The Mineral Resources of the Bor Metallogenic Zone: A Review

Rade Jelenković[1], Dragan Milovanović[2], Dejan Koželj[3] and Miodrag Banješević[4]

[1]Belgrade University, Faculty of Mining and Geology, Đušina 7, Belgrade, Serbia (rade.jelenkovic@rgf.bg.ac.rs)
[2]Belgrade University, Faculty of Mining and Geology, Đušina 7, Belgrade, Serbia (milovdr@beotel.net)
[3]Rakita Exploration d.o.o. Bor, Cara Lazara bb, 19210 Bor, Serbia (Dejan_Kozelj@fmi.com)
[4]Balkan Exploration and Mining d.o.o. 11000 Belgrade, Serbia (miodrag@reservoirminerals.com)

143-155 14 Figs. 2 Tabs. doi: 10.4154/gc.2016.11

Article history:
Received December 09, 2015
Revised and accepted January 22, 2016
Avaliable online February 29, 2016

ABSTRACT

The Bor metallogenic zone is one of the most important metallogenic units in the Republic of Serbia. Volcanic processes in this unit are characterized by the domination of extrusive volcanic activity, and the change of depositional environment during the numerous volcanic cycles, as well as facial transitions and huge deposition of syn- and post eruptive resedimented volcanoclastics. The predominant metals in the Bor metallogenic zone are copper and gold, accompanied by iron, base-metals, silver, molybdenum, and minor platinum-group elements. The most prominent morphogenetic types of deposit comprise porphyry copper-gold, cupriferous pyrite, massive base-metal sulphides and hydrothermal veins, iron oxides skarns, carbonate replacement polymetallic deposits, volcanogenic epithermal gold mineralization of the high sulphidation type, and exceptionally rare clasts of copper sulphide ore mechanically accumulated in small sedimentary basins filled by pyroclastics.

The total production of the Bor metallogenic zone since 1902 has been near 652 Mt of ore with 4.93 Mt of copper and 280 tons of gold. Mineral resources of the Bor metallogenic zone are estimated at over 20 millions of tons of copper and 1,000 tons of gold. The main geological characteristics of selected metallic mineral deposits in this area are described in this paper.

Keywords: Bor ore deposits, Bor-Srednogorie metallogenic zone, porphyries and related mineralizations, copper, gold, resources, reserves

1. INTRODUCTION

The Bor metallogenic zone *senso stricto* belongs to the Bor-Srednogorie metallogenic zone which is a part of the Tethyan Eurasian Metallogenic Belt (TEMB) (JANKOVIĆ, 1976). This the Alpine-Balkan-Carpathian-Dinaride geodynamic province (ABCD) is a part of the Alpine-Himalayan orogenic system that extends from Western Europe to South East Asia (HEINRICH & NEUBAUER, 2002; SCHMID et al., 2008). The orogen resulted from the convergence and collision of the Indian, Arabian, and African plates with the Eurasian craton, initiated in the Middle Jurassic, through the Cretaceous time, and continuing until the present (BOROJEVIĆ ŠOŠTARIĆ et al., 2014; PALINKAŠ et al., 2008). The structural setting of the region reflects large-scale oroclinal bending during post-collision tectonics throughout the Tertiary including major transcurrent fault systems with an overall dextral displacement in excess of 100 km (KRÄUTNER & KRSTIĆ, 2002).

The most significant segment of the TEMB economically comprises the Upper Cretaceous subduction related magmatic rocks and mineral deposits, referred to as the Banatitic Magmatic and Metallogenic Belt (BMMB) (BERZA et al., 1998) or the Apuseni-Banat-Timok-Srednogorie Belt (ZIMMERMAN et al., 2008). The BMMB intrusives and dominant extrusive rocks were emplaced during a 30-million-year period from ~90 Ma to 60 Ma and may have been the result of complex tectonic and magmatic emplacement melting.

The Bor-Srednegorie metallogenic zone as a part of the Carpatho-Balkan metallogenic province extends from Lilieci - Linbcova and Bozovici in the north, over Bor to Burgas, proceeding into the Black sea and Tracia in Turkey (JANKOVIĆ, 1980, 1990, 1997). It is over 600 km long and up to 20 km wide (JANKOVIĆ et al., 2003).

The easternmost magmatic complex in the Serbian part of the belt is the Timok Magmatic Complex (TMC) (BANJEŠEVIĆ, 2006). Volcanic processes in the TMC are characterized by the predominance of extrusive volcanic facies, and the change of depositional environment during the volcanic cycle, as well as facial transitions and heavy deposition of syn- and post eruptive resedimented volcanoclastics. Magmatic activity generally progresses from east to west. Magmatism lasted continuously for 10 Ma starting in the Upper Turonian (the oldest andesitic rock is 89 Ma) till Upper Campanian (CLARK & ULLRICH, 2004). The age of the Valja Strž plutonites is 78 Ma (BANJEŠEVIĆ, 2006).

Copper and gold/silver, accompanied by iron (sulphide, oxide) and base-metals, molybdenum, sporadically PGE, are the predominant metals in the Bor metallogenic zone. The most prominent morphogenetic types of deposits are porphyry copper / gold, cupiferous pyrite, massive base-metal sulphides, and hydrothermal veins, skarns of iron oxides, skarns of lead-zinc sulphides, volcanogenic epithermal gold mineralization of high sulphidation type, and exceptionally clasts of copper sulphide ore mechanically accumulated in the small sedimentary basin infilled with pyroclastics.

The ore deposits are grouped into several ore fields and districts, each characterized by some specific genetic features.

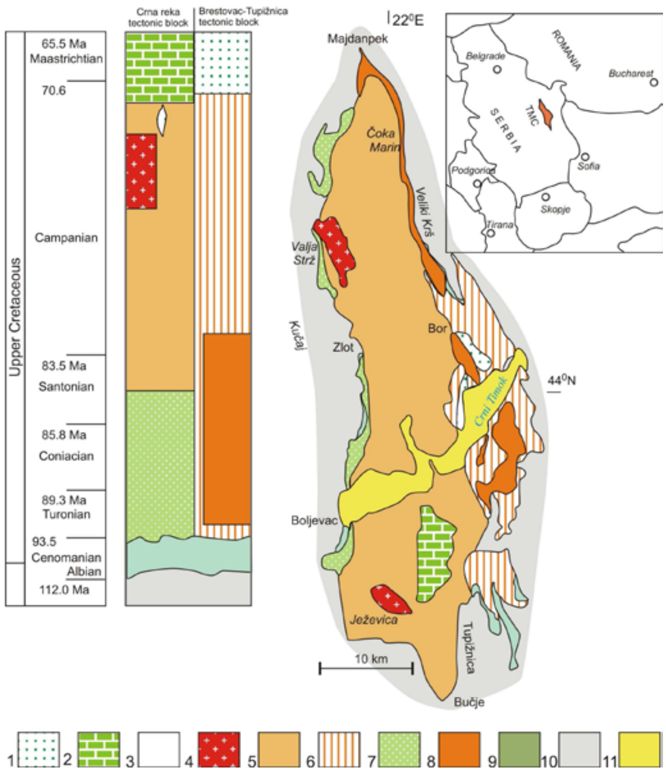

Figure 1. A simplified geological map of the Timok magmatic complex. Legend: 1. Bor clastites, 2. Vrbovac reef, 3. Boljevac latite, 4. Valja Strž plutonite, 5. Osnić basaltic andesite and Ježevica andesite, 6. Metovnica epiclastite, 7. Oštrelj sediments, 8. Timok andesite, 9. Lenovac clastites, 10. TMC basement rock, 11. Neogene and Quaternary sediments.

2. UPPER CRETACEOUS MAGMATIC SUITES OF THE TIMOK MAGMATIC COMPLEX

In the Bor metallogenic zone the volcano-intrusive complexes are represented by volcanic, volcano-sedimentary and plutonic rocks (Fig. 1). They derived from subcrustal, contaminated magma(s), as have been suggested by KARAMATA & DJORDJEVIĆ (1980). The $^{87}Sr/^{86}Sr$ ratio ranges from 0.707 to 0.712. The calc-alkaline series is prevalent with respect to tholeiite rocks. Volcanic rocks formed within three stages during the Upper Cretaceous. They are of andesitic composition, while dacite occurs sporadically. The plutonic granitoids correspond to composite complexes (from gabbro to diorite, monzonite and granodiorite).

In this zone we can recognize:

Timok andesite (AT) - The Timok andesites, predominantly amphibole andesite and high potassium trachyandesites, occur in the eastern parts of the TMC, where they overlie Cenomanian and Turonian sediments (DROVENIK, 1959; ĐORĐEVIĆ & BANJEŠEVIĆ, 1997; LJUBOVIĆ-OBRADOVIĆ et al., 2011, BANJEŠEVIĆ, 2015). They are covered by Senonian sediments (Oštrelj sediments and Bor clastites) and the Metovnica epiclastite (BANJEŠEVIĆ, 2015). Amphibole andesites and trachyandesites characterized by high potassium predominate.

According to their lithological, volcanological and petrographic characteristics (BANJEŠEVIĆ, 2010), the andesites are distinguished into the following facies: lava flows (coherent and autoclastic), shallow intrusions (lava domes, dykes and sills) and various volcaniclastic rocks. Volcanic activity was predominantly subterrestrial in an earlier volcanic phase and subaerial to submarine in a later volcanic phase.

High precision U/Pb zircon and $^{40}Ar/^{39}Ar$ dating, confirms ages from 89.0±0.6 to 84.26±0.67 Ma (Upper Turonian to Upper Santonian).

Metovnica epiclastite (EM) - The Metovnica epiclastite developed in the eastern part of the TMC in a shallow marine environment, infilling rough volcanic bedrock topography (ĐORĐEVIĆ & BANJEŠEVIĆ, 1997, ĐORĐEVIĆ, 2005). The rocks are coarse- to fine-grained, massive, coarsely banded, sometimes even laminated. They are composed of texturally and structurally different fragments deriving from different volcanic facies of the Timok andesite. The dominant type of transport processes are debris to grain flows. The EM are often interbedded with the Oštrelj sediments. Sometimes, the rocks contain a very well preserved Coniacian–Campanian microfauna (ĐORĐEVIĆ & BANJEŠEVIĆ, 1997; ĐORĐEVIĆ, 2005).

Osnić basaltic andesite (AO) and Ježevica andesite (AJ) - The rock suite corresponding to andesite – basaltic andesite of calc-alkaline to tholeiitic character can be distinguished among the Senonian volcanic rocks of the TMC. The first group includes pyroxene basaltic andesite (AO), while the second group comprises amphibole andesite (AJ). Both rock suites are located in the central and western parts of the TMC and are sometimes closely associated. These volcanic rocks are both underlain and overlain by Oštrelj sediments or the Vrbovac reef, respectively (BANJEŠEVIĆ, 2015).

The amphibole andesites are most frequently massive rocks. The chemical composition of the minerals is very similar to the pyroxene-bearing varieties, except that the plagioclases are more basic in the latter.

The volcanic rocks predominantly occur as lava flow facies (autobreccias and hyaloclastic breccias) and resedimented volcaniclastic deposits. Lava flow facies are up to several metres thick, while their length reaches several hundred metres.

The resedimented volcanoclastites are mostly stratified volcaniclastic rocks, psammitic to psephitic, of different origins and types of transport. Volcanic activity is predominantly effusive, rarely explosive. Eruptions are linear and mostly, randomly distributed, initiating the formation of volcanic islands. Volcanism took place terrestrially as well as in a submarine environment.

The U/Pb zircon dating of AO and AJ suggests ages ranging between 80.8 to 82.27±0.35 Ma confirming a Santonian–Lower Campanian age (BANJEŠEVIĆ et al., 2006; KOLB et al., 2013).

Valja Strž plutonite (PVS) - The plutonite occur at the western margin of the TMC. The rocks are grey to dark-grey in colour, of hypidiomorphic granular texture and massive structure, sometimes showing rectangular jointing (MAJER, 1953). They range in composition from monzodiorite and monzonite to diorite, Q-diorite, granodiorite, syenite and rare gabbro. This hypabyssal rock intruded into AO and AJ.

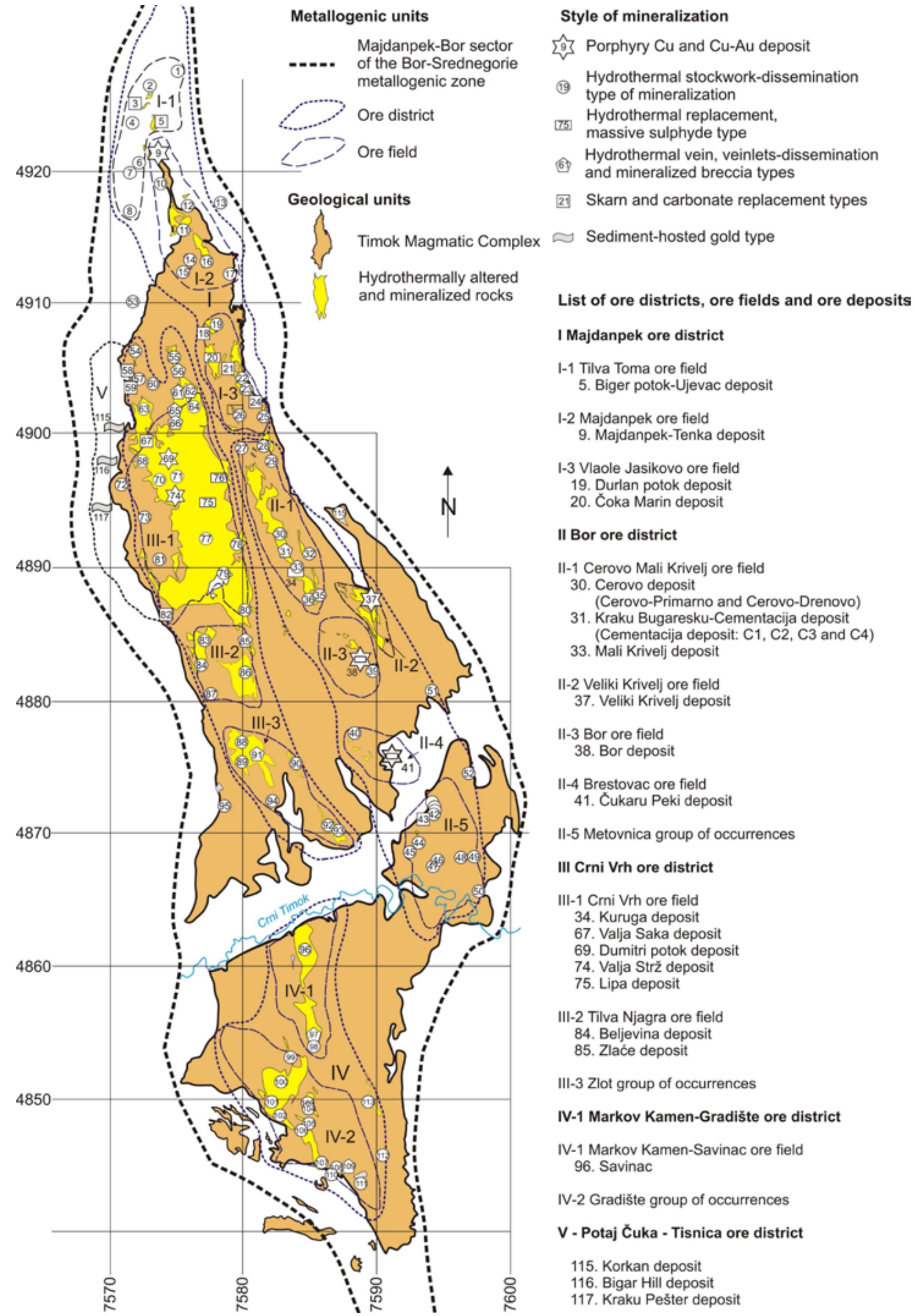

Figure 2. Metallogenic units, ore deposits and significant metallic mineral occurrences of the Bor metallogenic zone: (I) Majdanpek ore district: I-1 Tilva Toma ore field: Occurrences 1. Isenja, 2. Srednji Biger potok, 3. Veliki Ujevac-Biger, 4. Biger potok, 5. Potoj Čuka-Biger potok deposit, 6. Mali Ujevac-1, 7. Mali Ujevac 2, 8. Pojava 1. I-2 Majdanpek ore field: 9. Majdanpek-Tenka deposit, 10. Švajc, 11. Valja Fundata, 12. Šaška reka, 13. Mala Ravna reka, 14. Valja Mastaka, 15. Valja Lomit, 16. Valja Prerast, 17. Veliki Valja Prerast. I-3 Vlaole-Jasikovo ore field: 18. Ogašu Šućure, 19. Durlan potok deposit, 20. Čoka Marin deposit, 21. Ciganski potok-Lak zone (occurrences: 1, 2, 3), 22. Ciganski potok, 23. Mali Kurturaz, 24. Kornet, 25. Ogašu Pešteri, 26. Pogaru Ograda. (II) Bor ore district: II-1 Mali Krivelj-Cerovo ore field: 27. Frankuljac, 28. Strnjak, 29. Kuti, 30. Cerovo deposit (Cerovo-Primarno and Cerovo-Cementacija), 31. Kraku Bugaresku – Cementacija deposit (Cementacija: C1, C2, C3 and C4), 32. Biger potok, 33. Mali Krivelj deposit, 34. Kiridžijski potok, 35. Čoka Čurili, 36. Ujova reka. II-2 Veliki Krivelj ore field: 37. Veliki Krivelj deposit. II-3 Bor ore field: 38. Bor deposit, 39. Rukjavica. II-4 Brestovac ore field: 40. Brestovac, 41. Čukaru Peki deposit. II-5 Metovnica group of occurrences: 42. Markov potok, 43. Jovanovo brdo, 44. Suva reka, 45. Kameni potok, 46. Dosul Mare, 47. Dragina Čuka, 48. Paparkov potok, 49. Mišljenovac, 50. Goskovo potok. Individual occurrences 51. Ravna reka, 52. Ogašu reu, 53.Crna reka. (III) Crni Vrh ore district: Individual occurrences: 54. Veliki potok, 55. Ogašu pištolj, 56. Jasikovo, 57. Jagnjilo, 58. Musta Crna reka, 59. Ogašu Šujku, 60. Čoka Reu, 61. Omanilor, 62. Čoka Škrolopuj, 63. Čoka Žumeri, 64. Lipuca. III-1 Crni vrh ore field: 65. Čoka Bačilo, 66. Oman, 67. Valja Saka deposit, 68. Čoka Frasen, 69. Dumitru potok deposit, 70. Čoka Rakita, 71. Čoka Barbeš – Ogašu Kunuku – Ogašu Reš, 72. Vrokoluce, 73. Kraku Petrunj – Kraku Lung, 74. Valja Strž deposit, 75. Lipa deposit, 76. Kupinovo, 77. Čoka Kupjatra, 78. Pjatra Roš, 79. Crvena reka, 80. Valja Kržan, 81. Crna reka, 82. Susula. III-2 Tilva Njagra ore field: 83. Tilva Kumustaka, 84. Beljevina deposit, 85. Zlaće deposit, 86. Tilva Njagra, 87. Galonja potok. III-3 Zlot group of occurrences: 88. Ugoskur potok, 89. Krlinac, 90. Valja ku Frasej, 91. Zlot. Individual occurrences: 92. Tilva Kudrumu, 93. Punđilov potok, 94. Patranov potok, 95. Anđanov potok. (IV) Markov kamen – Gradište ore district: IV-1 Markov kamen – Savinac ore field: 96. Savinac deposit, 97. Veliko blato, 98. Markov kamen. IV-2 Gradište group of occurrences: 99. Ježevica, 100. Duboki potok, 101. Golema reka, 102. Graniče, 103. Mečji vis – Orlovo brdo 1, 104. Mečji vis – Orlovo brdo 2, 105. Mečji vis – Orlovo brdo 3, 106. Mečji vis – Orlovo brdo 4, 107. Aršica, 108. Mečji vis, 109. Široko polje, 110. Navodna strana, 111. Bukova glava. Individual occurrences: 112. Lasovo, 113. Šumlatica, 115. Cepe. (V) Potaj Čuka – Tisnica ore district: 115. Korkan deposit, 116. Bigar Hill deposit, 117. Kraku Pešter deposit, 118. Korkan East deposit.

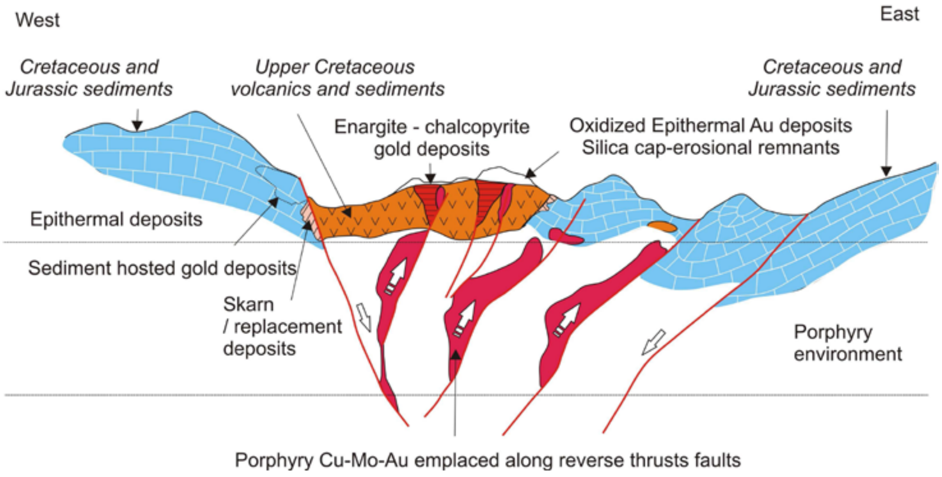

Figure 3. Schematic cross section through the Timok Magmatic Complex showing the location of different types of metallic mineral deposits.

According to U/Pb zircon analysis, the age of the Valja Strž plutonite is 78.62±0.44 Ma, (Upper Campanian), determined by von QUADT et al. (2002).

Boljevac latite (LB) - Numerous latitic dykes occur along the western border of the TMC. These rocks cross-cut the AO and the AJ. They appear in the form of shallow intrusions (dykes, sills and veins), seldom as lava flows. They are usually small masses, up to several tens of metres long and 3 to 4 metres thick. The rocks are dark-grey, showing very distinctive textures characterized by large, elongated phenocrysts of plagioclase and potassium feldspar, which sometimes exhibit fluid orientations. The texture is fine-grained, very fine-grained or hypocrystalline porphyrithic with a microcrystalline, intersertal and pilotaxitic groundmass. The latites consist of plagioclase, potassium feldspar, clinopyroxene and various accessory minerals (MILOVANOVIĆ et al., 2005). The latite cross-cut the AO and AJ, however their age is poorly constrained.

Hydrothermal alteration zones are significant characteristics of the Timok magmatic complex. They occupy an area of about 164 km^2 and represent one of the most important geological criteria in prospecting and exploration of copper and gold mineralization (Fig. 2).

Very frequently hydrothermal alterations (*potassic* – quartz, potassium feldspar, biotite, anhydrite; *phyllic* – quartz, sericite, pyrite; *argillic* – quartz, kaolinite, alunite, zunite, neobiotite; *propylitic* – chlorite, epidote, carbonate) show zonality, the intensity of which weakens with distance from the porphyry intrusions. Argillic and propylitic alterations are located in the peripheral part of hydrothermally altered and mineralized zones.

Predominant hydrothermal alterations are silicification and pyritization, accompanied by chloritization and less frequently argillization. They are not always ore-bearing and their formation is related partly to the action of volcanic vapours and gases and is not accompanied by hydrothermal solutions. Hydrothermally altered rocks, containing mineralization, are usually of small dimensions and show an increased content of the main (Cu, Au) and accompanying (Ag, Mo) elements.

3. METALLIC MINERAL RESOURCES OF THE BOR METALLOGENIC ZONE

There are 22 registered metallic mineral deposits and 96 significant mineral occurrences within the Bor metallogenic zone. All of them are located in 5 ore districts including 10 ore fields and 3 separate groups of mineral occurrences (Fig. 2).

Base metals (Cu, Pb-Zn), precious metals (Au, Ag) and some other metals (Fe), have been more thoroughly explored and their resources have been augmented, so that they still represent, in spite of numerous problems attending their exploitation, the potential for development for Serbia. The metallic mineral resources of the Bor metallogenic zone are grouped as follows:

a) Metallic mineral resources with economically significant reserves, which are currently being exploited, are already provided with processing capacities, and which continue to be the basis of the industrial development of the country. The basic characteristics of these deposits are predominantly low metal content and substantial ore potential. Currently 4 Cu deposits are in operation: Majdanpek, Veliki Krivelj, Bor system and Cerovo.

b) Identified mineral resources, which are beings exploited, or mineral resources occurring in minor quantities, sufficient for short periods of production (e.g. Čoka Marin etc).

c) Potentially significant, partially defined metallic mineral resources, the value of which depends on technical-economic parameters (Au mineral deposits: Korkan, Bigar Hill and others; Cu deposits: Mali Krivelj and others).

d) Mineral resources likely to be found in the Bor metallogenic zone. The metallogenic analyses and up-to-date geological exploration undertaken show that new resources of copper and gold are located in Serbia (porphyry copper-gold and related epithermal Cu-Au deposits /Čukaru Peki deposit, and sediment-hosted gold deposits).

4. STYLES OF ORE MINERALIZATION, ASSOCIATIONS OF MINERALS AND ELEMENTS

The Bor metallogenic zone and adjacent segments host a range of endogene mineral deposits. The most significant are:

Table 1. The main groups of metallic mineral deposits in the Bor metallogenic zone *senso stricto*.

Commodity	Genetic type	Morphology	Structural-textural variety	Mineral paragenesis	Cu (%)	Au (g/t)	Examples
Cu-Au	Porphyry copper deposits	s, iel, vez	s-d	py, cpy, mg, mo	0.1–0.7	0.07–0.25	Majdanpek
						locally 1 g/t	
	Hydrothermal-volcanogenic deposits	s, l, i	m-s, v-i	py, en, chl, co, bo, cpy, sph, ga	1.0–7.0	0.8–3.0	Bor, Lipa
		v	m-s, i-c, i	py, en, te, bo, cpy	0.1–0.64	0.1–0.7	Kraku Bugaresku
	Ore clasts	l	m-s	py, co, en, chl, bo, cpy	3.5	5.4	Novo Okno
Au	High sulphidation	l	d	el, nAu, Au-tl, en, lu, chl, co, sph, ga		0.84	Hydroquartzite
		s, c	m-s, d		2.1–3.3	2	Tilva Mika, M, N
		s, c	v, v-i		0.66–1.0		Kamenjar
		v, l	m-s			0.1–3.4	Čoka Kupjatra
		vez	m-s, v-i			0.1-2	Root parts of Tilva Roš
	Low sulphidation	v, i	m-s	el, nAu, py, sph, cpy		3–23	Zlaće
	Sediment-hosted	i, l, v	i, v	py		0.8–1.3	Bigar Hill
Pb-Zn, Ag	Skarn	i, l	m-s, s-d	ga, sph	0.21		Valja Saka
Cu, Au	Skarn	i, l	m-s, s-d	cpy, py	0.21		Beljevina
Fe	Skarn	i, l	m-s, s-d	mg	0.21		Potoj Čuka

Abbreviations: 1) Morphology: c: column, i: irregular, iel: irregularly elongated lenses, l: lense, s: stock, v: vein, vez: very elongated zones. 2) Structural-textural variety: i: impregnations, i-c: irregular clusters, m-s: massive sulphides, o-v: ore veins, s-d: stockwork–disseminate, v-i: veinlets-impregnation. 3) Minerals: Au-tl: Au-telluride, bo: bornite, chl: chalcocite, co: covellite, cpy: chalcopyrite, el: electrum, en: enargite, ga: galena, lu: luzonite, mg: magnetite, mo: molybdenite, nAu: native gold, py: pyrite, sph: sphalerite, te: tetrahedrite.

porphyry Cu-Au deposits and related high sulphidation Cu-Au mineralization, skarn and contact-replacement deposits (Fe, Pb-Zn, Cu-Au etc), vein deposits (Cu, Cu-Au), mechanically redeposited Cu-Au deposits and sediment-hosted deposits (Fig. 3).

According to morphogenetic types and mineral paragenesis, one can differentiate the following groups of deposits (Table 1).

The associations of elements concentrated in the previously mentioned ore deposits include: a) major elements: Cu, Au, Mo, Fe (py) ± Pb-Zn; b) trace elements, recoverable: Se, PGE, Ag, Cd and c) trace elements, unrecoverable: W, Sn, Bi, Sb, As, (Ba). The principal associations of elements are classified as follows: a) Cu, Au, Mo ± Ag, PGE (porphyry copper); b) Cu, Pb/Zn, Fe (py), Au/Ag ± Se, Bi, Sb (massive sulphide); c) Cu, Au, Fe (py), As ± W, Sn, Se, Sb (cupriferous massive sulphide/replacement); d) Fe-S (massive pyrite); e) Cu, Fe (py) ± Mo, Bi, W and Pb-Zn-Ag ± Cu-Au (skarn); f) sediment-hosted: Au, Fe.

5. THE PRESENT STATE OF THE SELECTED METALLIC MINERAL RESOURCES

The most significant metallic mineral resources of the Bor metallogenic zone are copper, gold, lead-zinc and iron.

5.1. COPPER MINERAL RESOURCES

Copper mineral resources of the Bor metallogenic zone are classified as follows: a) porphyry Cu and Cu-Au, b) hydrothermal volcanic mineral resources of copper-bearing pyrites, c) volcanogenic polymetallic hydrothermal mineral resources of Cu-Pb-Zn massive sulphides, d) polymetallic Cu-Pb-Zn mineral resources with a high contribution of gold, e) skarn mineralization and f) mechanically redeposited Cu-Au mineral resources.

Porphyry copper deposits (PCD) contain the highest concentrations of copper and gold and show common characteristics corresponding to a general model of porphyry copper systems. The differences and unique features exhibited by individual deposits reflect local variability. Ore mineralization is confined to shallow emplacement of porphyritic dykes (quartz diorite, granodiorite and/or monzonite porphyritic). The spatial relationship of the plutonic intrusion and porphyry copper mineralization is either evident (Crni Vrh) or assumed on the grounds of the development of porphyry dyke suites (Majdanpek, Borska reka, Veliki Krivelj).

Porphyry copper deposits are classified as follows: a) PCD related to diorite porphyry cluster (Valja Strž); b) PCD related to high-level dyke swarms above the plutonic body (Veliki Krivelj), c) PCD associated with high sulphidation massive sulphides (subvolcanic type, Bor–Borska reka) and d) PCD

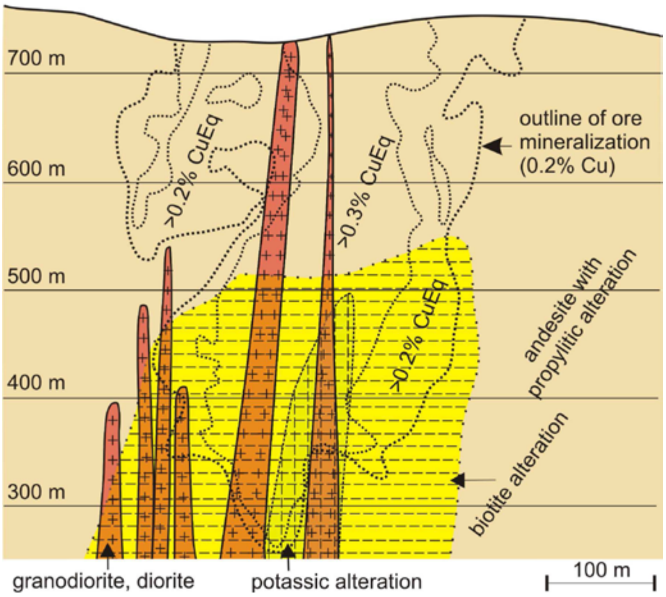

Figure 4. Cross-section through the Valja Strž porphyry copper deposit showing alteration and mineralization (2010)[1].

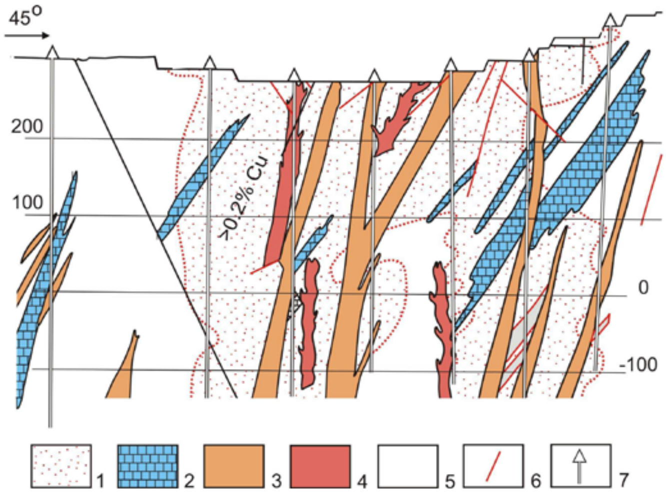

Figure 5. Cross-section through the Veliki Krivelj porphyry copper deposit (JANKOVIĆ et al., 2003) 1) Ore mineralization, 2) Limestones, skarns, 3) Andesites, 4) Quartzdiorite porphyry dykes, 5) Hydrothermally altered andesites, 6) Fault, 7) Drill-holes.

controlled by fault structures with subvolcanic intrusions of Upper Cretaceous andesites and hypabisal intrusions of granodiorite porphyrites, diorite porphyrites and, locally, granodiorites.

PCDs related to diorite porphyry cluster are located in the western part of the TMC. Ore mineralization is hosted by andesites and the Valja Strž granitoid complex which composition changes from monzonite granitoids up to diorites. Hydrothermal alteration of andesites and granitoids are characterized by biotitization, silicification and pyritization, partly by kaolinization and epidotization. Porphyry copper mineralization has been formed most probably in one stage and it corresponds to the ortogenetic model of porphyry copper mineralization. Valja Strž, Dumitru Potok, Dumitru Potok East and Čoka Rakita porphyry Au-Cu deposit belong to this group of porphyry copper deposits and mineral occurrences (Fig. 4).

PCD formed in the domain of dyke systems above magmatic complexes are localized in hydrothermally altered Upper Cretaceous andesites and pyroclastites as well as in volcano-sedimentary rocks, which were penetrated by numerous quartz-diorite porphyry (Veliki Krivelj deposit) (Fig. 5). The copper-bearing mineralization also comprises previously formed skarns and quartz-diorite-porphyry and andesite dykes. Facies of hydrothermal alterations comprise biotitization which laterally changes into seritization, silicification and pyritization in the rim parts of the ore bodies. In the deeper parts of deposits, there is also a local distribution of intensive sulphatization. Mineral associations comprise chalcopyrite, pyrite, scarcely molybdenite (50-150 ppm), pyrrhotite, magnetite, haematite, traces of enargite, galena and sphalerite. Gangue minerals are quartz and less often calcite, barite, siderite, while fluorite may be observed only in exceptional cases.

[1]DUNDEE PRECIOUS METALS (2010): Timok Project, Serbia National Instrument 43-101 Technical Report Prepared by Coffey Mining Pty Ltd on behalf of: Rodeo Capital Corp. 2010, 255 p. Retrieved from: http://www.avalaresources.com/i/pdf/Technical-Report-Timok-Project-Serbia.pdf.

A specific subtype of the previously described mineralization is located in the Cerovo – Mali Krivelj ore field (Fig. 6). The clearly expressed relationship of the ore mineralizations with quartzdiorite porphyry dykes in the Veliki Krivelj deposit is not confirmed in this case. The geological setting of the ore zone is a complex one. It is composed of Lower Cretaceous sediments, hydrothermally altered intrusive rocks and a volcano-sedimentary series.

Intensive kaolinization and pyritization are frequently accompanied by silicification. The majority of deposits show mutually separated characteristic zones: a) oxidation zone, and b) secondary sulphide enrichment zone. Dominant minerals are chalcocite and covellite. Chalcocite formed from chalcopyrite and pyrite, then covellite which frequently occurs with chalcocite but is less distributed and mainly formed by pseudomorphosis after chalcopyrite, pyrite and magnetite. Molybdenite, sphalerite and galena are rare.

PCD associated with high sulphidation system of massive sulphide mineralization is recognized in the Bor copper-gold deposits (i.e. Bor system). Along a subvertical volcanic structure, the length of which exceeds 2 km, porphyry copper mineralization is localized at depth (i.e. the Borska reka deposit), and above is well-developed high sulphidation system involving cupriferous pyrite ore (Fig. 7).

Porphyry copper mineralization is related to hydrothermally altered hornblende-biotite andesite and their pyroclastites intruded by quartz diorite porphyry dykes. Mineralization is associated with potassium silicate alteration, neobiotite, diaspore, gypsum, anhydrite, alunite and to a propylitic assemblage with widespread illite and chlorite. In the uppermost parts of the Borska Reka deposit, advanced argillic alteration coupled with intense pervasive silicification, marks upwards grading into a transition zone of previously developed high sulphidation mineralization.

Fault structures in the Borska reka deposit are the most prominent structural forms. The extensive dislocation of a NW-SE strike, known as the Bor fault, have brought the volcanoclastites into contact with the Bor conglomerates. The E-W

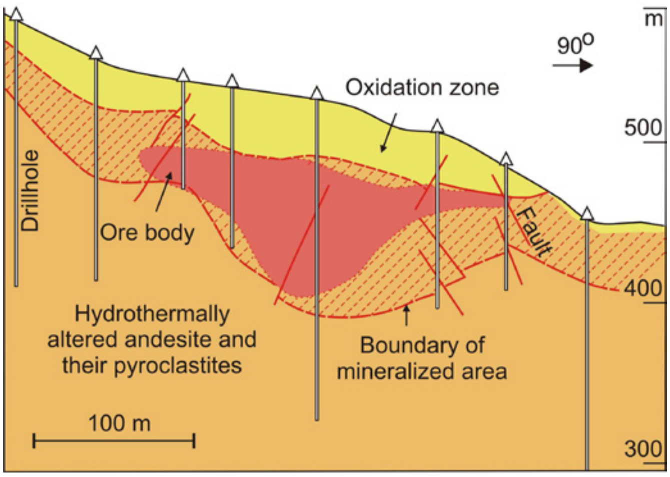

Figure 6. Cross-section through the Cerovo copper deposit (JANKOVIĆ, 1990).

striking faults that cross-cut the Bor fault have also been recorded. Fractures and fissures, mainly filled with alteration products and sulphide minerals, are widespread within the deposit.

The mineral composition of porphyry copper mineralization is complex: the main components are magnetite (1%), haematite, rutile, pyrite, chalcopyrite, bornite, molybdenite, covellite, chalcocite and digenite. The most extensive are pyrite and chalcopyrite, subsidiary bornite, chalcocite and covellite, while other minerals occur included in pyrite. Oxides of titanium and iron are accessory components of the host rocks. The gold content in the shallow parts of the deposit is higher (0.7 – 1.0 g/t) than in the deeper parts (~0.25 g/t).

PCD related to fault structures together with massive pyrite, and Pb-Zn sulphides are rare in the Bor metallogenic zone (Majdanpek deposit, Fig. 8). It is formed along a very narrow (only 300 m wide) and elongated 5 km long fault zone in which andesites and dykes of quartzdiorite porphyry are wedged at the contact of the Jurassic and Cretaceous limestones and Cambrian gneisses and amphibolites. The Majdanpek deposit consists of several types of mineralization formed in multistage processes: dominant porphyry copper-gold mineralization with molybdenite, massive sulphide, pyrite bodies, skarn magnetite and hydrothermal Pb-Zn sulphides in the form of massive-metasomatic bodies and ore veins.

Hydrothermal volcanic deposits of copper bearing pyrite (or, *volcanogenic cupriferous pyrite deposits*) are localized in andesites. The advanced argillite alteration prevails, and the mineralization suggests ore deposition under a high sulphur fugacity. The predominant metals and metalloids are Cu, Au, Fe and As. The W, Sn and Se mineralizations have also been recorded. Ore bodies of massive sulphides and stockwork-disseminated type of mineralization in the Bor deposit, and in the Brestovac ore field (Čukaru Peki Cu-Au deposit) belong to this type of ore deposit (Fig. 9).

The genetic model of mineralization in both deposits is very similar. It includes different styles of porphyry Cu-Au and high epithermal mineralization (Fig. 10).

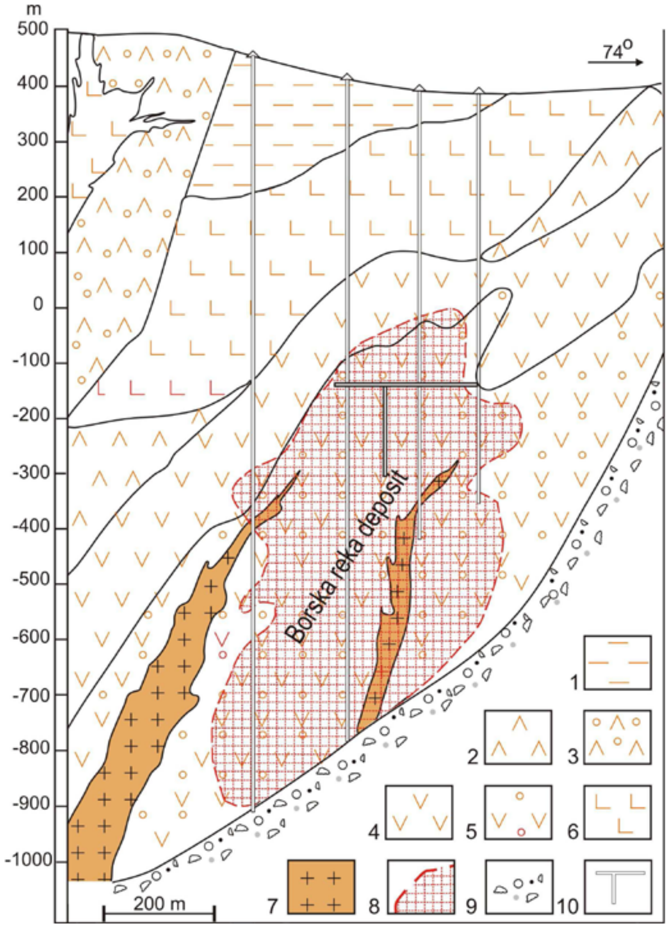

Figure 7. Cross-section through the Borska reka porphyry copper deposit (SIMIĆ & MIHAJLOVIĆ, 2006)[2]. 1) Pelite, 2) Hornblende-augite andesite, 3) Hornblende-augite andesite pyroclasts, 4) Hornblende-biotite andesite, 5) Hydrothermally altered hornblende-biotite andesite, 6) Augite-hornblende andesite pyroclasts, 7) Quartz diorite porphyry, 8) Outline of the Borska reka mineral deposit, 9) Bor conglomerates, 10) Underground workings.

The mineralization identified at the Čukaru Peki deposit belongs to the epithermal and porphyry copper-gold types (BANJEŠEVIĆ & LARGE, 2014). It occurs at depths between 400 m below the surface to greater than 2 km. The host rocks are Upper Cretaceous hornblende and hornblende biotite andesites, andesite breccias, hydrothermal breccia, and relatively rare diorite porphyry.

Three styles of mineralization are defined at Čukaru Peki:

1) High sulphidation type, comprising Cu-Au massive-sulphide, veins, stockwork and hydrothermal breccia matrix sulphide. This type of mineralization forms a single zone at depths ranging from 400 to over 1000 m below the surface. The predominant sulphides are covellite with bornite, enargite and chalcocite. Dominant alteration mineralogy is typical advanced argillic, including quartz, alunite, dickite and kaolinite.

2) Porphyry type of mineralization in the deeper parts of the Čukaru Peki deposit, at depths greater than about 1000 m.

[2]SIMIĆ, D. & MIHAJLOVIĆ, B. (2006): Elaborat o rezervama bakra i pratećih elemenata u ležištu Borska reka [Elaborate of reserves of copper and accompanied elements in Borska reka deposit – in Serbian].– Ministry of Mines and Energy, Serbia, Found of geological documentation, 147 p.

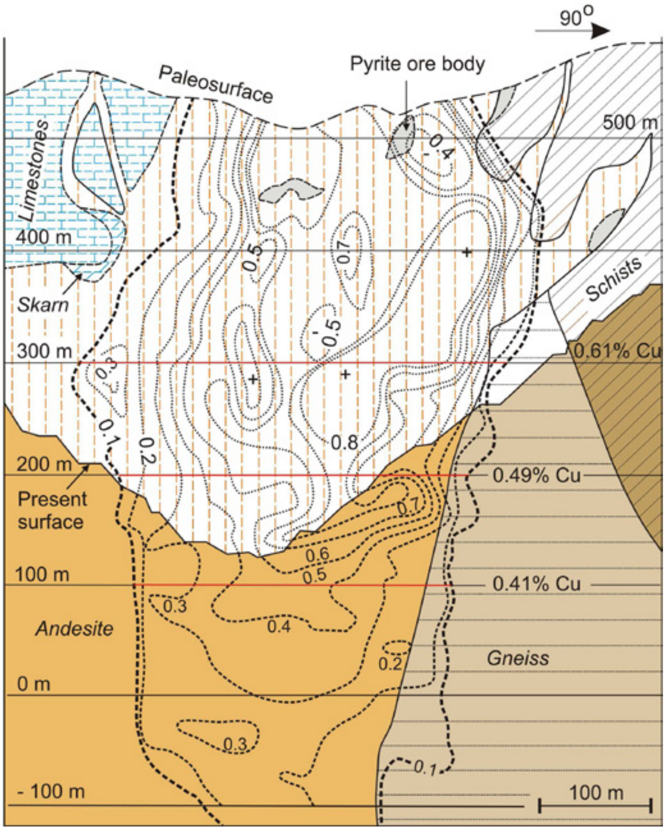

Figure 8. Cross-section through the Majdanpek porphyry copper deposit (VUJIĆ et al., 2005).

It consists of chalcopyrite and pyrite, with rare molybdenite. Anhydrite veins are commonly associated with this type of mineralization. Locally-developed argillic alteration (dominated by kaolinite and/or montmorillonite) variably overprints both high-sulphidation and porphyry-style alteration.

3) Transitional epithermal zone located between the high sulphidation and porphyry Cu-Au mineralization. It comprises covellite and enargite replacing the primary sulphide (chalcopyrite) in porphyry Cu-Au mineralization, and is associated with gypsum, anhydrite, calcite that is typical of the high sulphidation zone.

Based on preliminary observations, it is believed that the massive sulphide type of mineralization contains > 10 Mt of ore with > 5% Cu, which corresponds to the amount of ore and copper content exploited from Bor deposits in the period 1902-1941 (Čoka Dulkan ore body - 12 million tonnes of ore with 5.6% Cu and 2.6 g/t Au). Preliminarily estimation of mineral resources in the massive-sulphide type mineralization amounts to approximately 45 million tonnes of ore with 3% Cu and about 1.4 Mt of copper metal. Total mineral resources of copper could amount to between 500 and 1000 million tonnes. In this way, the newly-found copper and gold deposits Čukaru Peki, can be compared with the Bor Cu-Au complex, ranking highly on the world's deposit scale (RESERVOIR MINERALS, 2014)[3].

Volcanogenic polymetallic hydrothermal deposits of massive sulphides (Cu-Pb-Zn) with high gold content is formed in Upper Cretaceous volcanites under conditions of highly sulphidizing systems (Čoka Marin deposit, ŽIVKOVIĆ, 1987). It is located in a volcano-sedimentary series between pelites with disseminated haematite and with the intercalation of tuffs and volcanic breccia in the hanging wall and hydrothermally altered andesites and andesite breccia in the footwall. Ore bodies are in a form of elongated lenses which by its morphology are reminiscent of a stratiform type of deposit (Fig. 11). The mineral association consists of pyrite, gel-pyrite, limited pyrrhotite, marcasite, enargite, luzonite, chalcopyrite, scarcely bornite, sphalerite, galena and Pb-Zn sulphosalts. Gold is a very significant component of this ore mineralization, in the form of native gold or bound to sulphides. Stannine, cassiterite and bravoite occur locally as a component part of the mineral paragenesis. A significant part of the mineral paragenesis originates from colloid solutions. Gangue minerals are quartz, a limited quantity of barite, anhydrites, siderite, calcite and in exceptional cases fluorite.

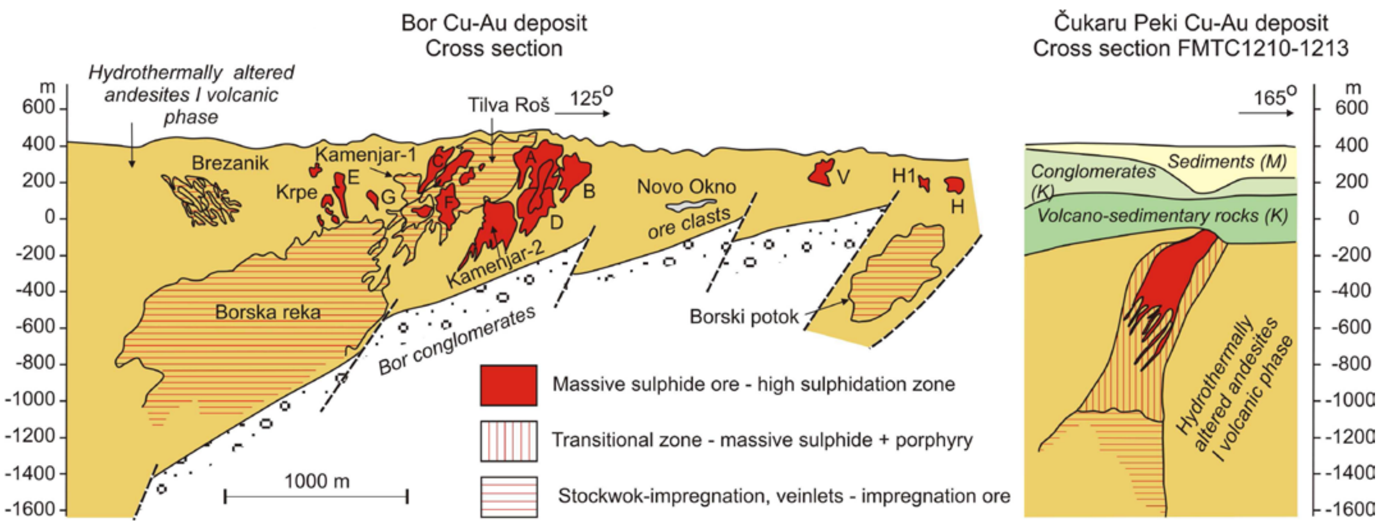

Figure 9. Cross-section through the Bor copper-gold deposit and the Čukaru Peki deposit.

[3]RESERVOIR MINERALS (2014): NI 43-101 Technical Report on a Mineral resource estimate on the Čukaru Peki deposit, Brestovac-Metovnica exploration permit, Serbia. Retrieved from: http://www.reservoirminerals.com

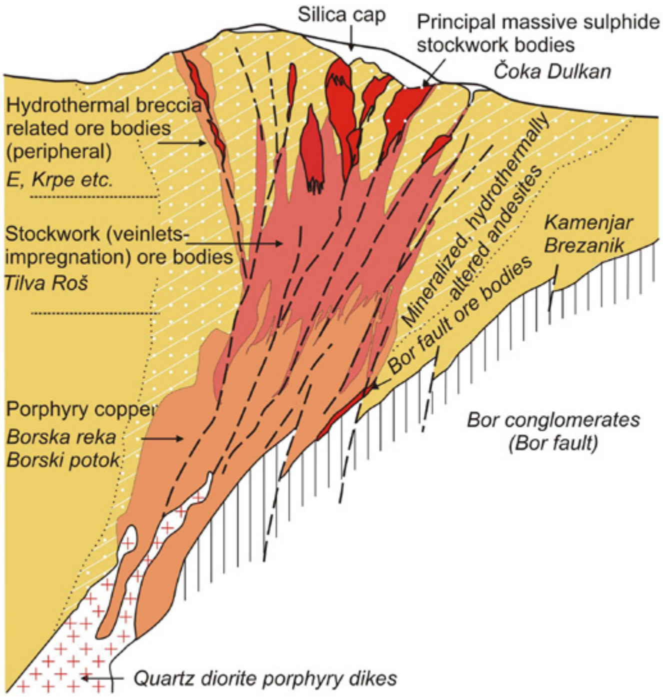

Figure 10. General genetic model of the Bor system.

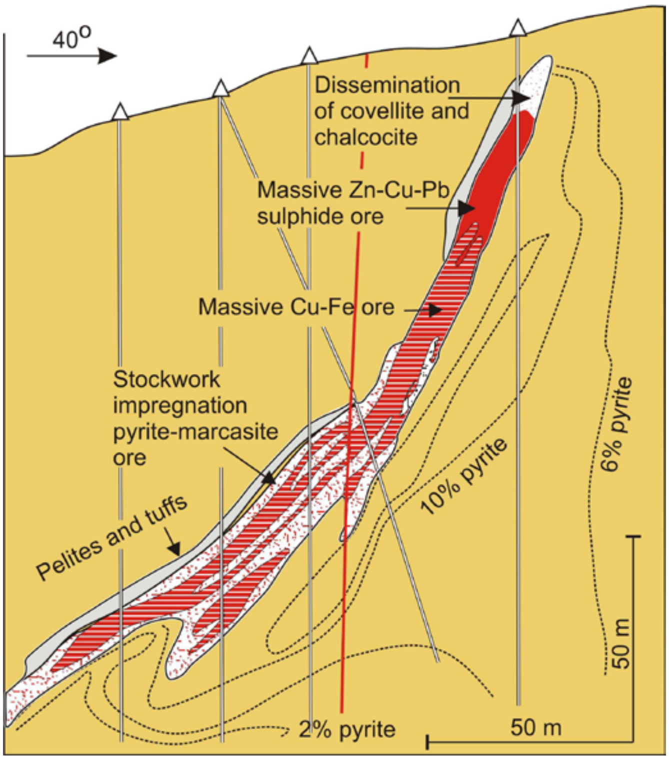

Figure 11. Cross-section through the ***Čoka Marin Pb-Zn-Cu-Au-Ag deposit*** (ŽIVKOVIĆ, 1987).

Country rock alterations are characterized by advanced argillite alterations (alunite, diaspore, sericite) and widespread silicification, pyritization and chloritization (ŽIVKOVIĆ, 1987). The ore mineralization contains 1-3% Cu, 5-8% Zn and up to 1% Pb, while the Au content is 5-10 g/t, locally over 20 g/t.

Copper skarn (contact replacement) ore-bearing zones include: 1) Veliki Krš zone and 2) Beljevina zone. Veliki Krš, 750 m long ore-bearing zone, includes several small ore bodies (1-8 m in width). Dominant minerals are pyrrhotite, chalcopyrite, bornite, sphalerite, molybdenite, pyrite, chalcocite, galena etc. Beljavina is a zone 600 m long and 20-12 m in width and includes the Beljanica deposit and several small mineral occurrences with the same mineral composition. The copper content varies from 0.44-0.94%.

Mechanically redeposited Cu-Au mineral resources. The Novo Okno ore deposit belongs to this type of mineralization; its ore reserves are 2 250 000 tons, average copper concentration 4.85% (JANKOVIĆ et al., 2003). Ore-clasts are formed by the explosive destruction of the primary massive copper sulphide deposits of the Bor deposits, their ejection onto the surface and gravity slides down the volcanic land-slopes into a marine basin (ANTONIJEVIĆ, 2011). There are also some occurrences of ore-clasts near Metovnica and north of Bor town (Čoka Bare, Ujova).

5.2. GOLD MINERAL RESOURCES

Gold mineral resources of the Bor metallogenic zone are widely distributed. Gold is present as an accompanying component in porphyry copper deposits and as an epithermal, high-sulphidization type, low sulphidization type and sediment-hosted gold mineralization type (KOŽELJ, 2002).

High-sulphidation epithermal gold mineralization comprises deposits and occurrences in which gold is a leading constituent of the mineralization (Čoka Kupijatra and Tilva Njagra) as well as deposits in which gold is an accompanying, but very significant mineralization component (hydrothermal volcanic copper deposits – ore bodies of massive sulphides in the upper part of Bor deposit, then Čoka Kuruga, Lipa, as well as polymetallic deposits Cu, Pb, Zn of the type Čoka Marin type).

Low sulphidization epithermal gold mineralization is known in the area of Zlaće-Crvena Reka as an independent mineralization system, accompanying porphyry copper deposits which are localized in high-plutonic levels where numerous dykes occur (deposit Veliki Krivelj, Cerova) and as the youngest mineralization stage in porphyry copper deposits (e.g., the Majdanpek deposit).

Sediment-hosted gold mineralization is located along the western margin of the TMC (the Potaj Čuka – Tisnica ore district, i.e. Bigar Hill, Kraku Pešter and Korkan deposits). The district, as currently defined, is at least 25 km in length and up to 10 km wide. Gold mineralization is associated with a complex geological and structural sequence of limestone/marble, calc-silicate hornfels, biotite-magnetite hornfels, monzonite, diorite dykes, andesitic volcanic and volcaniclastic rocks, schists and tuffaceous sedimentary rocks. The mineralized area is extensively faulted and intruded by numerous diorite and monzonite complexes with associated thermally metamorphosed aureoles, indicating the potential for sufficient permeability and the rheologic contrast for fluid

[4]AVALA RESOURCES (2014). Timok Gold Project NI 43-101 Technical Report and Mineral Resource Estimates. Retrieved from: http://www.avalaresources.com.

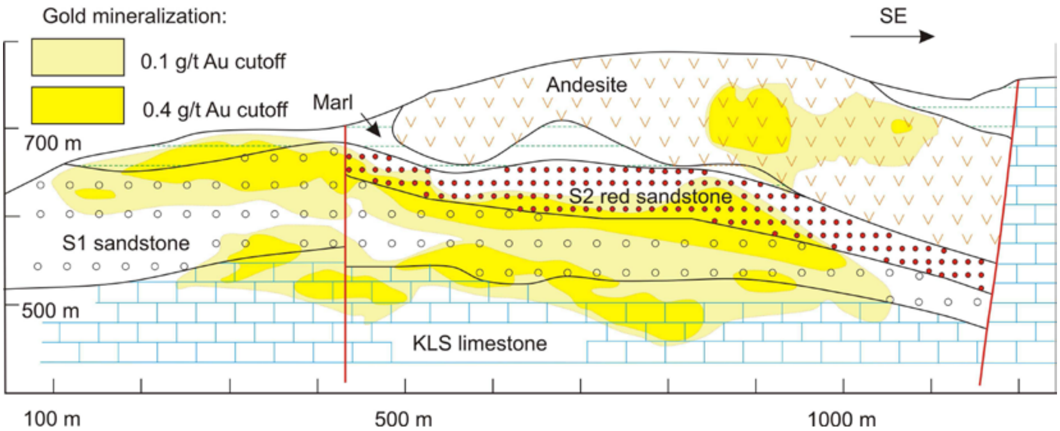

Figure 12. Cross-section through the Bigar Hill gold deposit (van der TOORN et al., 2013).

movement and hydrothermal deposition (AVALA RESOURCES, 2014)[4].

The gold mineralization appears to be associated with fine-grained pyrite (sulphidation reaction) and with alteration zones including kaolinitization, decarbonatization of calcareous sedimentary rock and occasionally silicification.

The gold mineralization is mostly hosted within a favourable sedimentary package which is underlain by Jurassic and Lower Cretaceous limestones (KLS limestone) and consists predominantly of calcareous sandstones and conglomerates which include an interbedded fine-grained sandstone and clay-rich siltstone unit. The upper portion of the target stratigraphy consists of 'red' sandstones and volcanic-lithic clastics (S2 red sandstones) which are in turn overlain by calcareous marls, andesitic volcanics and derivative clastic rocks, which represent the youngest portion of the stratigraphy.

5.3. LEAD-ZINC MINERAL RESOURCES

According to mineral associations and conditions of formation, lead-zinc mineral resources of the Bor metallogenic zone can be classified as follows: a) skarn / carbonate replacement type (Pb, Zn, Ag sulphide) mineral resources, b) mineral resources of vein Pb-Zn sulphide type and c) mineral resources of massive Pb-Zn sulphides, of volcanic origin. All of them are mainly of small dimensions, but locally may be of economic interest.

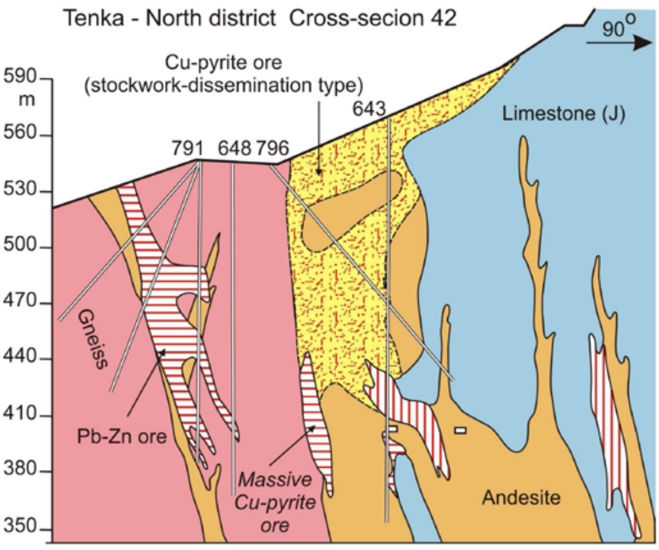

Figure 13: Cross-section through the Tenka Cu-Pb-Zn deposit (VUJIĆ et al., 2005).

Skarn Pb-Zn and carbonate replacement polymetallic (Au, Ag, Pb, Zn, As) deposits rarely occur. The Valja Saka skarn deposit formed in a small limestone block close to the Valja Strž granitoide complex. The mineral paragenesis includes galena and sphalerite as the dominant minerals. Estimated ore reserves are 500 000 tons with 2.1% Pb, 1.85% Zn and 0.21% Cu. Korkan East occurrences are located in the deeper part of the Korkan Au deposit, in the contact zone between the limestones and andesites of the TMC. The gold and base metal mineralized rocks at Korkan East show characteristic features of carbonate replacement deposits. It comprises a polymetallic style of mineralization, containing elevated levels of gold, silver, lead, zinc, and arsenic.

Hydrothermal vein deposits of lead-zinc sulphides are relatively frequent in the Bor metallogenic zone *senso stricto*, but are not economically viable. Thickness of ore veins is most frequently between 0.2-1 m. Along the strike they quickly narrow. Ore viens are localized usually in andesites, as independent ore bodies, or they are formed in certain copper deposits usually in the last stage of mineralization. The latter is the case with the porphyry copper deposits of Majdanpek and Borski potok, where copper-bearing mineralization is cross-cut by hydrothermal veins of lead-zinc sulphides.

Ore deposits of massive lead-zinc sulphides are rare in the Bor metallogenic zone. It is located on the rim of porphyry Cu-Au mineralization in North district of Majdanpek deposit (type: Tenka, Fig. 13).

Tenka deposit is formed at the contact of Jurassic limestones and Upper Cretaceous subvolcanic intrusions of andesites. These are typical metasomatic bodies that occurred along the steep breaking zone so that ore bodies are in the form of steep columns and morphologically complex ore veins, with additional local lenses and isometric ore bodies.

Dimensions of the ore bodies are variable; thicknesses vary from several to 20 m, locally up to 30 m; with a length of up to 450 m. The vertical interval of mineralization does not exceed 150 m.

Table 2. Mineral resources and ore reserves of copper, gold and silver in the selected mineral deposits of the Bor metallogenic zone *senso stricto* (Explanation: M-Measured mineral resources, I-Indicated mineral resources, If- Inferred mineral resources /PERC, 2008/[5]. Balance A+B+C1-Balance (economic) reserves /according to the Book of Regulations on Classification and Categorization of Reserves of Solid Mineral Raw Materials and Keeping a File on Them, 1979/[6]. Ore reserves – Proven and Probable reserves, according to PERC, 2008. Data source: [(1)] - Ministry of Mines and Energy, Serbia. [(2)] - Found of geological documentation RTB, [(3)] - Reservoir Minerals, [(4)] - Avala Resources).

Deposit	Mineral resources (cut-off 0.2% Cu)	Ore, t	Cu, %	Au, g/t	Ag, g/t	Cu, t	Au, t	Ag, t
[1]Majdanpek NR	M+I	228 085 000	0.3	0.256	1.94	684 255	58.39	442.48
	Balance, A+B+C1	228 085 000	0.3	0.256	1.94	684 255	58.39	442.48
	Ore reserves	46 200 132	0.362	0.37	1.39	167 244	17.094	64.22
[1]Majdanpek SR	M+I	409 171 000	0.328	0.06	0.54	1 342 080	24.55	221
	Balance, A+B+C1	246 082 000	0.36	0.19	1.44	885 895	46.76	354.36
	Ore reserves	98 257 000	0.398	0.23	1.49	391 062	22.6	146.4
[1]Čoka Marin	M+I	270 800	2.16	5.35	37	5 849	1.45	10.02
	Balance, A+B+C1	220 700	2.08	5.92	40.53	4 600	1.31	8.94
	Ore reserves	110 600	3.64	15.87	152.49	4 025	1.76	16.87
[1]Valja Strž	I+If (0,3% Cu)	108 200 000	0.26	0.19	0.79	281 320	20.56	85.48
	Balance, A+B+C1	47 299 000	0.31	0.27	0.9	146 627	12.77	42.57
	Ore reserves	36 977 000	0.281	0.227	0.865	103 905	8.394	31.985
[1]Kraku Bugaresku – Cementacija	M+I	70 092 715	0.3	0.09	1.21	210 278	6.31	84.81
	Balance, A+B+C1	45 800 000	0.31	0.09	1.2	141 980	4.12	54.96
	Ore reserves	24 991 000	0.34	0.09	1.2	84 969	2.25	29.99
[1]Cerovo	M+I	319 377 890	0.31	0.14	0.86	990 071	44.71	274.66
	Balance, A+B+C1	150 138 000	0.33	0.14	0.94	495 455	21.02	141.13
	Ore reserves	88 750 000	0.36	0.17	1.06	319 500	15.09	94.08
[1]Veliki Krivelj	M+I	506 460 237	0.367	0.07	0.4	1 858 709	35.45	202.58
	Balance, A+B+C1	465 150 000	0.34	0.07	0.4	1 581 510	32.56	186.06
	Ore reserves	152 739 000	0.337	0.07	0.39	514 730	10.69	59.57
[1]Bor – Mine	M+I	18 310 000	0.8	0.2	1.5	146 480	3.66	27.47
	Balance, A+B+C1	16 338 000	0.86	0.21	1.6	140 507	3.43	26.14
	Ore reserves	7 263 000	1.02	0.24	1.7	74 083	1.74	12.35
[1]Borska reka	If	450 922 103	0.49	0.109	1.72	2 209 518	49.15	776
	M+I	556 911 000	0.57	0.206	1.67	3 174 393	114.72	930.041
	Balance, A+B+C1	319 969 000	0.5	0.2	1.62	1 599 845	63.99	518.35
	Ore reserves	130 463 000	0.56	0.24	1.66	730 593	31.31	216.57
[2]Mali Krivelj	If+I	353 329 000	0.29			1 024 654		
[3]Čukaru Peki	If	65 300 000	2.6	1.5		1 697 800	97.95	
[4]Potoj Čuka – Tisnica	If	4 300 000		1			4.3	
	I	67 420 000		1.14			76.86	
4Korkan East	If	1 370 000		3.4			4.66	
Resources M+I		2 108 678 642				8 571 369	386.66	2 211.33
Resources If		520 522 103				3 920 764	172.5	794.27
Balance, A+B+C1		1 519 081 700				5 680 674	244.35	1 774.99
Ore reserves		585 750 732				2 390 111	110.93	672.04

The mineral paragenesis comprises pyrite as the most dominant mineral, then sphalerite, galena, chalcopyrite, scarcely enargite and luzonite, pyrrhotite, tetrahedrite, rarely bornite. Gold occurs as its native form but also bound to sulphides. Copper, lead and zinc are irregularly distributed in the ore bodies. The mineral potential of the Tenka deposit has been estimated as 4 million tons of ore with 0.5 % Cu, 1.1 % Pb, 4.4% Zn, 1.3 g/t Au and 28 g/t Ag.

Besides the Tenka deposit, polymetallic mineralization (Cu, Zn, Pb with gold), closely related to pyrite ore bodies, is also known in the Dolovi locality in the Southern district of the Majdanpek deposit.

[5]Pan-European Code for Reporting of Exploration Results, Mineral Resources and Reserves (The PERC Reporting Code), 2008.

[6]Pravilnik o klasifikaciji i kategorizaciji rezervi čvrstih mineralnih sirovina i vođenju evidencije o njima, Službeni list SFR Jugoslavije broj 53/1979 [The Book of Regulations on Classification and Categorization of Reserves of Solid Mineral Raw Materials and Keeping a File on Them].– Unpubl. report, Službeni list SFR Jugoslavije broj 53/1979. Beograd.

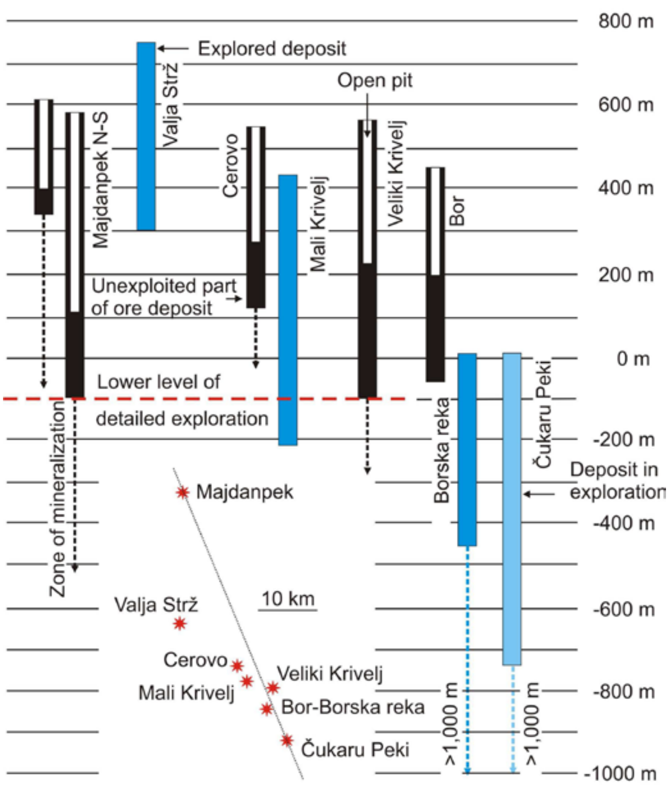

Figure 14. Vertical interval of copper-mineralization in selected copper-gold deposits.

5.4. IRON MINERAL RESOURCES

Iron mineral resources belong to groups of: a) skarn mineralization and b) limonite ore bodies in relation to porphyry copper deposits.

Skarn iron (magnetite) mineralization is located in two main zones: 1) Žagubica zone and 2) Majdanpek zone.

In the Žagubica ore-bearing zone (i.e. Frasen-Biger potok-Umka zone) where small occurrences Potaj Čuka and Umka are located, the Ca-skarn mineralized zone covers 5 km^2 (15 km x 0.5-3 km). Ore bodies are in the form of nests and lenses composed of compact magnetite ores. Magnetite ore from Potoj Čuka contains 59.2% Fe, 4.1% SiO_2, 0.05% P and 0.06% S. Magnetite ore from the Umka zone (cover 2 km^2), contains 64.6% Fe, 4.5% SiO_2, 0.06% P and 0.05% S.

The Majdanpek ore-bearing zone contains several small compact magnetite ore bodies in the form of nests and lenses with 58.7% Fe, 4.0% SiO_2, 0.07% P and 0.05% S.

Limonite ore bodies are located in the Majdanpek ore deposit. They were formed as a result of the oxidation of pyrite ore bodies. The biggest one is the Blašard ore body. Indicated mineral resources of limonite are 2 Mt with 45% Fe, 0.4% Cu, 0.1-1.3% Zn and 0.1-0.5% Pb.

6. MINERAL RESOURCES AND MINERAL RESERVES

Mine production from copper-gold mineral deposits of the TMC from 1902 to the present day was 652 Mt of ore with 4.93 Mt of Cu and 280 tons of gold. Today, officially confirmed, measured and indicated copper and gold resources in the identified ore bodies are 8.57 Mt of Cu and 310 tons of gold. Inferred copper resources are 3.92 Mt of Cu and 156 t of gold (Table 2). In this way, the Bor metallogenic zone according to copper and gold resources represents one of the most important metallogenic units in Serbia.

Prognostic mineral resources of the Bor metallogenic zone are estimated at over 20 millions of tons of copper and 1,000 tons of gold in currently identified ore bodies.

7. CONCLUSION

During more than 100 years of exploration it was established that cooper and gold mineralization are not uniformly distributed in the TMC. The most significant deposits are located in its northern part, between Majdanpek and Bučje. In the northern extension of the TMC, where the trough structure continues into a fault to the Danube and Romania, and in the southern extension in the Nevlje-Borov dol area (Serbian-Bulgarian border), copper-gold mineralization was identified but not systematically explored. The probability for new copper and gold deposit discoveries in these areas is considerably lower when compared to the Bor metallogenic zone *senso stricto*.

Judging by the vertical interval of copper-gold mineralization observed in the of existing mineral deposits in the Bor metallogenic zone the possibilities for discovering new copper and gold mineral resources, are at depth (Fig. 14). This supports the earlier mentioned discovery of copper-gold mineralization in the Brestovac ore field and in the deeper part of the Borska reka porphyry copper deposit in the Bor system. It is important to say that in the past the largest number of copper and gold deposits was investigated in detail only to the level of -100 m.

On the other hand, there is recently defined, previously unrecognized sediment-hosted type of gold mineralizations located along the western margin of the Timok magmatic complex. They share many common geological characteristics with the Carlin-type gold deposits in Nevada, USA, including the characteristics of the sedimentary host and the metal association (Au, As, Hg, Tl, Sb, and base metals). The fine-grained nature of the gold, the high gold to silver ratio and alteration types, including argillization, decarbonization and locally additions of quartz, speaks in favour of the necessity for new investments in geological exploration of this type of mineralization. The presently identified resources of gold in this type of mineralization represent more than 30% of the previously known quantities of gold in porphyry and other Cu-Au deposits in the Timok magmatic complex. According to the presented results of geological exploration, an additional significant gold mineralization is associated with carbonate replacement deposits composed of arsenopyrite, sphalerite and galena (Korkan East). The link between the replacement deposit at Korkan East and the nearby lower temperature sediment-hosted gold is unclear.

The authors of this paper their knowledge, ideas and research methods were given of the best known geology of mineral deposits in this area, acad. Ivan JURKOVIĆ and Professor Slobodan JANKOVIĆ. Continue their work. Thank them.

Abbreviations

ABCD; Alpine-Balkan-Carpathian-Dinaride geodynamic province. AJ; Ježevica andesite. AO; Osnić basaltic andesite. AT; Timok andesite. BMMB; Banatitic Magmatic and Metallogenic Belt. EM; Metovnica epiclastite. LB; Boljevac latite. Mt; Million tonnes. PDC; Porphyry copper deposits. PGE; Platinum group elements. PVS; Valja Strž plutonite. TEMB, Tethyan Eurasian Metallogenic Belt. TMC; Timok Magmatic Complex.

REFERENCES

ANTONIJEVIĆ, I. (2011): The Novo Okno copper deposit of olistostrome origin (Bor, Eastern Serbia).– Annales géologiques de la Peninsule balkanique, 72, 101–109. doi: 10.2298/GABP1172101A

BANJEŠEVIĆ, M. (2006): Gornjokredni magmatizam Timočkog magmatskog kompleksa [*Upper Cretaceous magmatism of the Timok magmatic complex* – in Serbian, with an English abstract].– PhD thesis, Faculty of Mining and Geology, Belgrade University, Belgrade, 184 p.

BANJEŠEVIĆ, M. (2010): Upper Cretaceous magmatic suites of the Timok Magmatic Complex. Annales géologiques de la Peninsule balkanique, 71, 13–22. doi: 10.2298/GABP1071013B

BANJEŠEVIĆ, M. (2015): Geološka karta Republike Srbije (Kartografska građa) [Geological Map of the Republic Serbia (Cartographic composition, Zaječar 1 – 1:50000)], Zaječar 1 – 1:50000.– Geološki zavod Srbije, Beograd.

BANJEŠEVIĆ, M., CVETKOVIĆ, V., VON QUADT, A., PEYTCHEVA, I. & COCIĆ, S. (2006): Geodynamic reconstructions based on the magmatism in the Timok Magmatic Complex (East Serbia) – part of the Carpathian-Balkan Belt.– 18th Congress of Carpathian-Balkan Geological Association, Belgrade, 27–29.

BANJEŠEVIĆ, M. & LARGE, D. (2014): Geology and mineralization of the new copper and gold discovery south of Bor Timok magmatic complex.– Proceedings of the XVI Serbian Geological Congress, Serbian Geological Society, Donji Milanovac, 2014, 739–741.

BERZA, T., CONSTANTINESCU, E. & VLAD, S.N. (1998): Upper Cretaceous magmatic series and associated mineralization in the Carpathian-Balkan Orogen.– Resource Geology, Tokyo, 48/4, 281–306.

BOROJEVIĆ ŠOŠTARIĆ, S., PALINKAŠ, L., NEUBAUER, F., CVETKOVIĆ, V., BERNROIDER, M. & GENSER, J. (2014): The origin and age of the metamorphic sole from the Rogozna Mts., Western Vardar Belt: New evidence for the one-ocean model for the Balkan ophiolites.– Lithos, 192–195 (2014), 39–55. doi:10.1016/j.lithos.2014.01.011

CLARK, H.A. & ULLRICH, D.T. (2004): $^{40}Ar/^{39}Ar$ age data for andesitic magmatism and hydrothermal activity in the Timok Massif, eastern Serbia: implications for metallogenetic relationships in the Bor copper-gold subprovince.– Mineralium Deposita, 39, 256–262. doi: 10.1007/s00126-003-0370-3

ĐORĐEVIĆ, M. & BANJEŠEVIĆ, M. (1997). Geologija južnog depa Timočkog magmatskog kompleksa, Tumač geološke karte 1:50000 [*Geology of the southern part of the Timok Magmatic Complex, Booklet and Geological Map 1:50000* – in Serbian].– Federal Ministry of Economy FR Yugoslavia, Belgrade, 171 p.

ĐORĐEVIĆ, M. (2005): Volcanogenic Turonian and epiclastics of the Senonian in the Timok Magmatic Complex between Bor and the Tupižnica Mountain, eastern Serbia.– Annales géologiques de la Peninsule balkanique (for 2004 – 2005), 66, 63–71. doi: 10.2298/GABP0566063D

DROVENIK, M. (1959): Complement to understanding the Timok eruptive massive rocks.– Rasprave in poročila, Geologija, 5, 11–21 (in Slovenian).

HEINRICH, C.A. & NEUBAUER, F. (2002): Cu-Au-Pb-Zn-Ag Metallogeny of the Alpine-Balkan-Carpathian-Dinaride Geodynamic Province.– Mineralium Deposita, 37, 533–540. doi: 10.1007/s00126-002-0271-x

JANKOVIĆ, S. (1976): The copper deposits and geotectonic setting of the Tethyan Eurasian Metallogenic Belt. 25th Intern. Geol. Congr. Sydney.– Mineral deposits, 12, 37–47, (1977). doi: 10.1007/BF00204503

JANKOVIĆ, S. (1980): Metallogenic features of copper deposits in the volcano-intrusive complexes of the Bor district, Yugoslavia.– Monograph European copper deposits. JANKOVIĆ, S. & SILLITOE, R.H. (eds.): SGA – Spec. publ. No 1, Copper Mining, Smelting and Refining Corporation, Bor and Department for Economic Geology, Faculty of Mining and Geology, Belgrade University, Belgrade, 42–49.

JANKOVIĆ, S. (1990): Rudna ležišta Srbije: Regionalni metalogenetski položaj, sredine stvaranja, i tipovi ležišta [*The ore deposits of Serbia: Regional metallogenic settings, environments of deposition, and types* – in Serbian, with an English abstract].– Faculty of Mining and Geology, Belgrade, 760 p.

JANKOVIĆ, S. (1997): The Carpatho-Balkanides and adjacent area: a sector of the Tethyan Eurasian metallogenic belt.– Mineralium Deposita, Vol. 32, No. 5, 426–433. doi: 10.1007/s001260050110

JANKOVIĆ, S., JELENKOVIĆ, R. & VUJIĆ, S. (2003): Mineralni resursi i prognoza potencijalnosti metaličnih i nemetaličnih mineralnih sirovina Srbije i Crne Gore na kraju 20. veka [*Mineral resources and prognosis of potential of metallic and non-metallic mineral raw materials in Serbia and Montenegro at the end of the 20th century* – in Serbian, with an English abstract].– Engineering Academy of Serbia and Montenegro. Belgrade, 875 p.

KARAMATA, S. & DJORDJEVIĆ, P. (1980): Origin of the Upper Cretaceous and Tertiary magmas in the eastern part of Yugoslavia.– Bulletin Academie des Serbe des Sciences et des Arts, Classe des Sciences Mathematiques et Sciences Naturalles, v. 32, 1–p.

KARAMATA, S., KNEŽEVIĆ-DJORDJEVIĆ, V. & MILOVANOVIĆ, D. (2002): A review of the evolution of Upper Cretaceous–Paleogene magmatism in the Timok Magmatic Complex and the associated mineralization.– In: KOŽELJ, D. & JELENKOVIĆ, R. (eds.): Geology and metallogeny of the copper and gold deposits in the Bor Metallogenic Zone, QWERTY, Bor, 15–28.

KOLB, M., VON QUADT, A., PEYTCHEVA, I., HEINRICH, C.A., FOWLER, S.J. & CVETKOVIĆ, V. (2013): Adakite-like and normal arc magmas: distinct fractionation paths in the East Serbian segment of the Balkan-Carpathian. Arc Journal of Petrology, 54/3, 421–451. doi: 10.1093/petrology/egs072

KOŽELJ, D. (2002): Epitermalna mineralizacija zlata Borske metalogenetske zone: Morfogenetski tipovi, strukturno-teksturni varijeteti i potencijalnost [*Epithermal gold mineralization in the Bor metallogenic zone: Morphogenetic types, structural-texture varieties and potentiality* – in Serbian, with and English Abstract].– Grafomed, Bor, 216 p.

KRÄUTNER, H.G. & KRSTIĆ, B. (2002): Alpine and Pre-Alpine structural units within the Southern Carpathians and the Eastern Balkanides.– Proceedings of XVII. Congress of Carpathian- Balkan Geological Association Bratislava, September 1 – 4, 2002, Geologica Carpathica, 53, Special Issue, 7 p.

LJUBOVIĆ-OBRADOVIĆ, D., CAREVAC, I., MIRKOVIĆ, M. & PROTIĆ, N. (2011): Upper Cretaceous volcanoclastic-sedimentary formations in the Timok Eruptive Area (eastern Serbia): new biostratigraphic data from planktonic foraminifera.– Geologica Carphatica, 62/5, 435–446. doi: 10.2478/v10096-011-0031-x

MAJER, V. (1953): Prilog razumevanju monconitskih stena u istočnoj Srbiji [*Complement to the understanding of monzonitic type rocks in eastern Serbia – in Serbian, with an English abstract*].– Vesnik Geozavoda, 10, 135–147.

MILOVANOVIĆ, D., KARAMATA, S. & BANJEŠEVIĆ, M. (2005): Petrology of the alkali basalts of Zlot, Timok Magmatic Complex (eastern Serbia).– Tectonophysics, 410/1–4, 501–509. doi:10.1016/j.tecto.2005.06.012

PALINKAŠ, L., BOROJEVIĆ ŠOŠTARIĆ, S. & STRMIĆ PALINKAŠ, S. (2008): Metallogeny of the Northwestern and Central Dinarides and Southern Tisia.– Ore geology reviews, 34/3, 501–520. doi: 10.1016/j.oregeorev.2008.05.006

SCHMID, S.M., BERNOULLI, D., FUGENSCHUH, B., MATENCO, L., SCHEFER, S., SCHUSTER, R., TISCHLER, M. & USTASZEWSKI, K. (2008): The Alpine–Carpathian–Dinaridic orogenic system: correlation and evolution of tectonic units.– Swiss J Geosci, 101, 139–183. doi: 10.1007/s00015-008-1247-3

VAN DER TOORN, J., DAVIDOVIC, D, HADJIEVA, N., STRMBANOVIC, I., MÁRTON, I., KNAAK, M., TOSDAL, R., DAVIS, B. & HASSON, S. (2013): A new sedimentary rock-hosted gold belt in eastern Serbia.– Mineral deposit research for a high-tech world, 1–4, (2013), 691–694.

VON QUADT, A., PEYTCHEVA, I., CVETKOVIĆ, V., BANJEŠEVIĆ, M. & KOŽELJ, D. (2002): Geochronology, geochemistry and isotope tracing of the Cretaceous magmatism of East Serbia as part of the Apuseni-Timok-Srednogorie metallogenic belt. 17th Congress of Carpathian-Balkan Geological Association.– Geologica Carpathica, Special issue, 175–177.

VUJIĆ, S., GRUJIĆ, M., SALATIĆ, D., RADIVOJEVIĆ, S. & JELENKOVIĆ, R. (2005): Rudnik bakra Majdanpek: razvoj, stanje, budućnost [*Copper mine Majdanpek: development, state, future* – in Serbian, with and English abstract].– Planeta print, Beograd, 171 p.

ZIMMERMAN, A., HOLLY, J., STEIN & JUDITH L. HANNAH, KOŽELJ, D. BOGDANOV, K. & BERZA, T. (2008): Tectonic configuration of the Apuseni-Banat-Timok-Srednogorie belt, Balkans-South Carpathians, constrained by high precision RE-OS molybdenite ages.– Mineralium Deposita (2008), 43, 1–21. doi: 10.1007/s00126-007-0149-z

ŽIVKOVIĆ, P. (1987): Petrologija i alteracije ležišta Čoka Marin 1 [*Petrology and alterations of Čoka Marin 1 ore deposit* – in Serbian].– MSc thesis, Faculty of Mining and Geology, Belgrade, 46 p.