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TECHNO-ECONOMIC PARAMETERS RELATED TO THE VRSHNIK Cu-Au ORE BODY, BUCHIM COPPER MINE, EASTERN MACEDONIA

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ABSTRACT

Calculated ore-bearing coefficient in the Vrshnik ore body was 0.78%, meaning that within the ore body boundaries only 22% of mass is not mineralized somehow, which is highly compatible with remaining three ore bodies within the Buchim porphyry copper mine. The calculated value of variation coefficient (V) has shown value of 70% that is in the range of 43-100%, which displays that this ore body belongs to the third group of deposits with uneven mineralization. An average copper, gold and silver concentrations were determined as 0.305% Cu, 0.18g/t Au and 0.91 g/t Ag, respectively. Minimal economic content (MEC) within the Vršnik ore body, as represent of this kind of mineralization, was determined as 0.160% Cu. In similar manner was calculated the lowest copper boundary (cutoff grade), which have shown value of 0.138% Cu and thus allowing certain decrease of contents in exploited ore. Also, there were calculated so called copper monometal values, which included influence of the present gold and silver in the ore. Calculated copper monometal was set at relatively fair 0.399% Cu that represents solid mainstay for exploitation of copper in these low percentage ores. Calculated ore reserves in this particular ore body were 13 577 267 t of ore with 0.305% Cu, 0.18 g/t Au and 0.91 g/t Ag and increased mine life for additional 6 years.

Keywords: Vrshnik ore body, primary mineralization, secondary enrichment mineralization, variation coefficient, minimal economic concentration.

INTRODUCTION

The unique Macedonian active copper porphyry deposit, Buchim, is situated on the the border between the Serbo-Macedonian massif and the Vardar zone and in terms of metallogeny it belongs to the Lece-Chalkidiki metallogenic zone [1]. The deposit itself is located in eastern central Macedonia, 10 km west of the town of Radovis. Here we would like to stress some facts for the Vršnik ore body, which is one of the four bodies within the Buchim copper mine that is in active exploitation. This ore body is very specific since there were determined three types of porphyry Cu-Au mineralization. In the shallowest parts, close to the surface, occur oxide ores with copper concentrations in the range 0.3-0.4% Cu, while gold concentrations are high as well, reaching up to 0.5 g/t Au. The second ore type in this ore body is related to the zones of secondary sulfide enrichment or cementation zone, which goes up to 100 m at depth. That mineralization mainly consists of chalcocite and covellite with copper concentrations in the range of

0.3 – 0.5% Cu. The third ore type is represented by primary, poor Cu-Au sulfide mineralization reaching even 300 m at depth. Above mentioned features of this ore mineralization gave us an initiative to calculate several important techno-economical parameters, which can define the economic type of this mineralization. Namely, the degree of ore bearing in these types of ore mineralization is variable, but calculation at particular levels and different drill holes gave the more realistic ratio of mixed types of mineralization within this ore body. Some techno-economic parameters related to the Vrshnik ore body can be found in some previous works [2], [3].

GEOLOGICAL FEATURES

Geological composition of the Buchim deposit consists of the Precambrian metamorphic (gneiss, micaschist and amphibolite) and Tertiary rocks. Gneisses are the most common lithology members and are the most favorable lithology setting for deposition of ore mineralization. Several alternating varieties of gneisses are determined according to their mineral composition: biotitic, amphibole-biotitic, micas, metasomatic etc. Tertiary magmatic rocks are present as several latitic subvolcanic-volcanic crosscuts and andesite-latites around which three ore bodies are lineated, which points to direct relationship of the magmatism and mineralization in the deposit. Spatially and paragenetically porphyry copper mineralization is related to latites and latite-andesites. They occur as small subvolcanic intrusions (dikes and necks) distributed NNW-SSE and NE-SW along fault structures and exibit pronounced holo to hipo-crystalline porphyritic structure and massive texture. The age of the rocks ranges from 27.5 to 24.5 m.y. [3].

ORE MINERALIZATIONS

More than three decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis [1] [4], [5], [6], [7], [8]. 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), which are spread over an area of approximately 10 km^2 [9]. The Central, Bunardzik and Vrsnik ore bodies are related to andesitic porphyry intrusions, whereas the Cukar ore body consists of a supergene copper mineralization [9]. It should be pointed out that the primary sulphide mineralization played the major role in production of copper. Within the text that will follow we are going to give the major features of the Vrshnik ore body, which is subject of analysis in this paper.

The Vrsnik ore body is situated east of the Centralen del orebody at a distance of some 200 m. In contrast to the Centralen del and Bunardzik ore bodies, emplaced into gneiss, the Vrsnik orebody is featuring the mineralization chiefly hosted by the intrusions (andesite) and partly by gneiss. The mineralization is not uniform throughout the ore body. The Vrsnik ore body’s longer axis (N-S direction) is 300 m long, while the width of the ore body ranges around 200 m, which indicates its small size. In regards to mineralization the following minerals has been confirmed there: pyrite, chalcocite, chalcopyrite, pyrrhotite, magnetite, Fe-hydroxide, covellite, ilmenite, sphalerite, galena, molybdenite, enargite, anglesite, malachite, cassiterite, bornite etc. In contrast to other ore bodies, Vrsnik is particularly strongly characterized by widespread supergene chalcocite that is emplaced into andesite and partly into gneisses.

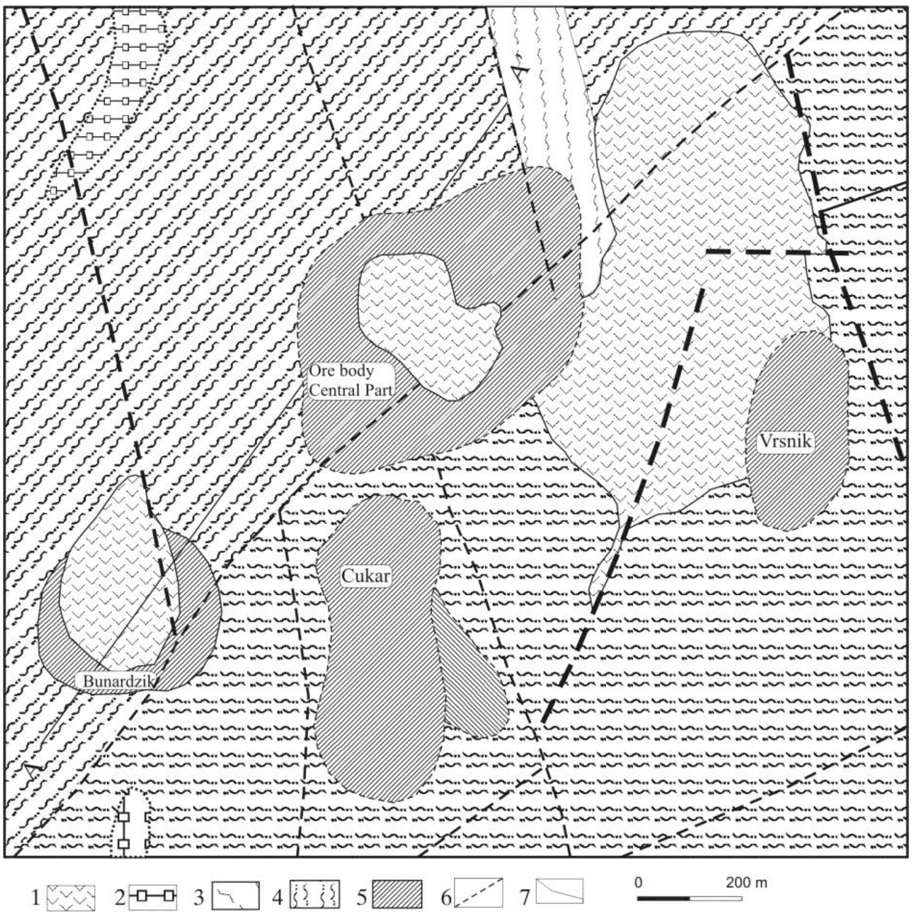

Fig. 1. Simplified geological map of the Buchim deposit [4]
1. Andesite and latite; 2. Amphibolite; 3. Muscovite schist; 4. Gneiss; 5. Ore body; 6. Fault; 7. Ore body contour.

TECHNO-ECONOMIC PARAMETERS

Within this chapter we are going to display the major parameters of the techno-economic evaluation of the Vrshnik ore body situated in the Buchim copper mine, which directly are pointing out to a possibility of productive exploitation of copper ore from this particular ore body and possibility to create profit. Here in more details are given results from calculations of ore-bearing coefficient, variation coefficient, average concentrations of major ore metals (Cu, Au), minimal economic concentration, cutoff grade, calculation of mine life as a function of calculated ore reserves.

Ore-bearing coefficient.- The ore-bearing coefficient defines the ratio between the total mineralized area within the ore body and certain poor (waste) zones (content below the limit of 0.15% Cu), within that same ore body. In the Vrshnik ore body from the 18 exploration cross sections with 60 drill holes and 2678 m of mineralized area, 2098 m were mineralized above 0.15% Cu while the 590 m displayed mineralization below the limit of 0.15% Cu, but however significantly over the Clark values. Using the formula given below [10], we have managed to calculate aforementioned coefficient.

$$K_r = \frac{m_1}{m_2} = \frac{2098}{2678} = 0.78$$

Kr - Ore-bearing coefficient

m_1- Productive interval (mineralized area >0.15% Cu)
m_2 - Total mineralized interval

This gave us an opportunity to calculate the ore-bearing coefficient of 0.78, which points out that within the defined ore body there are 22% of mass below the accepted minimal economic concentration of 0.15% Cu. Additionally we would like to stress out that the ore-bearing coefficients throughout all drill holes ranged from 0.12 up to 1.0 while along the exploration cross sections those ranges were slightly narrower, 0.12-0.92.

Variation coefficient.- This coefficient defines spatial distribution of useful mineral components in the the deposit or more precisely how evenly mineralization is represented in the deposit (ore body). In the Vrshnik body's case there were drilled 85 exploration drill holes of which 60 drill holes defined the ore body. In those 60 drill holes were sampled 1339 samples, which have defined an average contents of Cu, Au, Ag and Fe_3O_4. The basic parameters for calculation of variation coeficient in the Vrshnik ore body were selected from 19 the most representative drill holes totaling 585 m (Table 1).

Table 1. Basic parameters for calculation of variation coefficient in the Vrshnik ore body, Buchim Mine

Drillhole	N	$\bar{C}$ (%)	$\sum X^2$	δ	V(%)
ID-100	7	0.199	0.146	0.155	78
ID-22	15	0.245	0.538	0.196	80
ID-35	15	0.337	0.954	0.261	77
ID-36	22	0.368	1.449	0.263	71
ID-43	25	0.464	2.827	0.343	74
ID-42	32	0.543	5.646	0.427	79
ID-108	9	0.208	0.220	0.166	80
ID-40	32	0.252	0.536	0.131	52
ID-114	13	0.368	1.279	0.326	88
ID-117	9	0.292	0.212	0.163	56
ID-27	13	0.294	0.162	0.116	39
ID-20	8	0.236	0.114	0.128	54
ID-31A	133	0.265	3.869	0.171	64
I-27	15	0.283	0.114	0.090	32
ID-30	85	0.294	1.780	0.146	50
I-14	15	0.247	0.200	0.119	48
ID-28	75	0.274	3.300	0.211	77
I-13	24	0.366	2.614	0.337	92
I-26	38	0.263	1.665	0.212	81
$\sum$	585	0.31	27.625	0.217	70

First of all we have calculated an average copper content, as it is given below:

$$C^{-} = \frac{\sum C}{N} = \frac{181.582}{585} = 0.310\%$$

N-total number of samples
C-Average copper concentration(Cu%)

Then we have proceeded with calculation of median sqaure deviation and variation coefficient as given below:

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{27.625}{584}} = \sqrt{0.047303} = 0.217$$

$\sum X^2$ -Sum of square deviations from an average values

δ -medium square deviation

$$\text{V}= \frac{\delta x100}{C^{-}} = \frac{0.217x100}{0.310} = \frac{21.7}{0.310} = 70\%$$

V-Variation coefficient

The value of 70% for the variation coefficient is within the range of 32-92%, which points out to an irregular mineralization representative for most of the hydrothermal copper and polymetallic mineralizations.

An average concentration of useful component(s) .- An average concentation of useful component represents the average presence of one or more components within an ore body. By the basic method of calculation of ore reserves within the Vrshnik ore body (level blocks) it was determined that for calculated B and C1 category of reserves the average values of useful components are 0.305% Cu, 0.18 g/t Au and 0.91g/t Ag.

Calculating the Minimal Economic Concentration (MEC). – This calculation should provide a clear answer to the question, does the explored deposit or ore body (represented by calculated reserves within) can fulfill the economic requirements for viable exploitation of that ore body. Aforementioned calculation should display, does the exploitation will cover all the production costs and in the same time to achieve adequate profit, equivalent to the required cost effective coefficient. Bearing in mind that here we were working only with one small part of the Buchim deposits, we used Gudalin’s formula [10] where have been considered the following parameters: exploitation costs, utilization of the mineral resource, price of the final product or more precisely the final ore product (copper, gold and silver). As we already mentioned, this calculation was performed by the formula:

$$MEC = \frac{100 \cdot S}{Ie \cdot Io \cdot \text{Im} \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot \text{Im}} \right)}$$

where: S-costs of exploitation and processing of 1t ore (Te i To) 7.13 US$/t
r-dillution during the exploitation 3%
Ie- dillution coefficient during the exploitation (1- ($r/100$))

Io-coefficient of extraction during enrichment, 89%
Im-efficiency coefficient during the metalurgical processing, 95%
Co-market price of copper (at the moment of calculation), 7000 US$/t
Sm-costs of metalurgical processing of the final product unit, 1350 US$/t
St-cost for transport per tonne ore concentrate, 31 US$/t
g-concentration of metal in ore concentrate, 21%

$$MEC = \frac{100 \cdot S}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} = \frac{100 \cdot 7.13}{0.97 \cdot 0.88 \cdot 0.95 \left(7000 - 1350 - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} =$$

$$= \frac{713}{0.811 \cdot (5650 - 155.389)} = \frac{713}{4455.69} = 0.160\% Cu$$

MEC = 0.160 % Cu

Calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.160% Cu.

Calculation of monometal.- Ore reserves calculation of the Vrshnik ore body have shown that it is natural product that contains in average 0.305% Cu and associated elements 0.18g/t Au and 0.91 g/t Ag. Comparing those values of useful components with the necessary MEC (0.160% Cu) we may conclude that the ore body have contents higher than the minimal one. In those cases we trying to calculate all present useful components to one monometal (in this case copper). That calculation was performed using transformation factor (*f*) for associated components (Au, Ag) on the basis of Cu expressed as monometal. The transformation factor is calculated as follows:

$$f_{Au} = \frac{C_{Au} \cdot Io_{Au} \cdot \mathrm{Im}_{Au} \cdot Co_{Au}}{C_{Cu} \cdot Io_{Cu} \cdot \mathrm{Im}_{Cu} \cdot Co_{Cu}}$$

$\mathbf{C_{Au}}$-average content of Au in ore (g/t)
$\mathbf{Io_{Au}}$-usage efficiency of Au in flotation process (%)
$\mathbf{Im_{Au}}$-metallurgical usage of Au (%)
$Co_{\mathbf{Au}}$ – gold in concentrate (g/t)
$\mathbf{C_{Cu}}$-average content of Cu in ore (%)
$\mathbf{Io_{Cu}}$- usage efficiency of Cu in flotation process (%)
$\mathbf{Im_{Cu}}$- metallurgical usage of Cu (%)
$Co_{\mathbf{Au}}$ – copper in concentrate (%)

In that manner we have calculated for the Vrshnik ore body:

$$f_{Au} = \frac{0.18 \cdot 0.5 \cdot 0.92 \cdot 43}{3.05 \cdot 0.88 \cdot 0.95 \cdot 7} = \frac{3.5604}{17.8486} = 0.199$$

$$f_{Ag} = \frac{0.91 \cdot 0.31 \cdot 0.5 \cdot 0.6}{3.05 \cdot 0.88 \cdot 0.95 \cdot 7} = \frac{0.08463}{17.8486} = 0.0047$$

$$Cu = C_{Cu} + (Cu_{Cu} \cdot f_{Au}) + (C_{Cu} \cdot f_{Ag}) =$$

$$Cu = 0.305 + (0.305 \cdot 0.199) + (0.305 \cdot 0.004) = 0.367\%$$

$$\mathbf{Cu_{monometal}} = \mathbf{0.367\%}$$

The calculation above have shown that useful components calculated to the Cu monometal, 0.367% Cu, is 0.367% Cu, which is higher than the needed one calculated with MEC (0.160% Cu) and in that direction the ore reserves can be considered as economically viable itself.

Cutoff grade.- This grade defined as the level of mineral in an ore below which it is not economically feasible to mine (GS) was calculated after intensive analysis of several parameters such are: dilution coefficient of ore during excavation (L_e=3%), efficiency of usability during enrichment (L_o=88%), efficiency of usability during metallurgical processing (L_m=94.7%), cost for enrichment of 1t ore (S_o=2.90 US$/t), transport costs for 1 t of ore concentrate (S_t=31 US$/t), costs for metallurgical processing per unit of final product (S_m=1350 US$/t), market price of copper at the moment of calculation (C_o=7000 US$/t), costs for excavation of 1t of ore and copper metal content in ore concentrate (g=21%). In that manner we have calculated the cutoff grade as follows:

$$GS = \frac{100 \cdot So}{Le \cdot Lo \cdot Lm \cdot \left(Co - Sm - \dfrac{100St}{gLm} \right)} = \frac{100 \cdot 6.14}{0.97 \cdot 0.88 \cdot 0.95 \left(7000 - 1350 - \dfrac{100 \cdot 31}{21 \cdot 0.95} \right)} =$$

$$= \frac{614}{0.97 \cdot 0.88 \cdot 0.95 \left(7000 - 1350 - \dfrac{100 \cdot 31}{21 \cdot 0.95} \right)} = 0.138\%$$

GS= 0.138% Cu

The calculated cutoff grade takes only copper in consideration although we have gold and silver as valuable components in the Vrshnik's ore. Bearing in mind all the above calculated parameters we have calculated the ore reserves within the Vrshnik ore body and corresponding concentrations of certain metals in them (Table 2).

Table 2. Calculation of ore reserves in the Vrshnik ore body

Parameters		**Category**		
		B	**C_1**	**B + C_1**
Commodity	**unit**	9459606	4117661	13577267
Cu	%	0.327	0.253	0.305
Au	g/t	0.192	0.157	0.18
Ag	g/t	0.91	0.91	0.91
Cu	t	30973.5	10417.8	41391.3
Au	kg	1 819	645.4	2464.4
Ag	kg	8646.51	3754.26	12400.77

From the total of calculated ore reserves in the Vrshnik ore body in an ammount of 13 577 267 t (B+C_1 category) with an average content of 0.305% Cu, 0.18 g/t Au and 0.91 g/t Ag to *oxide ore* belong 5 427 684 t (B+C_1 category) with an average content of 0.342 % Cu, 0.188 g/t Au and 0.69 g/t Ag while the rest of 8 149 583 t with an average 0.280%Cu, 0.177 g/t Au and 1.06g/t Ag belongs to *sulfide ore*.

CONCLUSION

The Vrshnik ore body is one of the most important ore bodies for the production of copper ore in the Buchim Mine with calculated ore reserves of 13 577 267 t of ore with an average grade of 0.305% Cu, 0.18 g/t Au and 0.91 g/t Ag and specific style of three types of ore mineralization: oxide, sulfide and secondary sulfide enrichment. The ore bearing coeffiecient was calculated at 0.78, variation coefficient 70%, minimal economic concentration 0.160% Cu and cutoff grade of 0.138% Cu. All these techno-economic parameters have positive effects to the exploitation of this ore body, which with existing capacity of the Buchim mine provides additional 6 years of production.

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