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

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Abstract

The calculated ore-bearing coefficient in the Bunardzik ore body was 0.82%, meaning that within the ore body boundaries only 18% of the mass is not mineralized somehow, which is highly compatible with the remaining three ore bodies within the Buchim porphyry copper mine. The calculated value of the variation coefficient (V) has shown a value of 54% that is in the range of 43-100%, which displays that this ore body belongs to the third group of ore bodies with uneven mineralization. Average copper, gold and silver concentrations were determined as 0.30% Cu, 0.35 g/t Au and 1.0 g/t Ag, respectively. Minimal economic content (MEC) within the Bunardzik ore body, as a representation of this kind of mineralization, was determined as 0.2099% Cu. In a similar manner was calculated the lowest copper boundary (cutoff grade), which has shown a value of 0.1399% Cu thus allowing a certain decrease in the contents of the exploited ore. Also, the so called copper monometal values were calculated, which included the influence of the present gold and silver in the ore. The calculated copper monometal was set at relatively fair 0.399% Cu that represents solid mainstay for exploitation of copper in these low percentage ores. Thee calculated ore reserves in this particular ore body were 24 042 751 t of ore with 0.257% Cu, 0.35 g/t Au and 0.91 g/t Ag and increased mine life for additional 4.4 years.

Key words: *Bunardzik ore body, copper mineralization, variation coefficient, minimal economic concentration.*

INTRODUCTION

The Bučim porphyry Cu deposit is located in the border area between the Serbo-Macedonian Massif (SMM) and the Vardar Zone (VZ) 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 about the Bunardzik ore body, which is one of the four bodies within the Buchim copper mine that is in active exploitation. The Cu-Au mineralization within this ore body is mainly of primary type, formed during hydrothermal processes at several subsequent stages within the temperature range 300-400ºC [2,3]. The latest findings defined ores with copper concentrations in the range 0.257% Cu, while gold concentrations are high as well, reaching up to 0.35 g/t Au followed by silver concentrations up to 0.91 g/t Ag. The 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 calculations 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 Bunardzik ore body can be found in some previous works [2,3].

GEOLOGICAL FEATURES

The geological setting 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 a direct relationship of the magmatism and mineralization in the deposit. Spatially and paragenetically, the 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 exhibit 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

The Buchim deposit is composed of a magmatic complex consisting of three proven finger-like porphyry stocks (Central Part, Vrsnik and Bunardzik) while the Cukar ore body, a supergene mineralization developed in gneiss, has already been mined out (Figure 1) [2]. More than three decades of study of this deposit have shown that it is characterized by a complex mineral assemblage and mineral paragenesis [1,4-9]. 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]. The primary sulfide mineralization plays the major role in the production of copper. Within the text that will follow, we are going to present the major features of the Bunardzik ore body, which is the subject of analysis in this paper.

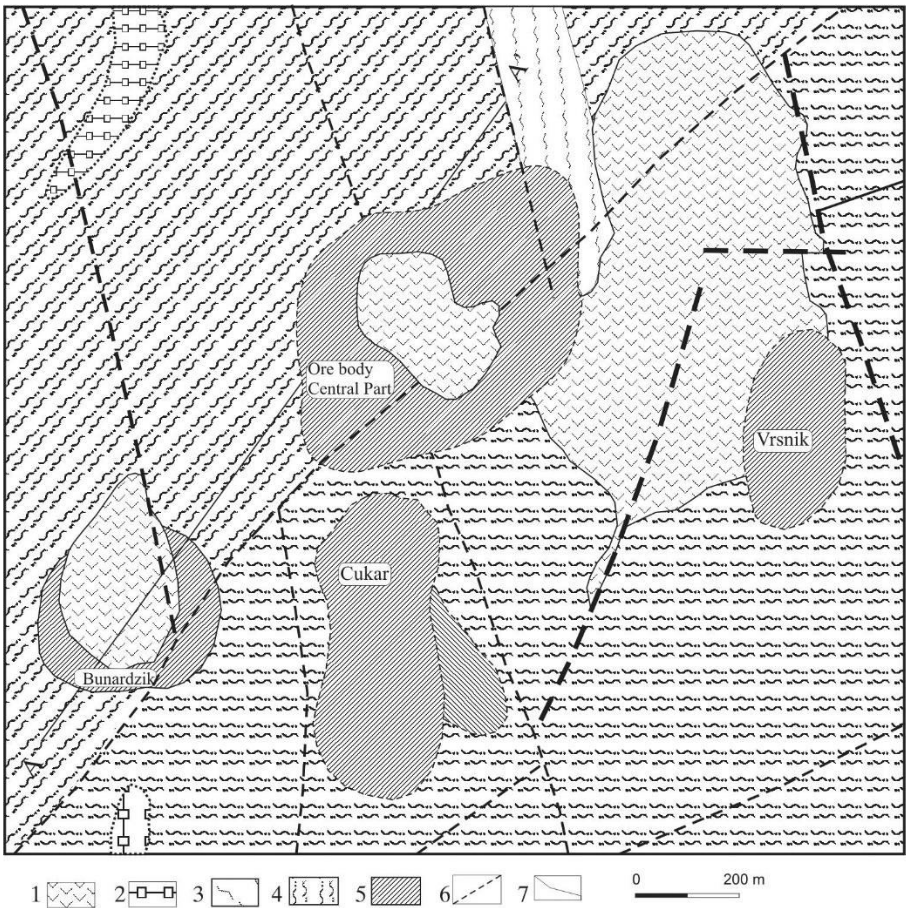

Figure 1. Simplified geological map of the Buchim deposit [4].
1. Andesite and latite; 2. Amphibolite; 3. Muscovite schist; 4. Gneiss; 5. Ore body; 6. Fault; 7. Ore body contour.

The Bunardzik ore body is situated southwestern of the Central part orebody at a distance of some 300 m. Similar to the Central part ore body, the Bunardzik ore body is emplaced into gneiss, which is quite in contrast to the Vrsnik orebody with its mineralization chiefly hosted by the intrusions (andesite) and partly by gneiss. The mineralization is not uniform throughout the ore body (veinlets, stockworks and impregnations), although it belongs to the primary type of copper mineralization, which have a major role in the copper production from the Buchim Mine. The Bunardzik ore body's longer axis (N-S direction) is 300 m long, while the width of the ore body ranges around 100-150 m, which indicates its small size and composite half-moon shape that mimics an andesite intrusion form. In regard to mineralization the following minerals have been confirmed there: pyrite, chalcopyrite, pyrrhotite, magnetite, hematite, rutile, Fe-hydroxide, native gold, covellite, chalcocite, ilmenite, sphalerite, galena, molybdenite, enargite, anglesite, malachite, cassiterite, bornite, bismuthinite, freidrichite, krupkaite, emplectite, cosalite etc.

TECHNO-ECONOMIC PARAMETERS

In this part of the paper, we are going to display the major parameters of the techno-economic evaluation of the Bunardzik ore body situated in the Buchim copper mine, which are directly pointing to a possibility of productive exploitation of copper ore from this particular ore body and the possibility to create profit. Here the results from the 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 are given in more details.

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 Bunardzik ore body from the 7 exploration cross sections with 18 drill holes and 2994 m of mineralized area, 2442 m were mineralized above 0.15% Cu, while the 552 m displayed mineralization below the limit of 0.15% Cu, but however significantly over the Clark values. Using the formula given below [10,11], we have managed to calculate the aforementioned coefficient.

$$K_r = \frac{m_1}{m_2} = \frac{2442}{2994} = 0.82 \qquad (1)$$

where: K_r - Ore-bearing coefficient,
m_1- Productive interval (mineralized area >0.15% Cu), and
m_2 - Total mineralized interval.

This gave us an opportunity to calculate the ore-bearing coefficient of 0.82, which points out that within the defined ore body there are 18% of mass below the accepted minimal economic concentration of 0.15% Cu. Additionally, we would like to stress that the ore-bearing coefficients throughout all drill holes ranged from 0.12 up to 0.99, while along the exploration cross sections those ranges were slightly narrower, 0.12-0.85.

Variation coefficient. This coefficient defines the spatial distribution of useful mineral components in the deposit or, more precisely, how evenly mineralization is represented in the deposit (ore body). In the Bunardzik body's case 41 exploration drill holes were drilled there of which 33 drill holes defined the ore body. In those 33 drill holes 515 samples were taken, which have defined an average contents of Cu, Au, Ag and Fe_3O_4. The basic parameters for calculation of the variation coefficient in the Bunardzik ore body were selected from 7 of the most representative drill holes totaling 515 m (Table 1).

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

Drillhole	N	C^{-} (%)	$\sum X^2$	δ	V(%)
NM-4	57	0.196	0.629	0.105	54
N-5	96	0.237	1.568	0.126	53
NM-5	69	0.249	0.680	0.100	40
M-5	96	0.363	4.590	0.219	60
ML-5	76	0.217	0.875	0.109	50
L-5	52	0.322	1.446	0.167	52
N-6	69	0.202	0.538	0.089	44
$\sum$	515	0.259	10.326	0.142	54

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

$$C^{-} = \frac{\sum C}{N} = \frac{133.161}{515} = 0.259\ \% \tag{2}$$

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

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

$$\delta = \sqrt{\frac{\sum X^2}{N-1}} = \sqrt{\frac{10.326}{514}} = \sqrt{0.020089} = 0.412 \tag{3}$$

$\sum X^2$ -Sum of square deviations from average values, and
δ -medium square deviation

$$V = \frac{\delta x100}{C^{-}} = \frac{0.142 \cdot 100}{0.259}\frac{14.2}{0.259} = 54\% \tag{4}$$

where: V-Variation coefficient.

The value of 54% for the variation coefficient is within the range of 32-92%, which points to an irregular mineralization representative for most of the hydrothermal copper and polymetallic mineralizations.

An average concentration of useful component(s). An average concentration of a 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 Bunardzik ore body (level blocks), it was determined that for the calculated B and C1 category of reserves the average values of useful components are 0.257% Cu, 0.35 g/t Au and 0.91g/t Ag.

Calculating the Minimal Economic Concentration (MEC). This calculation should provide a clear answer to the question if the explored deposit or ore body (represented by the calculated reserves within) can fulfill the economic requirements for viable exploitation of that ore body. Aforementioned calculation should display if the exploitation will cover all the production costs and at the same time 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 the Gudalin's formula [10,11] where the following parameters have been considered: 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:

$$MEC = \frac{100 \cdot S}{I_e \cdot I_o \cdot I_m \cdot \left(C_o - S_m - \frac{100 \cdot S_t}{g \cdot I_m}\right)} \quad (5)$$

where: *S*-costs of exploitation and processing of 1t ore (Te i To) 12.0 US$/t,
r-dilution during the exploitation 3%,
Ie- dilution coefficient during the exploitation (1- (r/100)),
Io-coefficient of extraction during enrichment, 88%,
Im-efficiency coefficient during the metallurgical processing, 95%,
Co-market price of copper (at the moment of calculation), 8200 US$/t,
Sm-costs of metallurgical processing of the final product unit, 1000 US$/t,
St-cost for transport per ton ore concentrate, 30 US$/t, and
g-concentration of metal in ore concentrate, 21%.

$$MEC = \frac{100 \cdot S}{I_e \cdot I_o \cdot I_m \cdot \left(C_o - S_m - \frac{100 \cdot St}{g \cdot I_m}\right)}$$

$$= \frac{100 \cdot 12.0}{0.97 \cdot 0.88 \cdot 0.95 \left(8200 - 1000 - \frac{100 \cdot 30}{21 \cdot 95}\right)}$$

$$= \frac{1200}{0.811 \cdot (7200 - 150.375)} = \frac{1200}{5716.68} = 0.2099\% Cu$$

$$MEC = 0.2099\%\ Cu$$

The calculated minimal economic concentration displays that for a cost effective production the MEC value should not be lower than 0.2099% Cu.

Calculation of monometal. – The ore reserves calculation of the Bunardzik ore body has shown that it is a natural product that contains an average of 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 has contents higher than the minimal one. In those cases, we try 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 [10,11]:

$$f_{Au} = \frac{C_{Au} \cdot Io_{Au} \cdot Im_{Au} \cdot Co_{Au}}{C_{Cu} \cdot Io_{Cu} \cdot Im_{Cu} \cdot Co_{Cu}} \quad (6)$$

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

In that manner, we have calculated for the Bunardzik ore body:

$$f_{Au} = \frac{0.35 \cdot 0.5 \cdot 0.92 \cdot 45}{2.57 \cdot 0.88 \cdot 0.95 \cdot 8.2} = \frac{7.245}{17.61786} = 0.41123$$

$$f_{Ag} = \frac{0.91 \cdot 0.31 \cdot 0.5 \cdot 0.9}{2.57 \cdot 0.88 \cdot 0.95 \cdot 8.2} = \frac{0.126945}{17.61786} = 0.007205$$

$$Cu = Cu_{Cu} + (C_{Cu} \cdot f_{Au}) + \left(C_{Cu} \cdot f_{Ag}\right) = \quad (7)$$

$$Cu = 0.257 + (0.257 + 0.41123) + (0.257 + 0.007205) = 0.364538\%$$

$$Cu_{monometal} = 0.364538\%$$

The calculation above has shown that the useful component calculated to the Cu monometal is 0.364538% Cu, which is higher than the needed one calculated with MEC (0.2099% Cu) and in that direction the ore reserves can be considered as economically viable.

Cutoff grade. This grade defined as the level of mineral in an ore below which is not economically feasible to mine (CG) was calculated after an intensive analysis of several parameters such as: dilution coefficient of ore during excavation (Le=3%), efficiency of usability during enrichment (Lo=88%), efficiency of usability during metallurgical processing (Lm=95.0%), cost for enrichment of 1t ore (So=2.90 US$/t), transport costs for 1 t of ore concentrate (St=30 US$/t), costs for metallurgical processing per unit of a final product (Sm=1000 US$/t), market price of copper at the moment of calculation (Co=8200 US$/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:

$$CG = \frac{100 \cdot S_o}{L_e \cdot L_o \cdot L_m \cdot \left(C_o - S_m - \frac{100St}{gLm}\right)} \quad (8)$$

$$= \frac{100 \cdot 8.0}{0.97 \cdot 0.88 \cdot 0.95 \cdot \left(8200 - 1000 - \frac{100 \cdot 30}{21 \cdot 0.95}\right)} =$$

$$= \frac{800}{0,97 \cdot 0,88 \cdot 0,95 \cdot \left(8200 - 1000 - \frac{100 \cdot 30}{21 \cdot 0,95}\right)} = 0,1399\%$$

CG= 0.1399% Cu

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

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

Parameters		Category		
		B	C_1	$B + C_1$
Commodity	unit	13 811 980	10 230 771	24 042 751
Cu	%	0.282	0.222	0.257
Au	g/t	0.38	0.30	0.35
Ag	g/t	0.86	0.97	0.91
Cu	t	39 000.6	22 690.5	61691.1
Au	kg	5 284.11	3 041.4	8 325.67
Ag	kg	11 907.84	9 900.89	21 808.73

The total of calculated ore reserves in the Bunardzik ore body are in the amount of 24 042 751 t (B+C1 category) with an average content of 0.257% Cu, 0.35 g/t Au and 0.91 g/t Ag.

CONCLUSION

The Bunardzik 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 24 042 751 t of ore with an average grade of 0.257% Cu, 0.35 g/t Au and 0.91 g/t Ag and specific style of primary porphyry copper ore mineralization, followed by gold and silver contents. The ore bearing coefficient was calculated at 0.82, variation coefficient 54%, minimal economic concentration 0.2099% Cu and cutoff grade of 0.1399% Cu. All these techno-economic parameters have positive effects on the exploitation of this ore body, which, with existing capacity of the Buchim mine, provides additional 4.4 years of production.

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ТЕХНО-ЕКОНОМСКИ ПАРАМЕТРИ ПОВРЗАНИ СО РУДНОТО ТЕЛО НА Cu-Au РУДА БУНАРЏИК, РУДНИК ЗА БАКАР БУЧИМ, ИСТОЧНА МАКЕДОНИЈА

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Резиме

Пресметаниот коефициент на рудоносност во рудното тело Бунарџик изнесува 0,82%, што значи дека во границите на рудното тело само 18% од масата не е минерализирано, што е многу компатибилно со преостанатите три рудни тела во рудникот за порфирски бакар Бучим. Пресметаната вредност на коефициентот на варијација (V) покажа вредност од 54% што е во опсег од 43-100%, што покажува дека ова рудно тело спаѓа во третата група на рудни тела со нерамномерна минерализација. Просечните концентрации на бакар, злато и сребро беа одредени како 0,30% Cu, 0,35 g/t Au и 1,0 g/t Ag, соодветно. Минималната економска содржина (MEC) во рудното тело Бунарџик, како претставник за овој вид минерализација, е утврдена како 0,2099% Cu. На сличен начин беше пресметана и најниската граница за бакарот (гранична содржина), која е со вредност од 0,1399% Cu и со тоа дојде до одредено намалување на содржината во експлоатираната руда. Исто така, беа пресметани и вредностите на бакар монометал, кои вклучуваат влијание на сегашното злато и сребро во рудата. Пресметаниот бакар монометал беше поставен на релативно коректните 0,399% Cu што претставува цврста основа за експлоатација на оваа руда со низок процент на бакар. Пресметаните резерви на руда во ова конкретно рудно тело беа 24 042 751 t руда со 0,257% Cu, 0,35 g/t Au и 0,91 g/t Ag и зголемен век на траење на рудникот за дополнителни 4,4 години.

Клучни зборови: *рудно тело Бунарџик, минерализација на бакар, коефициент на варијација, минимална економска концентрација.*