

Cat.	Q (t)	Cu (%)	Au (g/t)	Ag (g/t)	Fe_3O_4 (%)	Cu (t)	Au (kg)	Ag (kg)	Fe_3O_4 (t)
B	9 459 606	0,327	0,192	0,91	1,32	30 973	1 819	8 647	124 867
C_1	4 117 661	0,253	0,157	0,91	1,16	10 418	645	3 754	47 765
B+C_1	13 577 267	0,305	0.180	0,91	1,27	41 319	2 465	12400	172 632

The results obtained for the Vrshnik ore body, especially with exploration drilling on a grid 50 x 50 m and 50 x 33 m allowed categorization of ore reserves into B and C1 category. Total ore reserves in amount of 13 577 267 t has been calculated down to level 330 m mostly according to a single deep exploration drill hole (ID-31A, 345 m) below the level E 525/510. Mineralization of this drill hole is of high importance for further geological explorations of deeper parts of the Vrshnik ore body (Figure 5; [2]). At the following Table 2, are shown total geological ore reserves of oxide ore in the Vrshnik ore body, down to level E 630/615 m. Concentration of oxide copper in those ores reaches above 20%.

Table 2. Geological ore reserves of oxide ore within the Vrshnik ore body.

	Ore (t)	**Content of Cu %**	**Cu metal in ore (t)**
Rich oxide ore (Cu>0,15%)	3 600 000	0,441	15 876
Poor oxide ore (Cu=0,1-0,15%)	1 800 000	0,144	2 592
Total ore for leaching	5 400 000	0,342	18 468

During 2011 it was started with special exploitation of oxide ore from the Vrshnik ore body and formation of heap leaching piles, layered by polymer cover at the bottom. The facility for production of cathode copper has been located just below the dump No. 1, and it has been functional since 2012 (Figure 6).

Figure 6. Facility for production of leaching solutes rich with copper.

In Table 3, has been systematized review of exploited ore reserves from the Vrshnik ore body during the period starting from 2011 until June, 2015, when exploitation of oxide ore from southern parts of the Vrshnik ore body officially ended, at level E 630/615 m.

Table 3. Exploited oxide ore from the Vrshnik ore body with Cu, Au and Ag concentrations by separate ore levels.

Level	**Quantity (t)**	**Cu (%)**	**Au (g/t)**	**Ag (g/t)**	**Cu (t)**	**Au (kg)**	**Ag (kg)**
675/690	68 000	0,170	0,11	0,42	116	7	29
660/675	2 100 000	0,362	0,28	0,74	7 602	588	1 554
645/660	1 931 800	0,350	0,28	0,74	6 761	541	1 430
630/645	619 251	0,290	0,10	0,45	1 796	62	279
615/630	200 949	0,280	0,09	0,45	563	18	90
Total	4 920 000	0,342	0,25	0,69	16 837	1 216	3 381

In Table 4 are shown geological, exploitable and exploited (until June, 2015) ore reserves within the Vrshnik ore body.

Table 4. Total geological, exploitable and exploited ore reserves (until June, 2015) within Vrshnik ore body

Type of ore reserves	Geological ore reserves	Exploitable ore reserves	Exploited ore reserves
Category	$B+C_1$	$B+C_1$	$B+C_1$
Quantity (t)	5 400 000	4 700 000	4 920 000
Cu (%)	0,342	0,335	0,342
Au (g/t)	0,19	0,20	0,25
Ag (g/t)	0,69	0,68	0,69
Cu (t)	**18 468**	**15 745**	**16 837**
Au (kg)	1 026	940	1 216
Ag (kg)	3 726	3 196	3 381

CONCLUSION

Oxide ore within the Vrshnik ore body accounts for one third of the total amount of established geological ore reserves in this particular ore body and it represents the main raw material for the copper leaching facility at the Buchim Mine. The total volume of oxide ore that is mostly already exploited is about 5 Mt with an average content of 0,342% Cu, which represents a remarkable quality for ore used in the copper leaching facility. The main mineralogical features characteristics coincide with the term oxide ore and ore from zone of cementation of the Vrshnik ore body where main carriers of the copper mineralization are malachite, azurite, cuprite, native copper while as main ore minerals occur chalcocite and covellite. The so-called oxide mineralization in the Vrshnik ore body occupies a vertical range of 50 m, between ore levels E 675 to E 630, while beneath the level 630 is confirmed, mostly in the northern part that mineralization transforms into a primary mineralization dominated by chalcopyrite.

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