The Characteristics of Mine Waters in Copper Deposit of Bor (East Serbia)

By Veselin DRAGIŠIĆ[1]

[1] The Faculty of Mining and Geology, Institute of Hydrogeology
University of Belgrade, Djušina 7, 11000 Belgrade; Yugoslavia

ABSTRACT

The copper deposit of Bor is situated in central parts of East Serbia known in geology and mining industry as the eruptive region of Timok. The beginning of modern mining engineering in this region dates back to the discovery of the ore deposit of Bor in 1902. With the first extracted tons of copper ore some problems relating to the action of mine waters in mining work arose. These problems concern the increased inflows of ground waters, their effect on the stability of mine work, the aggressive action of mine waters on the equipment and contamination of surface and ground waters in broader surroundings of mining works.

INTRODUCTION

The copper deposit of Bor is situated in the central part of East Serbia known in the mining and geologic practice as the eruptive zone of Timok. It is one of the major ore regions in Europe. In addition to three large copper deposits that are being mined today (Bor, Majdanpek and Veliki Krivelj), there are also other less known copper deposits as well as frequent occurrences of copper mineralization (Fig. 1).

The beginning of modern mining in this region relates to the discovery of ore deposit of Bor. Exploratory work started in 1897; Čoka Dulkan deposit, the first in the system of ore bodies was discovered in 1902 and copper was melted at Bor as early as 1905.

Initial tons of copper ore mined, resulted in problems related to the effect of ground waters on mining works. These problems were evidenced primarily in increased inflows of ground water, their influence on the stability of works, the influence of aggressive mine waters on the equipment, etc. There were also same problems related to copper extraction from "blue" copper waters. All these problems manifested differently depending on the way and stage of exploitation.

Mine waters formed in mining works of copper deposit of Bor, represent the integral characteristic of natural and anthropogenic processes occurring in the narrower and wider zone of the deposit.

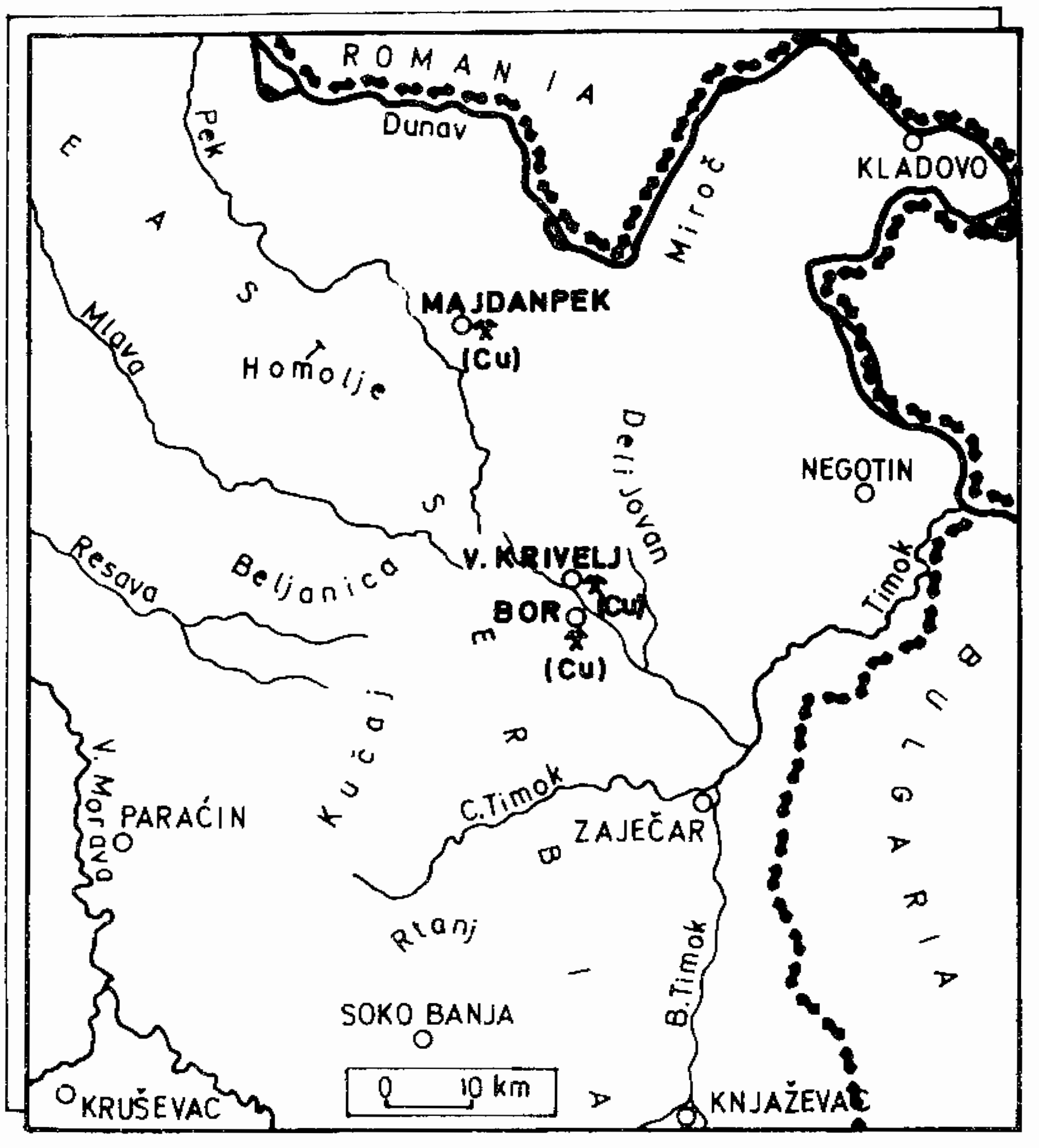

Fig.1. Geographical situation of the Bor copper mine

THE FORMATION AND AMOUNT OF MINE WATER INFLOWS

The mine field of Bor is made up of volcanic, sedimentary and hydrothermally altered and mineralized volcanic rocks (Fig.2). Apart from this rock mass there are also heavy deposits of the ore and flotation waste and melted slag in the immediate vicinity of the mine.

The copper deposit of Bor is composed of a great number of ore bodies of massive-sulphide and porphyrin type. The following ore minerals are represented: chalcopyrite, chalcocite, covellite, neodigenite, enargite, bornite, luzonite and tetrahedrite.

Copper ore is mined in a combined way: there is underground mining through the system of mine works and surface mining through opencast mine directly above the mine works (Figs. 2 and 3).

The inflow of mine waters in underground workings of copper mine of Bor is formed from the outflow of fracture waters from conglomerates, pelytes, volcanic and hydrothermally altered rocks and also from the waters used in the process of mudding the working cavities, from waters used in the process of drilling, as well as waters that are directed by the system of boreholes and shafts from opencast mine directly to mine works (Fig. 3). Surface waters include waters from atmospheric precipitation, ground waters discharged into opencast mine and waters from goafs intersected by the opencast mine.

The basic characteristic of natural and anthropogenic processes which determine the

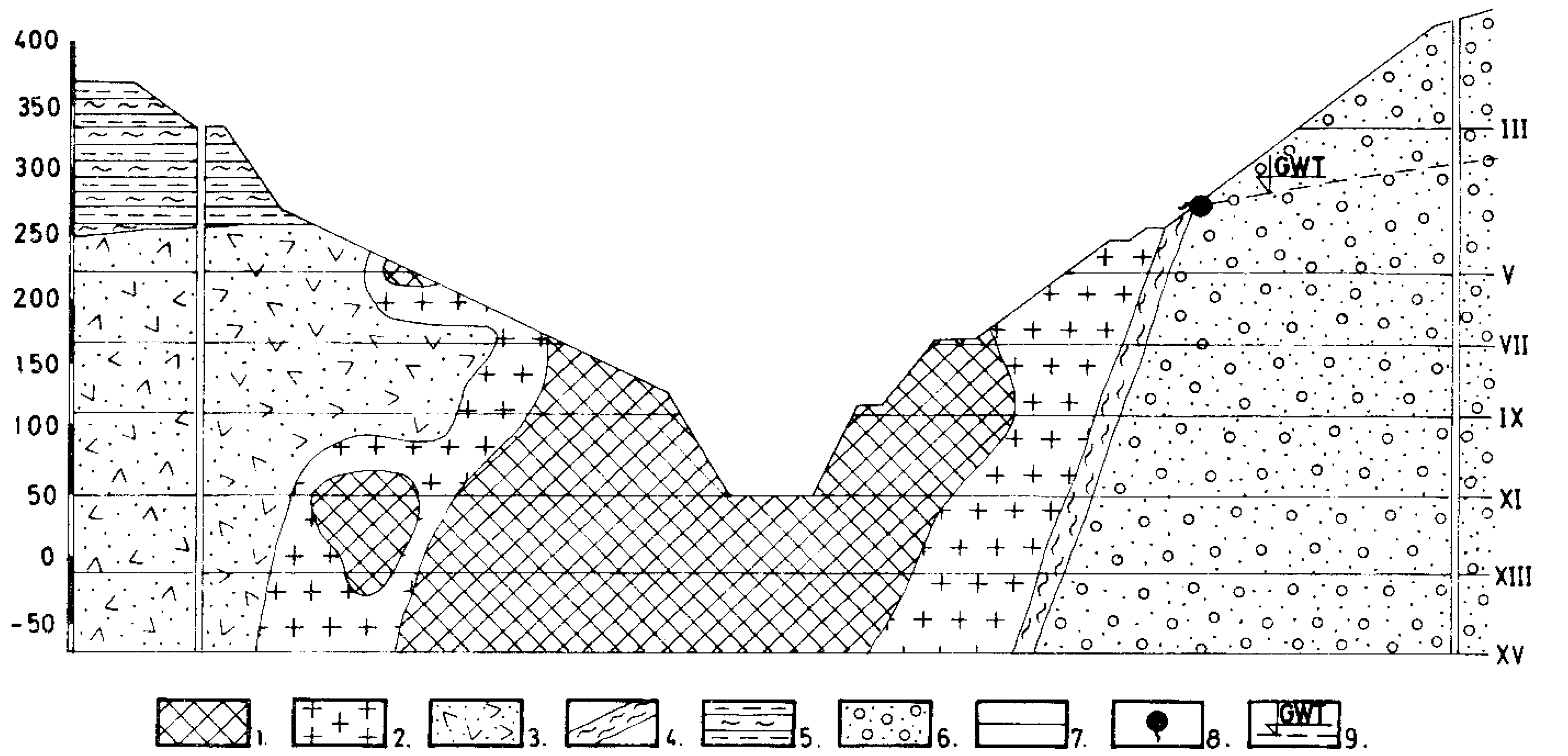

Fig.2. Schematic geological cross-section of copper deposit Bor
1. Ore body; 2. Hydrothermally altered volcanic rocks; 3. Pyroclastic rocks hornblende-biotite andesite; 4. Fault (fault clay); 5. Pelytes; 6. Conglomerates; 7. Working horizon; 8. Spring; 9. Ground water table

amount of inflow of mine waters is that they are random in time and space so that the amount of mine water inflows has the characteristics of a random process. Since the causes of water inflow into the mine of Bor are random occurrences such as precipitation and, to a lesser extent, the quantities of the ore recovered, the regime of inflow can be defined in the function of the said processes by means of the theory of random processes.

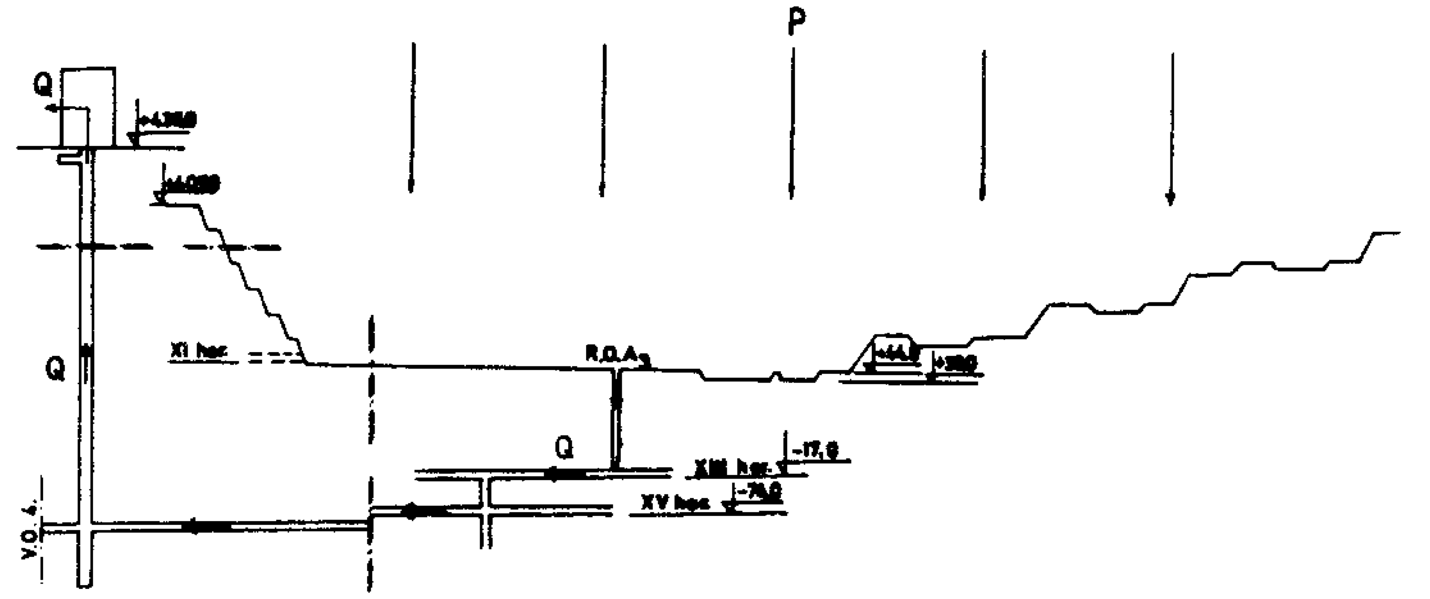

Fig. 3. Schematic ilustration of the working mine works in the Bor copper mine
P - Precipitation; Q - Mine water

The results of calculation of the autocorrelation and cross-correlation functions (Fig. 4) show that there is a statistically significant autocorrelation dependence in the process of mine water inflows $\langle R_q,(\tau)\rangle$. The cross-correlation dependence between the inflow of mine waters and tonnage of ore recovered $\langle R_q,T(\tau)\rangle$ is also statistically significant but with adverse effects. However, the cross-correlative dependence between the inflow of mine waters and precipitation $\langle R_q,\rho(\tau)\rangle$ is statistically insignificant and the form of cross-correlation function shows that dependence is cyclic in character. This is the consequence of periodic processes of the sum of monthly precipitations.

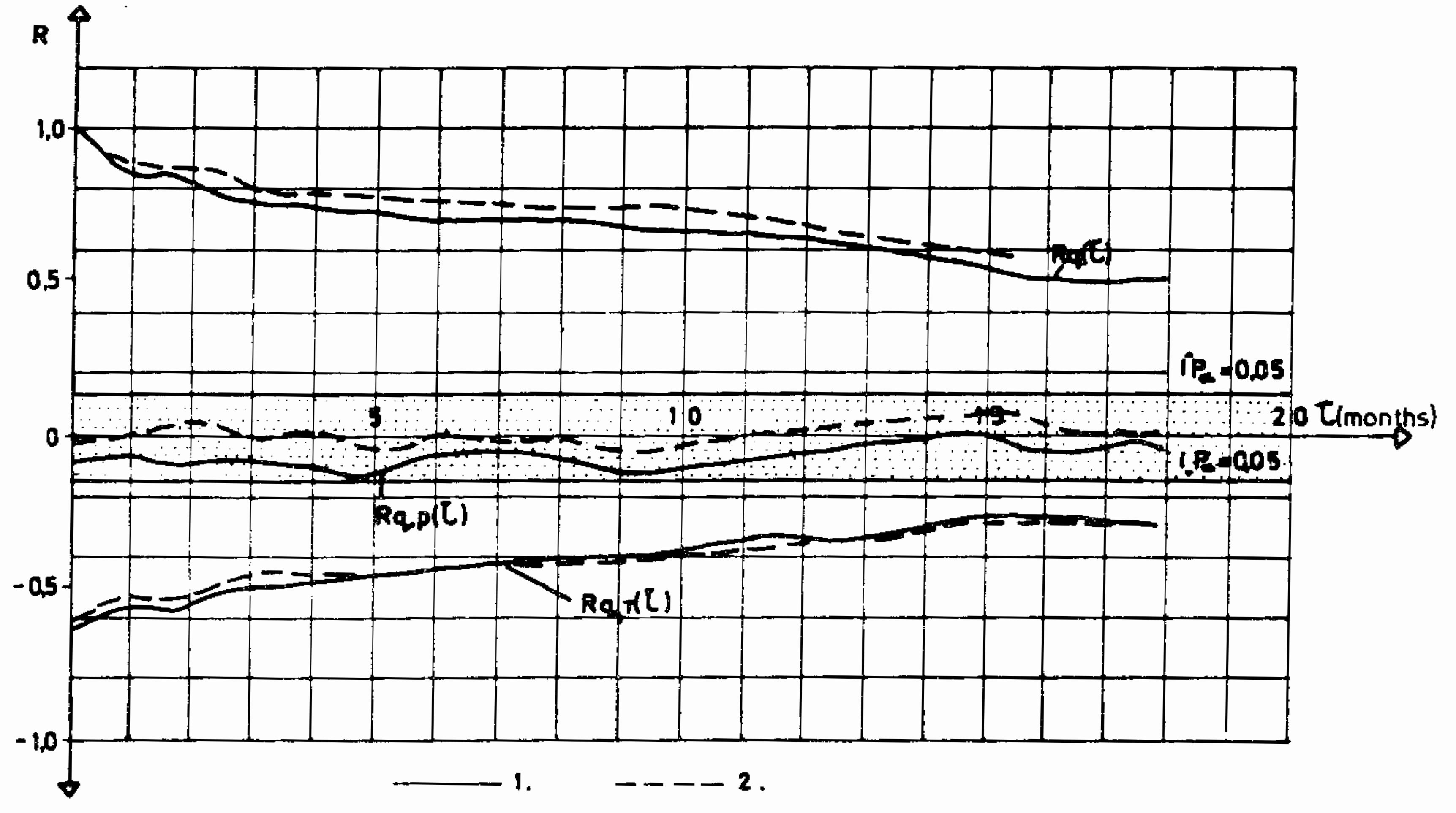

Fig. 4. Autocrosscorelation functions
1. Linear; 2. Nonlinear

Owing to a marked regularity of inflow and tonnage of the ore recovered, some prognostic dependencies have been established. They can be successfully employed in forecasting the inflow of mine water from one to five months in advance.

In the period from 1971 to 1984 the mean annual inflow of mine waters into the mine of Bor was 100,22 l/s. However, it should be noted that they are average values and that the amount of annual inflows shows an increasing trend, as the period of exploitation grows longer.

The conditions for mine water inflows will significantly change once the ore mining from opencast mine of Bor (end of 1991) has been ended and subsequently filled. The inflow into underground workings is expected to be reduced in the absence of direct connection between "surface" waters from opencast mine. Also, the inflows will be more balanced.

THE PHYSICAL AND CHEMICAL PROPERTIES OF MINE WATERS

As a result of complex geochemical processes in copper deposit of Bor and some natural and anthropogenic factors, mine waters of specific physical and chemical characteristics are formed. These specific properties are evidenced in increased mineralization, the total contents of ion Fe, ion SO^{2-}_4 and in individual microelments as well as in law values of pH and of specific electric resistance and in the extremely high Eh values. By their chemical composition, mine waters from copper deposit of Bor belong to the sulphate class, most often in calcium group. The main source of the prevailing ion (SO^{2-}_4) is sulphuric acid produced in the process of oxidation of pyrite (Fe_2S), numerous copper sulphides ($CuFeS_2$ - chalcopyrite, Cu_2S - chalcocite, CuS - covellite, Cu_3AsS_4 - enargite, Cu_5FeS_4 - bornite, $CuFe_2S_3$-cubanite and $(Cu_2, Zn, Fe)_3\ Sb_2S_6$ - tetrahedrite, etc.) and of the sulphides of zinc, lead, molybdenum, etc.

The concentration of hydrogen ions increases in the process of dissociation of sulphuric acid. In some cases this result in the lowering of pH values below 1 and of the specific electric resistance (SEO<1 Om m) and in the Eh increased value above 0,8 V.

Chemical composition of the sum of mine waters pumpaged from the mine of Bor through the new service shaft for the period from 1.07.1985 - 2.06.1986 is represented by the Kurlov formula as follows:

$$M_{1.8-4.0}\ \frac{SO^{4}_{92-100}}{Ca_{56-81}\ Mg_{8-29}\ Na{+}K_{8-23}}\ pH_{2.5-4.0}$$

The contents of ion SO^{2-}_4 are extremely high and are within the range from 1.244,38 - 2.784,00 mg/l, as well as the contents of total iron (Fe^{2+} + Fe^{3+}) that are in the range from 89,36 to 893,60 mg/l. The content of microelements in mine waters of the ore deposit of Bor is given in Table 1.

Table 1. Spectrochemical analysis of dry residues of mine waters in copper deposit of Bor, in mg/l

	Mine waters on the exit from "New service shaft" 1.07.1985.	Mine waters discharged into opencast mine from goafs ("Tilva Mika") 18.08.1986.
B	*	0,0307
Cr	0,0417	0,2338
V	0,0867	0,1692
Ni	0,5782	0,8000
Co	0,1253	0,0461
Cu	3,2125	0,1138
Zn	7,0675	-

Mn	16,0625	7,5386
Sc	0,0355	0,0400
Y	0,1188	*
Sr	2,1202	1,2616
Pb	0,0257	0,0215
Ba	0,2088	1,2000
Ca	16,0625	15,3850
Mg	16,0625	15,3850
Fe	16,0625	15,3850
Al	16,0625	15,3850
Ti	0,1446	3,6925

* Below the detection limit of spectrographic method

The copper content in mine waters has always attracted attention of numerous researchers. Thus, in his account of travels in East Serbia, T. Djordjević (1905) makes mention of "blue" copper waters. According to his description, these waters were running from ore deposit in jets and along the walls of ground workings "crusts of bluestone" could be seen.

The first analyses of "blue" waters date back to 1906 with copper contents being from 0,404 - 0,445 g/l.

V. Simić (1969) notes that in the first half of 1946 some 94.016 m^3 of "blue" water were discharged from mine works with 4.04 g/l of copper and some 225.448 m^3 of acidulous water with 1,78 g/l of copper.

During May of 1964 the Institute for Copper Research of Bor carried out their initial informative qualitative testing of mine waters in the mine of Bor at levels V, VI, VIII, IX, and XI (Table 2). The results of the survey showed the unbalanced contents of copper in mine waters. In the course if these tests the uncontrolled mixing of "blue" and "white" waters occurred. This resulted in the dilution of copper concentration.

By testing the contents of copper in "blue" mine waters used in technologic process of copper extraction, the following copper contents were recorded in the period from 1977 to 1982 (Table 3).

Table 2. Results of qualitative testing of mine waters in the mine of Bor (G. Hovanec, 1966)

Level	Ore body	pH	Fe(g/l)	Cu(g/l)
V	Tilva Ronton (left wing)	5,45	0,01	0,040
V	Tilva Ronton (right wing)	2,05	4,85	1,650
V	Tilva Mika	3,05	0,09	1,040

V	Tilva Mika + Tilva Roš Tilva Ronton	2,85	0,45	0,075
V	Tilva Roš + Tilva Ronton	2,60	1,56	0,570
V	Čoka Dulkan	3,00	0,15	0,330
Total water from levels V and VI		2,90	0,23	0,280
Total water from level VI		2,70	1,72	1,400
VII	Tilva Roš + Kamenjar	3,00	1,71	1,950
Total water from level VII		2,70	2,31	2,420
I IX	Tilva Mika	2,20	8,80	5,570
IX	Blue water from direction of shaft	3,00	1,04	1,380
Total water from level XI		2,85	1,44	2,000
Water at the entrance to "cementation"		2,85	1,37	0,890

Table 3. Survey of average monthly contents of copper in mine waters (mine of Bor) in the period 1977-1982

Year	Contents of Cu (g/l) as per months											
	1	2	3	4	5	6	7	8	9	10	11	12
1977	0,40	0,38	0,32	0,36	0,38	0,38	0,38	0,24	0,23	0,18	0,21	0,17
1978	0,14	0,22	0,21	0,21	0,21	0,26	0,19	0,15	0,18	0,15	0,11	0,19
1979	0,14	0,14	0,12	0,10	0,15	0,50	0,44	0,22	0,18	0,19	0,20	0,22
1980	0,29	0,39	0,33	0,27	0,25	0,23	0,23	0,16	0,12	0,12	0,14	0,16
1981	0,18	0,18	0,18	0,16	0,17	0,18	0,15	0,12	0,12	0,12	0,20	0,18
1982	0,14	0,15	0,16	0,55	0,15	0,11	0,14	0,18	0,13	0,17	0,14	-

From the data on copper concentrations in mine waters, a conclusion may be drawn that they have been drastically reduced in recent years which is the consequence of uncontrollable mixing of "blue" and "white" waters due to the specific method of mining and to the deposit dewatering. Namely, all "surface" waters from opencast mine are directed by means of the system of wells to dook workings. In this process their mixing with "blue" copper water occurs.

Owing to high contents of copper, "blue" mine waters were used until the end of 1982 in the technologic process of copper production with considerable quantities of this metal having been obtained. It should also be noted that this is the cheapest way of producing copper at Bor. Due to the repairs of the mine shaft of Bor and to the transition to a new drainage system, copper is not extracted from mine waters any more.

REFERENCES

1. Anderson R.L. Distribution of the Correlation coefficient, Ann. Math. Statist. 8, 1-13 (1941).
2. Dragišić V. On the Need of Exploration of Mine Waters in Sulphide Deposits, I Yugoslav Symposium on Mining Geology, A Collection of Papers, Priština, 131-137 (1985)
3. Hovanec G. Production of Copper from Goafs at Bor, a Collection of Papers, RMF (Faculty of Mining and Metallurgy), Institute for Copper Recearch, Vol. IV, Bor, 151-164 (1966)
4. Prohaska S., Dragišić V. The Prognosis of Inflow of Mine Waters in Copper Mine Shaft of Bor, XXI October Symposium of Miners and Metallurgists, Bor, 61-67 (1989).
5. Simić V. A Historical View of mining Related to Copper Ore Deposit of Bor and Surrounding Regions, a Collection of Papers, RMF and Institute for Copper Research, Vol. VIII, Bor, 1-201 (1969).