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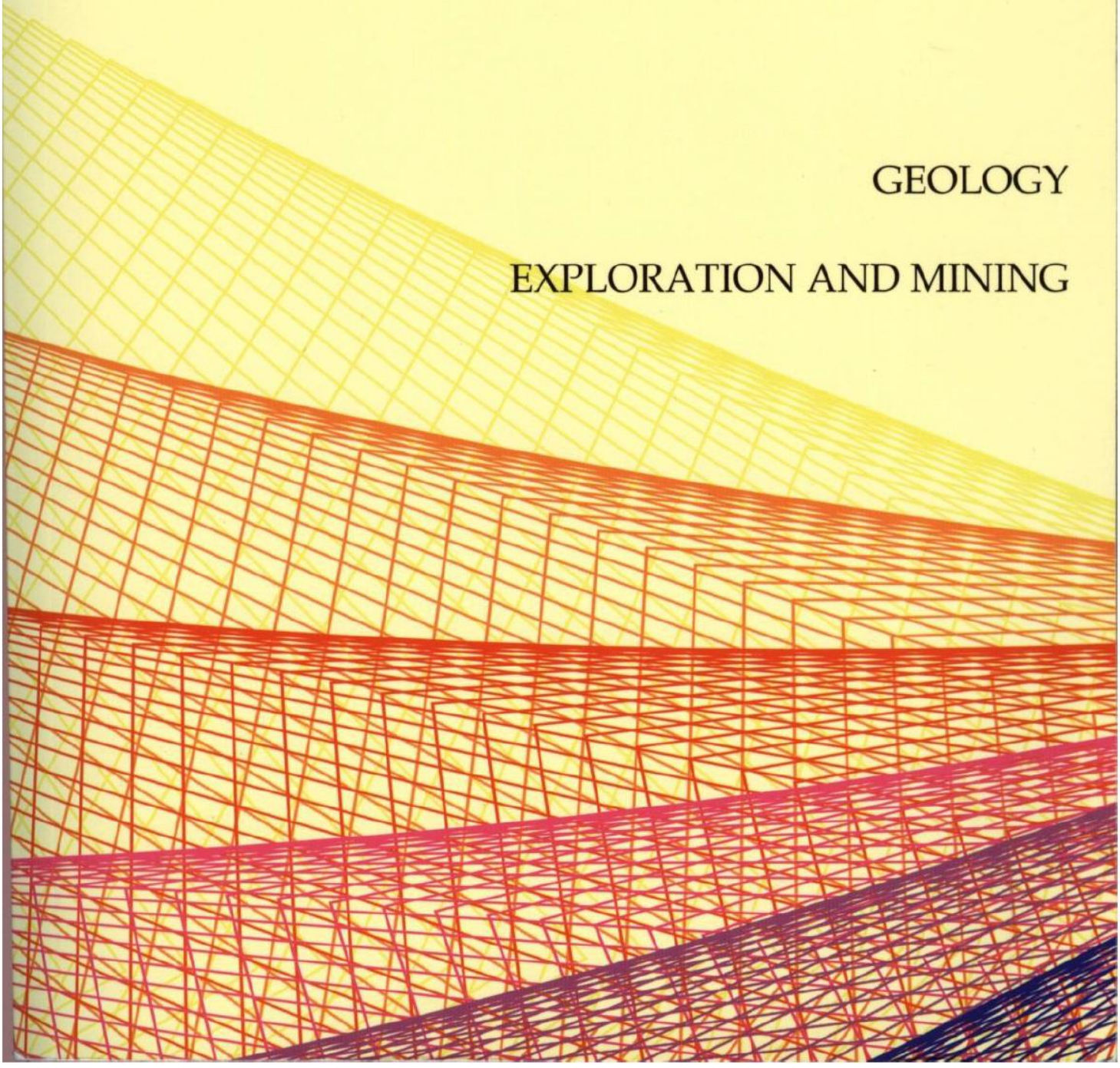

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Cu-Au VALORIZATION FROM POORLY MINERALIZED ORE BODIES IN THE BUCHIM COPPER MINE, EASTERN MACEDONIA

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ABSTRACT

Slightly over 30 years from the Buchim are exploited poor porphyry copper mineralizations. From calculated total ore reserves of around 120 Mt with 0.3% Cu and 0.3 g/t Au, calculated at the cut-off grade of 0.20% Cu, during last 33 years has been exploited 110 Mt of ore with an average copper concentration of 0.236%Cu and gold of 0.297 g/t Au and cut-off grade of 0.15% Cu. The present remaining exploitable ore reserves in the Buchim mine are around 40 Mt with 0.25% Cu and 0.245 g/t Au at cut-off grade of 0.15% Cu. The present economic parameters calculated at the Bunardzik ore body, as the newest ore body ready for exploitation have shown that minimal economic concentration of copper in the ore should be at least 0.2099% Cu, its service life should be approximately 4.5 years (calculated at Buchim's annual production of 4Mt) and the value of the metal within it is approximatelly 289 millions US dollars. This is an information, which points out that these poor ore bodies within the Buchim mine undoubtely are providing profit with their exploitation.

Keywords: Buchim, valorization, poor ores, copper-gold, porphyry ore.

INTRODUCTION

The Buchim porphyry copper deposit is situated in the border area between the Serbo-Macedonian massif and the Vardar zone and in terms of metallogeny it belongs to the Lece-Chalkidiki metallogenic zone [1]. On a more local scale the Buchim copper mine is located in eastern Macedonia, 10 km west of the town of Radovis. The open pit mine started production in 1979 and produced 4 000 000 t of ore annually with 0.25%Cu, 0.27g/t Au and 1 g/t Ag, with a remaining reserves of approximately 100 Mt of low grade Cu-Au ores with some Ag and Mo. Those reserves were proved in four separate ore bodies with porphyry copper mineralization in the Buchim copper mine. The latest results related to the qualitatively-quantitatively features of copper ores from the Buchim mine have shown that there are changes in quantities of remaining ore reserves within the mine or that the mine has 47 Mt of ore with an average contents of 0.25% Cu and 0.25 g/t Au. The mine's annual capacity in 2012 was slightly increased (4 200 000 Mt ore) with the same concentrations of metals and cut-off grade of 0.15% Cu. Exploitation at the Buchim mine at the moment is from three of four ore bodies where has been proved exploitable ore reserves.

Curiosity related to the Buchim mine is the fact that the exploitation was performed on three types of ore: oxide, secondary sulfide enrichment and primary sulfide ore (mainly chalcopyrite mineralization). Especially representative used to be the secondary enrichment sulfide mineralization (chalcocite-covellite) that has been exploited during first few years of mine production, from the Cukar 1 ore body, where has been produced around 10 Mt od ore with an average copper of 0.5% Cu.

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. [2].

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 [3], [4], [5], [6], [7]. 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, which are spread over an area of approximately 10 km^2 [8]. The Central, Bunardzik and Vrsnik ore bodies are related to andesitic porphyry intrusions, whereas the Cukar ore body consists of a supergene copper mineralization [8]. It should be pointed out that the primary sulphide mineralization played the major role in production of copper.

The Cukar ore body, from which the Buchim mine have started its production, was located southern of the Central part ore body and mainly consisted of supergene copper mineralization developed in gneiss (Figure 1). The morphology of the Cukar ore body used to be directly reflection of flow of descendent solutions that involved primary ore mineralization and to the structural-textural features of the environment hosting the deposit. The shape of the ore body used to resemble a lens-like morphology. In contrast to other ore bodies, Cukar used to host an intensive supergene mineralization (chalcocite-covellite), whereas chalcopyrite was much less widespread. Also, within the Cukar ore body were detected magnetite, rutile, sphene, leucoxene, hematite, martite, Fe-hydroxide, pyrrhotite, cubanite, vallerite, sphalerite, molybdenite, cassiterite, gold, pyrite, bornite, and malachite. This ore body does not exist any longer because it was mined out.

The Centralen part ore body is the most important ore body in the Bucim deposit. It hosts nearly 70% of the total mineralization, which is formed in gneiss and round latite dike, and represents a typical example of primary copper mineralization (Cifliganec, 1987). The dimensions, registered so far are: (a) about 250 m vertical interval (at the 650-400 m absolute level) and (b) on a plane, the mineralized surface in the upper por-

tion of the ore body, together with the andesite intrusion, has a diameter of some 600 m. That means that the Centralen del ore body has the form of an irregular ring. There have been identified the following ore minerals: pyrite, magnetite, chalcopyrite, rutile, sphene, ilmenite, hematite, pyrrhotite, vallerite, cubanite, sphalerite, galena, bismuthinite, bornite, enargite, native gold, lineite. Also, there has been confirmed presence of Bi-Se association: bismuthine, galenobismuthine, friedrichite, krupkaite, emplectite, laitakarite, native bismuth and cosalite [5].

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.

The Bunardzik ore body is located southwest of the Centralen part orebody, at a distance of some 350 m (Figure 1). The difference is that the principal ore minerals less frequently occur in the Bunardzik orebody than in the Centralen del ore body. From the field observations was concluded that there is significant difference in the morphology of the Bunardzik ore body compared to the Centralen part, which is far from being symmetrical in relation to the andesite intrusion (Figure 2). The angles of dip of the outer surfaces outlining the ore body are smaller than the angles of dip of the contact andesite intrusion and on a planar surface it resembles a horse-shoe positioned around the southern part of the andesite intrusion emplaced in gneiss. The dimensions of the ore body on plane, in the upper portions of the deposit, are about 300x100 m, whereas its

vertical interval reads some 300 m. The following minerals have been registered: magnetite, pyrite, chalcopyrite, martite; ilmenite, hematite, leucoxene, bornite, molybdenite, galena, sphalerite, gold, pyrrhotite, and Fe-hydroxides. Secondary minerals are represented at an insignificant scale (chalcocite and covellite). We would like to stress out that in this ore body cementation minerals have been registered in deeper portions. Copper mineralization was deposited in gneisses and, in terms of the form in which it occurs, it belongs to stockwork-dissemination or porphyry type.

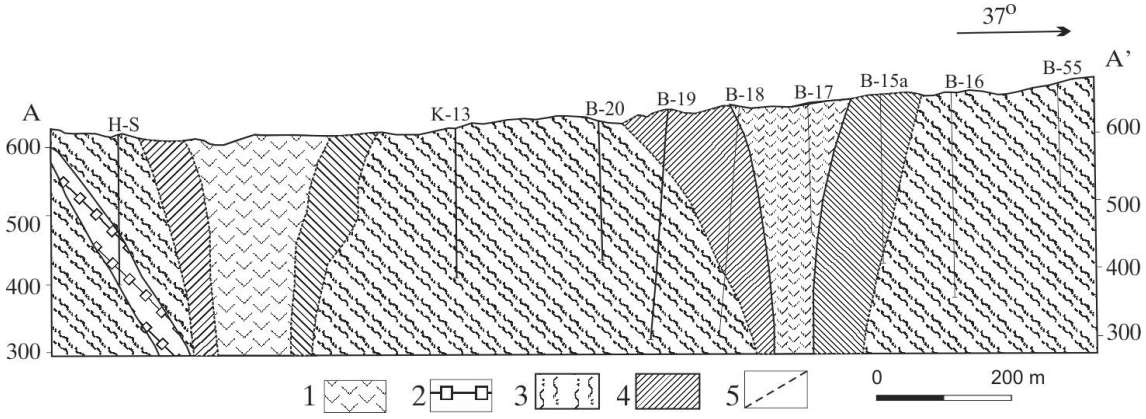

Fig. 2. Geological cross section of the Buchim deposit [4]
1. Andezite and latite; 2. Amphibolite; 3. Gneiss; 4. Primary Cu-mineralization; 5. Fault.

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.

GENERAL FEATURES OF PRODUCTION

The Buchim mine has started its production back in 1979 with a modest annual capacity of 645 000 tons with (0.4% Cu and 0.234 g/t Au), which already the next year was fourfold increased. Three years after the start of production the mine produced more than 3.5 Mt tons of ore annually, which positive trend was followed during the last more than thirty years (Figure 3). We would like to stress out that during the period of capital transformation of the Buchim mine, from state owned to private one, the production in the mine was ceased in 2003-2004 and it was restarted through the spring 2005. Recently its annual production reached amount of over 4 millions of tons of ore followed by uninterrupted ore quality in regards to copper and gold concentrations. As the mine production was progressing, geological explorations in direction of finding additional ore reserves were progressing, too.

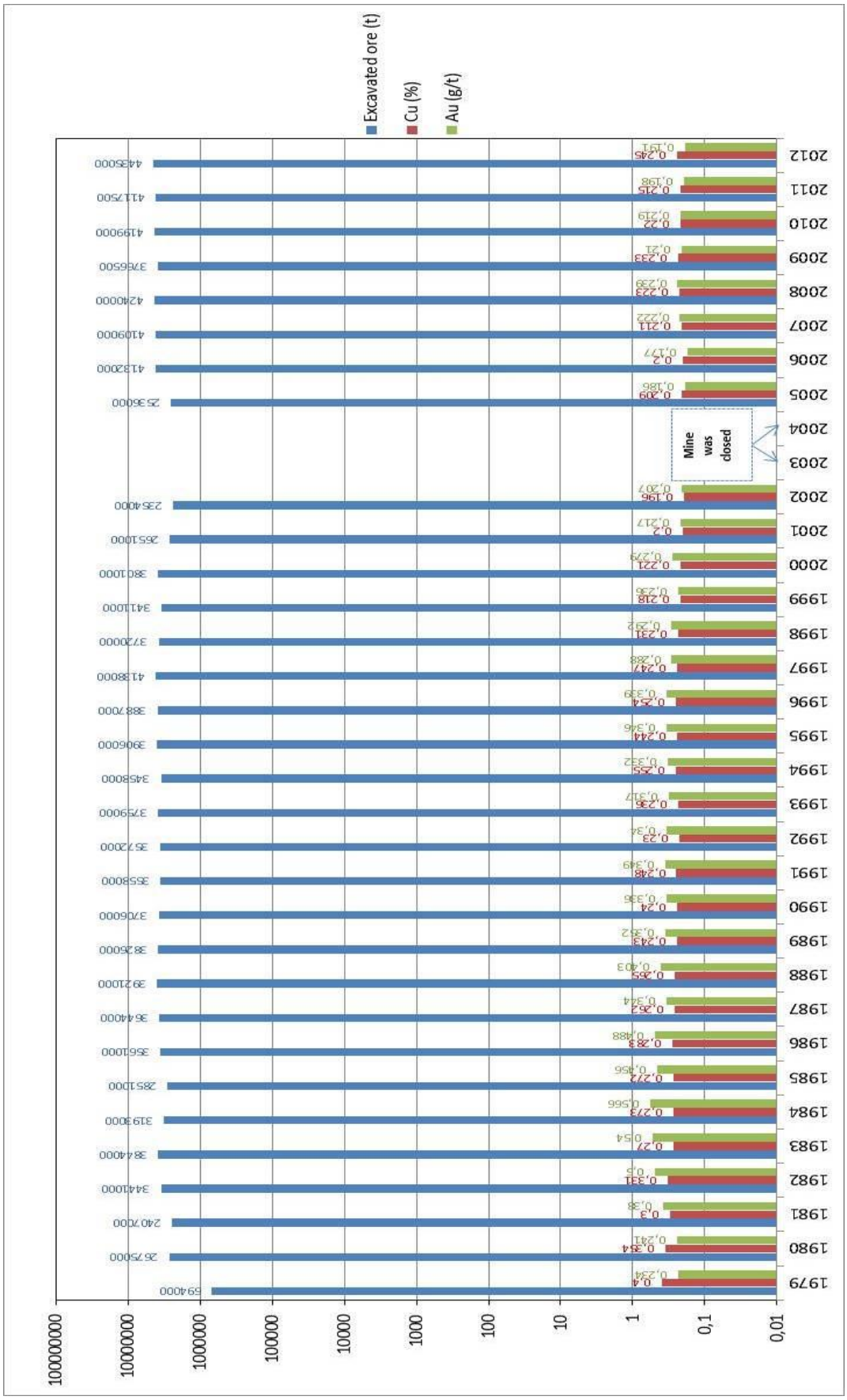

Fig. 3. Production of ore and its qualitative features during the period 1979-2012, Buchim Mine, Republic of Macedonia

There were determined and calculated geological ore reserves of more than 57 Mt in NE-body, Vrsnik and Bunardzik, which should be basis for production in years to come (Table 1).

Table 1. General review of the state of the ore reserves in the Buchim mine by individual ore bodies

Ore body	Geological ore reserves (Mt)	Average grade		Exploitable ore reserves (Mt)	Average grade		Exploited ore reserves (Mt)	Remaining ore reserves (Mt)	Average grade	
		Cu (%)	Au (g/t)		Cu (%)	Au (g/t)			Cu (%)	Au (g/t)
NE-Body	20	0.25	0.23	12	0.26	0.24	1	11	0.22	0.22
Vrsnik	13	0.31	0.18	10	0.32	0.19	1	9	0.30	0.21
Bunardzik	24	0.26	0.35	12	0.25	0.33	-	12	0.25	0.33
Central ore body	85	0.36	0.24	69	0.25	0.21	60	9	0.23	0.22
Cukar	10	0.64	-	9	0.60	-	9	-	-	-
Cukar II	26	0.22	0.20	21	0.21	0.20	21	-	-	-

Calculation of the minimal economic concentration of copper in the ore (MEC) for the Bunardzik ore body was performed with goal to determine does the particular ore body with calculated ore reserves satisfies conditions for economically viable exploitation. This calculation should give an exact answer to a dilemma, does the exploitation will cover all the related expenses and provide an appropriate profit, which should be an equivalent to the required coefficient of rate of return for that particular exploitation. Bearing in mind that we were dealing with only one part of the Buchim ore deposit (Bunardzik ore body) we have included formula parameters that were exclusively related to to the exploitation of that particular ore part: exploitation costs, efficiency of utilization of the ore (at all stages of its technological treatment), price of the final product or price of the copper metal. Calculation of the minimal economic concentration of copper in the ore (MEC) by Gudalin's formula [9] is:

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

S-expenses for exploration and treatment (flotation) of 1t of ore (12 US dollars /t)

p-dilution in the exploitation 3%

Ie-ore dilution coefficient during exploitation (1- (*p/100*)) or 0.97

Io-efficiency coefficient during the enrichment (88%)

Im- efficiency coefficient during the metalurgical treatment (95%)

Co-copper market price (8200 US dollars/t)

Sm-metalurgical expenses per unit of final product (1000 US dollars/t)

St-transport expenses per ton concentrate (30 US dollars/t)

g-metal content in concentrate (21%, which is a quality standardized for copper concetrate in Buchim Mine where flotation of ores from Bunardzik will take place, too)

$$MEC = \frac{100 \cdot S}{Ie \cdot Io \cdot \mathrm{Im} \cdot \left(Co - Sm - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} = \frac{100 \cdot 12}{0.97 \cdot 0.88 \cdot 0.95 \left(8200 - 1000 - \frac{100 \cdot St}{g \cdot \mathrm{Im}} \right)} =$$

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

MEC = 0.2099 % Cu

Calculated MEC suggests that the deposit should have at least 0.2099% Cu, so that we may calculate them as bilance ones.

Service life (life span) of the ore body Bunardzik was calculated as an inseparable part of the Buchim Mine. In that context we take curent Buchim Mine's annual production capacity of 3 500 000 with increase tendency up to 4 000 000 t of ore per year. Also, we have included calculated ore reserves of 24 042 751 t and dillution percent during exploitation (27%), which makes 73% of ore accessible for production. All these parameters were implemented into the formula for calculation of the service life of the Bunardzik ore body:

$$V_E = \frac{QKr}{4000000} = \frac{24042751 * 0.73}{4000000} = 4.4 \ \ years$$

V_E-exploitation service life of the ore body

Q-calculated ore reserves

K_r-dillution coefficient expressed as 1-(27/100) or 0.73

Calculations showed that service life of the ore body should be around 4.4 years.

Also, on the example of the Bunardzik ore body we have decided to calculate synthetic parameters such is the value assessment of the ore body without taking into account time factor. Below is given basic calculation:

$$V_u = (V_i - T_i) \cdot (P - G)$$

V_u - simplified value of the Bunardzik ore body, without taking into account time factor (US dollars/t)

V_i - value of useful mineral component within the ore body (US dollars/t; 8200 US$/t copper metal)

T_i - expenses for production of useful component-metal (US dollars/t; 1042 US$/t copper metal)

P - total metal reserves within the ore body

G – real or with the exploitation project anticipated losses of the mineral resource, calculated in ton(s) of metal, including all the stages treatment of ore.

In accordance to the formula above [9] and procedure for value assessment of the Bunardzik ore body without taking into an account time factor we are showing particular parameters related to this calculation:

$$V_u = (8200 - 1042) \cdot (47584.6 - 7137.7) =$$

$$V_u = 7158 \cdot 40446{,}92 = 289519051$$

$$V_u = 289519051 \ USD$$

From the sugested model of the value assessment of the Bunardzik ore body it can be seen that its value based on copper is up to 289 519 051 US dollars. For the price of copper was taken an average metal exchange price of copper during the 2010. This was only simplified assessment of the ore body value, where probably shoould be added the value of gold within it (that calculation is very similar to one shown above for copper).

CONCLUSION

The Buchim Mine is an unique active mine at the Balkan Peninsula, which at the moment exploits poor porphyry copper mineralizations with an average concentration of 0.22% Cu and 0.21 g/t Au. Annual production is up to 4 200 000 t of aforementioned ore. During last three and half decades from the Buchim Mine has been exploited more than 110 Mt of ore with low copper and gold concentrations, which clearly confirms the fact that this mine makes positive economic parameters although is one of the very rare in the World that exploits poor copper ores.

Calculated natural parameters of the Bunardzik ore body, which should be expoited in the years to come, clearly confirmed the model of achieving positive financial results during the poor ores explotitation from the Buchim Mine.

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