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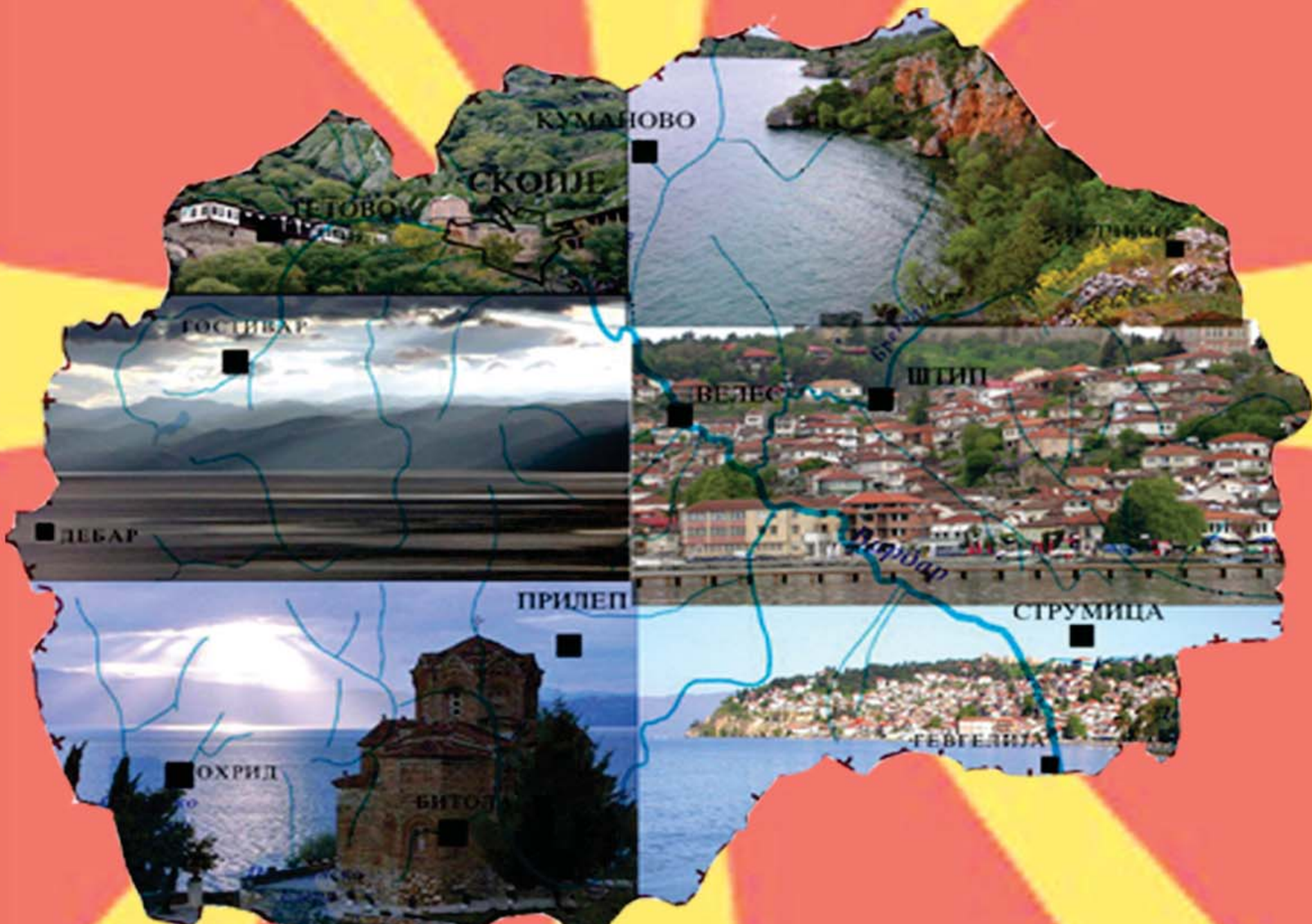
МАКЕДОНСКО ГЕОЛОШКО ДРУШТВО

ВТОР КОНГРЕС
на
Геолозите на Република Македонија

ЗБОРНИК НА ТРУДОВИ



Уредници:
Јовановски, М. & Боев, Б

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PORPHYRY Cu-Mo-Au-Ag-DEPOSITS OF THE NORTHEAST OF RUSSIA, COMPARISON WITH SIMILAR DEPOSITS OF THE R. MACEDONIA SEGMENT OF THE TETHYS BELT

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Abstract
By analogy with other metallogenic belts of the Circum-Pacific ring, the metallogenic belts in the Northeast of Russia are promising for discovery of large and superlarge porphyry-type Cu-Mo deposits. The spatial distribution of these deposits is controlled by intrusive domes in Middle Paleozoic, Late Jurassic-Early Cretaceous, and Late Cretaceous volcanic belts. New data on formation conditions and sources of ore matter are presented with respect to the deposits of the Baim and Koni-P'yagina ore districts of the Oloi and Uda-Murgal metallogenic belts. A comprehensive study of these porphyry copper deposits of both areas is undertaken to answer questions on the conditions of their formation. How do same of them differ from formation conditions of giant Cu-porphyry deposits?

Key words: comprehensive, study, copper, porphyry, formation.

INTRODUCTION

The forecasting, exploration, and evaluation of porphyry Cu-Mo deposits in volcanic belts in the Northeast of Russia is one of the most important current lines of research aimed at expansion of mineral resources of not only copper and molybdenum but also Au, Ag, and Pt-group and some other rare metals.

According to the modern concept, the largest metallogenic belts in the inner zone of the Circum-Pacific belt in northeastern Asia are controlled by accretionary and postaccretionary tectonic units superimposed on island-arc and oceanic terranes. Massive sulfide deposits of various types related to "green tuffs" were formed in these terranes, whereas porphyry Cu deposits, which are basic for several ore districts with epithermal Au-Ag and base-metal mineralization [1].

Under the current economic conditions of northeastern Russia, most of the known porphyry Cu-Mo deposits and occurrences are not promising for economic development. However, the metallogenic belts and zones where these deposits are located are extremely important in forecasting of potentially economic high-grade epithermal Au-Ag deposits.

Regularities in the distribution and formation mechanism of giant Cu-porphyry deposits have been discussed by many authors.

Deposits of the R. Macedonia discussed in this communication usually contain up to 150000 t of Cu with the Buchim deposits likely being the smallest in the world among similar recently mined deposits. The long-term economically profitable development of the latter refutes the traditional opinion that only Cu porphyry deposits with reserves at least of 2500000 t and Cu content exceeding 0.5% are profitable for exploitation. Therefore, complex study of dwarfish deposits of the R. Macedonia is as important as research into giant deposits of the Pacific ore belt for solving the problem of their formation mechanism and answering the question, how they differ compared to giant deposits.

A comprehensive study of these porphyry copper deposits of both areas is undertaken to answer questions on the conditions of their formation.

GENERAL OUTLINE OF Cu-PORPHYRY-TYPE DEPOSITS

Porphyry-type deposits are the main worldwide source of Cu and Mo; Au, Ag, and Pt-group and some other rare metals are recovered from this ore as by-products. Porphyry deposits are accompanied by numerous base-metal, Au-Ag, and Sb-Hg satellite deposits and placers and are important for the economic development of Chile, Peru, Uzbekistan, Kazakhstan, Mongolia, Armenia, Serbia, R. Macedonia, Bulgaria, Romania, and partly Mexico and Greece. Large and superlarge deposits of this type were recently found in Iran, Afghanistan, Pakistan, China, Mongolia, North and South America, Indonesia, the Philippines, USA, Canada, Australia, Papua New Guinea, and Russia; these deposits also will be involved in economic development. Porphyry deposits provide 20% approximately of the Au and Ag produced in the United States. Large Cu-porphyry deposits with average grades of 2 g/t Ag and 0.4 g/t Au are located in Arizona; their hypothetical resources are estimated at 80 Mt Cu.

The Bingham ore district in Utah ranks first in mining Cu and second in mining Mo. In 1890–1971, the Bingham porphyry copper deposit yielded about 31 kt Ag and 300 t Au, including 800 t Ag at a grade of 2 g/t in 1970 alone. As much as 4 kt Ag and 55 t Au were produced over the same period from base-metal ore of this district [2].

According to Krivtsov et al. [3], porphyry deposits are classified by Ag grades into: (I) Mo deposits virtually devoid of Ag, (II) Mo–Cu deposits with <1 g/t Ag, (III) Cu–Mo deposits with <1 to a few grams per ton Ag, and (IV) Ag–Cu deposits that commonly contain a few tens of grams per ton Ag. Although the Ag grade of porphyry copper ore is extremely low (no higher than 5–6 g/t, on average, and commonly 0.3–3.0 g/t), the bulk of silver produced is considerable owing to the enormous mass of ore involved in processing. Associated veins with high Ag and Au grades are often regarded as independent noble metal deposits.

In terms of Cu, Mo, Au, and Ag reserves, porphyry deposits are referred to as large and superlarge (100–1000 Mt of ore or more) with low and medium grades: 0.3–1.5% Cu, 0.001–0.05% Mo, 0.03–1.0 g/t Au, and 1–6 g/t Ag [4].

The deposits vary from Precambrian to Quaternary in age; Mesozoic and Cenozoic deposits are predominant; the latter prevail in the Pacific ore belt [4]. The classic porphyry copper provinces were formed in geodynamic settings of continental volcanic belts and volcanic island arcs.

The most important characteristics of porphyry systems [5, 6, 7] are as follows:

(1) Occurrence of ore-bearing minor porphyry intrusions (<2 km in diameter) composed of calc-alkaline and potassic, moderately alkaline rocks. The ore is also hosted in volcanic, sedimentary, and other country rocks. Coeval andesitic and dacitic volcanics are common for island arcs, while potassic, moderately alkaline rocks are typical of the continental setting.

(2) Hypabyssal depth of ore formation (1–4 km).

(3) Porphyritic texture of ore-bearing intrusions, where phenocrysts of feldspar, quartz, and dark-colored minerals are incorporated into a fine grained groundmass.

(4) Numerous intrusive phases may be pre-, syn-, and postore; late diatremes are typical of the West Pacific deposits.

(5) Progressive evolution of a steep ore-bearing stockwork from the early, short, and irregularly arranged veins and veinlets closely related to emplacement of intrusions via transitional veins lying in one plane to the late through veins and breccia bodies related to regional and local stress fields.

(6) Extensive development of metasomatic alteration and ore mineralization controlled by fractures in porphyry intrusions and country rocks.

(7) Several stages of hydrothermal alteration that develop progressively from early potassic and propylitic alteration to phyllic (sericitic) and intermediate and advanced argillic alteration.

(8) Sulfides and oxides vary from bornite and magnetite in the early mineral assemblages to transitional chalcopyrite and pyrite to late pyrite and hematite, pyrite and enargite, and pyrite and bornite.

(9) Cu–Au (Mo, Ag) is the major (economic) assemblage of metals; the Pb–Zn (Ba, Mn) assemblage also may be of economic importance; Mo is typical of central portions of continental deposits and marginal parts of island-arc deposits. Au is visible and submicroscopic and also occurs as electrum.

(10) The early metasomatic rocks and related Cu mineralization are generated by magma-derived hydrothermal fluids with a salinity of 30–60 wt % NaCl equiv at a temperature of >600 to 400°C. The fluids responsible for the formation of the late metasomatic alteration and ore mineralization contain a meteoric

component; they are less saline (<15 wt % NaCl equiv) and low-temperature (400–200°C). The host intrusions serve as a source of heat.

(11) The topology of the subducted plate controls ore mineralization in the overriding island arc. The subduction-related deformational setting gives rise to thickening of the crust, block uplifts, and faulting and fracturing favorable for development of ore mineralization.

DISTRIBUTION OF Cu-PORPHYRY DEPOSITS OF THE NORTHEAST RUSSIA

The promising porphyry Cu-Mo deposits and occurrences in the Northeast of Russia make up metallogenic belts of various ages (Fig.1). More than 110 Cu-Mo-porphyry deposits and occurrences are shown in the metallogenic map of the Northeast of Russia.

The specific metallogenic features of these belts are caused by tectono-magmatic reactivation in the transitional zone from ocean to continent and, in particular, are related to the formation of the Late Cretaceous marginal continental Okhotsk-Chukotka volcanic--plutonic belt (OChVB), which is superimposed on Triassic and Jurassic island-arc and cratonic complexes that were formed above seismofocal (paleosubduction) zones that plunge down to a depth of 600−700 km.

The Kedon metallogenic belt coincides with the Middle Paleozoic volcanic belt of the same name in the Omolon Cratonic Terrane (Fig. 1). Volcanic rocks of the Kedon belt overlap the Archean-Paleoproterozoic basement and its Phanerozoic sedimentary cover. The Rb−Sr age of volcanic rocks belonging to the Kedon Complex is 334−377 Ma [8].

The ore mineralization of the marginal continental volcanic-plutonic belt was formed in the Omolon Terrane during the Middle Paleozoic stage. Lateral zoning is expressed in localization of Cu-porphyry deposits in the east, epithermal Au-Ag deposits in the transitional zone, and Au-bearing jasperoids in the west.

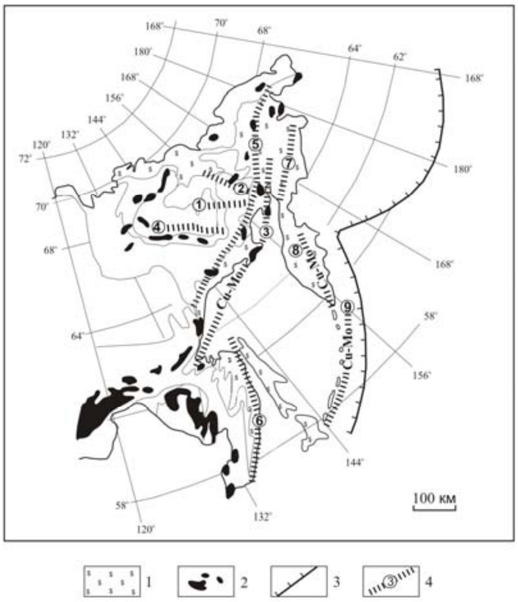

Figure 1. Porphyry Cu-Mo metallogenic belts in the marginal-sea province of northeastern Asia.
(1) Areas of volcanic rocks; (2) plutonic rocks; (3) deepwater trench; (4) porphyry Cu-Mo metallogenic belts (numerals in circles): (1) Kedon, (2) Oloi, (3) Uda--Murgal, (4) Yasachnaya River, (5) Okhotsk--Chukotka, (6) East Sikhote-Alin, (7) Koryak, (8) Central Kamchatka, (9) Kuril.

The Oloi metallogenic belt is controlled by an Early Cretaceous island arc system situated between the South Anyui and Omolon terranes (Fig. 1). Most of it is now located at the interfluves of the Oloi and Greater Anyui rivers, extending in the northwestern direction for 400 km at a width of 200 km in the central segment. The U-Pb zircon age of magmatic zircons from the Yegdegkych pluton is 141.8$\pm$2.0 Ma [9]. Numerous porphyry Cu-Mo and epithermal Au-Ag deposits are related to the island-arc magmatism. Cu-Mo stockworks are localized largely in stocks and minor intrusions of the gabbro-monzonite-syenite association, while epithermal Au-Ag veins develop at their periphery. Widespread magnetite and occurrence of Co and Pt minerals are typomorphic attributes of ore mineralization in the Oloi metallogenic belt.

The Uda-Murgal metallogenic belt is related to the inner zone of the OChVB and is controlled by the continent margin and the boundaries of the paleoisland arc that bears the same name [10]. The island-arc rocks are traced now near the left bank of the Uda River, on the Koni-P'yagina and Taigonos peninsulas, and in the basins of the Penzhina and Anadyr rivers (Fig. 1). The island arc is composed of tholeiitic basalts and basaltic andesites, including lavas, tuffs, tuffaceous breccias and siltstones; felsic rocks amount to 4%. The total thickness of this sequence varies from 3 to 7 km. The volcanic and sedimentary rocks were deposited on an uplift bordered by marine troughs like the Greater Kuril Islands [10].

The large area of porphyry Cu-Mo deposits coincides with the frontal zone of the OChVB, superimposed on the terrigenous-volcanic complex of the marginal continental arc, which is highly deformed and locally thrust over the continent.

The Okhotsk-Chukotka metallogenic belt, which comprises numerous volcanogenic deposits, extends for more than 3500 km along the eastern margin of the Asian continent and coincides with the Late Cretaceous-Paleogene volcanic-plutonic belt of the same name and its perivolcanic zone. The following types of ore mineralization are known in this belt: porphyry Cu-Mo deposits; epithermal Au-Ag veins; Au-sulfide impregnations; Au-mineralization related to granitoids; Sn- and Ag-bearing base-metal mineralization of vein, skarn, and porphyry types; and Hg- and Au-Sb-bearing veins. The belt consists of several metallogenic zones; porphyry Cu-Mo deposits are known in some of these zones. However, in most zones, no works aimed at prospecting for Cu-porphyry-type ore have been conducted.

GENETIC FEATURES OF NORTHEEAST RUSSIA CU-PORPHYRY MINERALIZATION

The Cu-Mo porphyry systems of the Koni-P'yagina ore district of the Uda-Murgal metallogenic belt were formed in a crust of transitional type in the course of active interaction of Early Cretaceous igneous complexes with Triassic and Jurassic island-arc rocks. The massive sulfide lodes hosted in island-arc complexes in the basement of younger volcanic and plutonic belts were sources of copper, as can be clearly seen from relationships of tonalites with the Triassic-Jurassic sequences of basalts and basaltic andesites in the coastal cliffs of the northern Okhotsk region. Numerous xenoliths of basaltic rocks that contain as much as 50% sulfides (bornite, chalcocite, and chalcopyrite) are especially striking in this respect (Fig. 2).

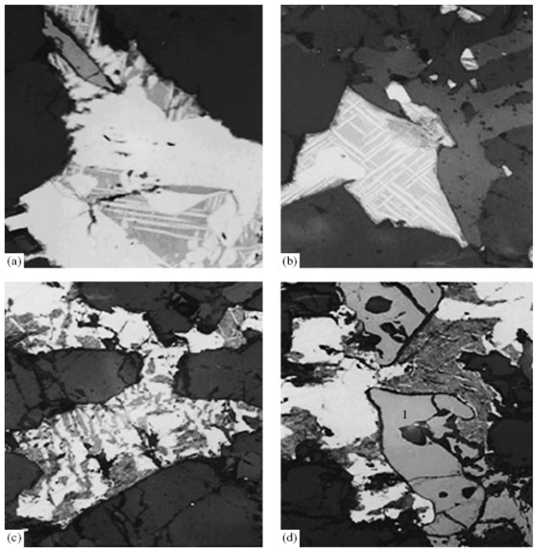

Figure 2. Cu-mineralization in xenoliths of the Ryabinovy stock. Polished sections, magn. 120.
(a, b) Exsolution structure of bornite in chalcopyrite; (c) intergrowth of bornite, chalcopyrite, and chalcocite; (d) the same in intergrowth with magnetite (1).

The geochemical specialization of Cu-porphyry ore also indicates its cognation with basalts; in particular, Cu reveals the closest correlation to chrome. The gain of molybdenum most likely was related to felsic volcanic and granitoid plutonic complexes. Indeed, porphyry Mo-deposits devoid of Cu (Oksa, Osenny) appear at a distance from island arcs and backarc faults limit the occurrence of copper mineralization.

Early magnetite is abundant at the deposits of the Oloi metallogenic belt. Furthermore, quartz-hematite veins were formed at the late hydrothermal stage in the Baim ore district [11]. V.G. Kaminsky suggested that magnetite at the Peschanka giant (8000000 t Cu, 435 t Au, 5000 t, Ag) porphyry deposit is a product of crystallization of the Yegdegkych pluton. Goryachev, Polovinkin [12] explained the occurrence of magnetite in the Innakh ore field by auto-metasomatic alteration that accompanied crystallization of magmatic melt. In our opinion, magnetite and hematite could have been formed as a result of remobilization and redeposition of iron from jaspilites that occur in the Precambrian basement of the Oloi-Berezovsky paleoceanic arc. This suggestion is supported by widespread jaspilites and magnetite skarn bodies in the Precambrian metamorphic sequences of the Omolon Cratonic Terrane adjacent to the arc. Blocks of Precambrian rocks may have been incorporated into the basement of this arc due to their displacement in the process of accretionary thrusting.

The evolution of an ore system and formation of an entire series of mineral deposits implies multiple redistribution of materials, so that newly formed minerals inherit and retain in their composition information on the preceding stages.

The well-known Dzhul'etta epithermal Au-Ag deposit (50 t Au; 1000 t Ag) may be cited as an example. This deposit is localized at the junction of three metallogenic units: the Omsukchan zone with a Sn, Ag, Fe, Pb, and Zn geochemical profile; the Yana-Kolyma Au-Ag-As metallogenic province; and the Uda-Murgal Cu-porphyry metallogenic belt. Their influence was imprinted on the mineralogical and geochemical specialization of the post-accretionary ore at the Dzhul'etta deposit, first of all, in the productive mineral assemblages: (I) electrum-fahlore, (II) polybasite-pearceite (Pb, Zn, Fe, Au, Ag, Cu, As, Sb), and (III) kustelite-acanthite (Au, Ag, Se).

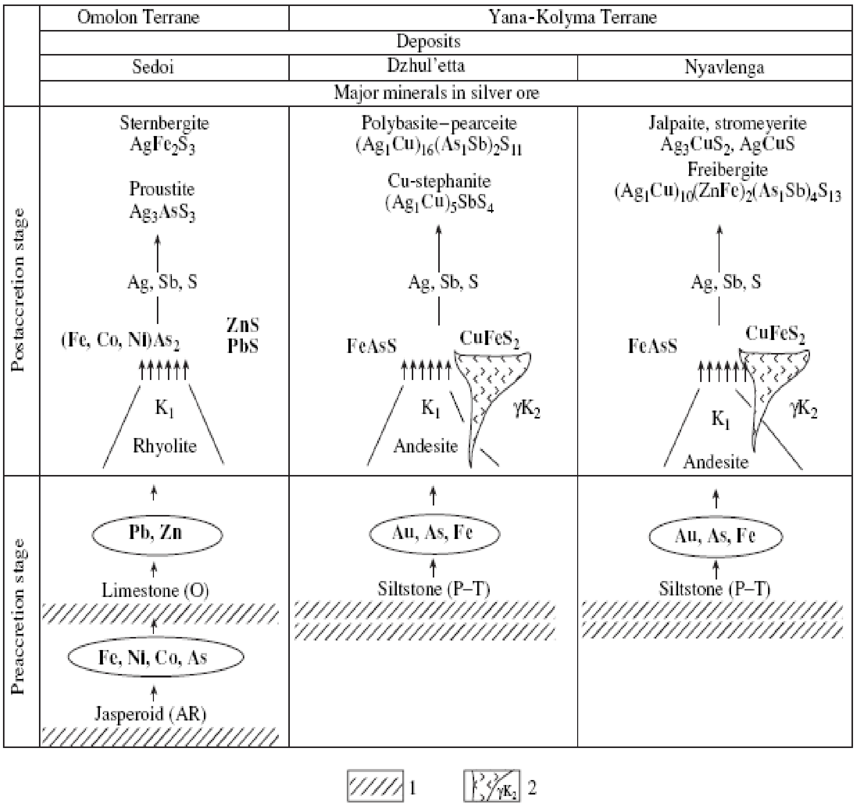

Figure 3. Mobilization and redistribution of material in rocks lying at the base of volcanic structures. (1) Sedimentary country rocks; (2) Late Cretaceous granitoids.

In terms of mineral species, this effect was expressed in development of As and Cu mineral phases (Fig. 3): polybasite (up to 2.5% As), pearceite (up to 10.5% Cu), and acanthite (up to 4% Cu and 3.4% As).

The second example concerns the Nyavlenga multistage epithermal Au-Ag deposit (30 t Au, 600 t Ag), situated 40 km west of the Dzhul'etta deposit. Upper Jurassic preaccretionary rocks of the Yana-Kolyma metallogenic province serve as the basement of the volcanic edifice that hosts the Nyavlenga deposit. These rocks are characterized by elevated contents of Au, As, Pb, and Zn. The gain of these components from the basement is reflected in a high As content of freibergite; high total sulfide contents, including galena and sphalerite; and development of the late quartz-arsenopyrite assemblage. The effect of the Uda-Murgal belt on the ore mineralization at the Nyavlenga deposit is expressed in the intramineral granitoid injections specialized for Cu and Mo and in the abundance of molybdenite, as well as Cu-

Ag sulfides (stromeyerite, jalpaite, and mckinstryite), in the Au-Ag ore (Fig. 3).

In the Omolon Cratonic Terrane, Paleoproterozoic jaspilites enriched in Fe, Co, and Ni, as well as Neoproterozoic-Lower Paleozoic carbonate rocks with dispersed Pb and Zn, exerted an influence on the composition of epithermal ores. These rocks were accreted in the Middle Paleozoic (the Kedon Group of volcanic rocks) and in the Mesozoic along the Konginsky Fault.

The epithermal Au-Ag and Ag-bearing base-metal deposits are localized in the young volcanic structures. Furthermore, it was established that the model isotopic age of Pb in galena from the Mesozoic deposit corresponds to the age of the basement: the Ordovician at the Sedoi occurrence and the Neoproterozoic in the Pravaya Vizual'naya area [9]. The concentrations of Co and Ni in loellingite of the productive assemblage reach 1.4 and 3.2 wt %, respectively. Sternbergite and argentopyrite are predominant as Ag mineral species (Fig. 3).

The examples cited above demonstrate that, in contrast to the Baim zone, the epithermal Au-Ag mineralization in the OChVB, to a certain extent, is isolated in time from the porphyry copper-molybdenum mineralization. Thus, the crustal sources of ore matter likely were different.

DISTRIBUTION Cu-PORPHYRY DEPOSITS OF THE R. MACEDONIA

The Cu porphyry deposits studied belong to the Lece–Chalkidiki metallogenic zone located at the transition between the Serbian–Macedonian Massif and the Vardar zone, and are genetically connected with small Tertiary subvolcanic-alcalkaline stocks such as the Tulare in Serbia, Buchim and Borov Dol in Macedonia; Vakhi, Gerakario, and Potokerasia in Greece; and others. Among these massifs, only the Buchim deposit in Macedonia has been mined recently.

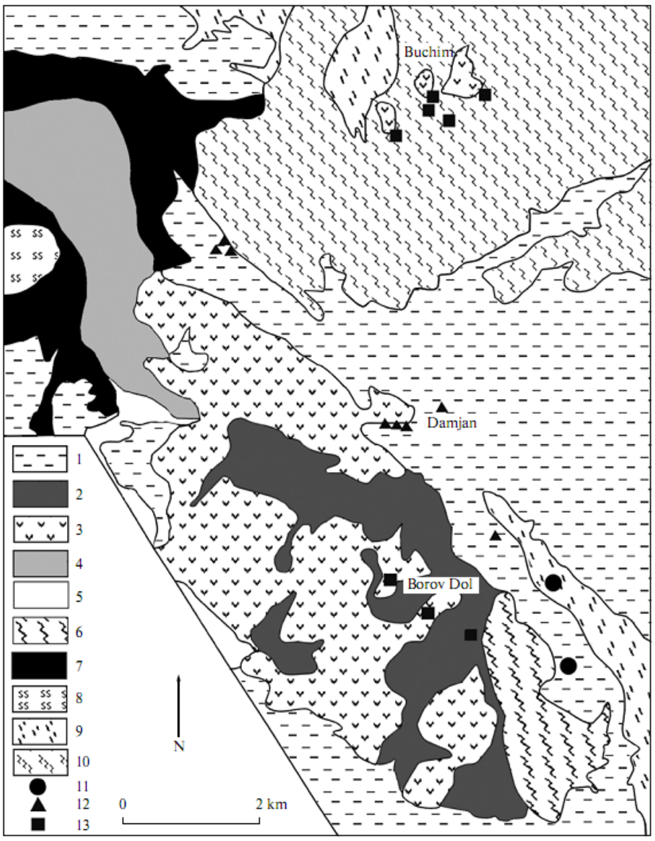

Figure 4. Geological map of the Buchim–Damjan–Borov Dol ore district. (1) Paleogene, Neogene, and Quaternary sedimentary rocks; (2) pyroclastic rocks; (3) andesite and latite; (4) Quaternary flysch; (5) carbonate rocks; (6) carbonate slate; (7) granite; (8) serpentinite; (9) muscovite schist, (10) gneiss; (11) Pb–Zn vein mineralization; (12) iron skarn mineralization; (13) Cu–Au porphyry mineralization.

The metallogenic features of the southern Balkan Peninsula are determined, on the one hand, by geodynamic evolution of the Tethys–Eurasian metallogenic belt (TEMB), which was defined by Jankovich et al [13] and, on the other, by old crystalline massifs. The belt was formed during the post-Mesozoic epoch instead of the Jurassic paleo-ocean Tethys, which was located between the southern continental margin of Eurasia in the north and the African–Arabian and Indian plates in the south.Volcanism in this region began in the late Oligocene, while ore mineralization is Miocene in age. Geochronological study by the K/Ar method revealed that andesites of the Damjan and Borov Dol fields were formed in the period of 28.0 to 26.5 Ma ago, while andesite stocks of the Buchim ore field appeared between 27.0 and 24.5 Ma ago [14].

The Buchim ore field is located in the northern part of the ore district in the Serbian–Macedonian Massif. The outer part of these structures is composed of gneisses, and their central parts are represented by latite stocks (Fig. 5).

The Buchim deposit is known from ancient times, although it was explored in detail only in the 1970s.

The Damjan ore field is located in the central part of the ore district in the Vardar zone 5 km south-west of the Buchim mine (Fig.4).

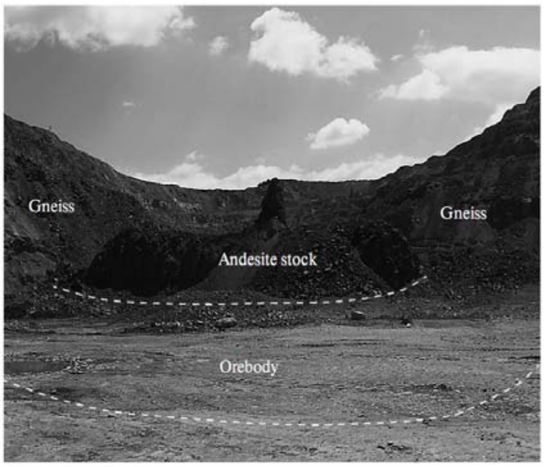

Figure 5. Open pit in the Central ore body at the Buchim deposit.

The important metallogenic feature of this ore district is the lack of economically significant Cu and Au concentrations in scarns of the Damjan deposit.

The Borov Dol ore field is located in the southernpart of the ore district in the Vardar zone. The volcanic caldera hosting this deposit is 5 km across being well developed in the district morphostructure (Fig. 4).

In addition to the above mentioned deposits, the northern part of the district hosts numerous ore occurrences with Cu porphyry mineralization: Vranjak, Orljak, Crn–Vrv–Kalapetrivci, Kosevo, Kosevska Reaka,and others.

GENETIC FEATURES OF THE RM Cu-PORPHYRY MINERALIZATION

Volcanics of the district represent derivatives of intermediate–acid magmas with relatively high alkali contents, which are highly differentiated from basic to highly acidic and calc-alkaline varieties. They belong to the high-potassic series being represented by andesites, latites, trachytes, rhyolites, and transitional rocks [14].

Previously, it was thought [15] that the parental magma of the volcanogenic–intrusive complex in the Serbian–Macedonian metallogenic zone resulted from partial melting of the continental crust in response to deep collision of continental blocks, which was intruded through a deep-seated fault into higher formations.

The subsequent analysis of $^{87}Sr/^{86}Sr$ isotope ratios and distribution of minor elements revealed that volcanic rocks of the study area resulted from mixing of material originating from the continental crust and upper mantle [16, 17]. In addition, it was shown [16] that by the concentrations of minor and trace elements the volcanics of the area are similar to their counterparts from active continental margins.

The original data (Fig.6) indicate that differentiation of the magmatic melt yielded conditions favorable for different interactions between mineral components. Concentrations of trace and accessory elements imply fractionation of minerals during magmatic evolution. The spider diagram demonstrates distinct positive Th and Y anomalies and insignificant negative Nb and TiO_2 anomalies; anomalously high K_2O, Rb, Nb, and Sc contents characteristic of subduction related magmas are established for Sample 5 (Fig. 6).

Thus, the geochemical study of minor elements indicates that igneous rocks of the deposits under consideration were most likely formed in the transitional zone between the continental crust and the upper mantle.

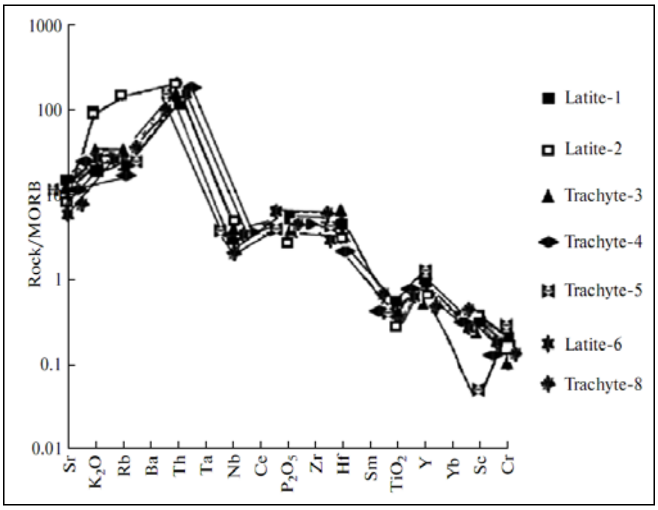

Figure 6. MORB-normalized trace element contents in volcanic rocks of the Buchim–Damjan–Borov Dol ore district. (1–3) Latite corresponding to nos. 1, 2, 6 in Table 3; (4–7) trachyte.

The study of stable isotopes is now used for obtaining more accurate information on the genesis of ore metals. The S isotope composition for the Buchim deposit was studied in 10 pyrite samples. As follows from the table, the S isotope composition in pyrite varies in narrow limits (+0.16 to +2.53‰ averaging +1.06‰ in all three ore bodies of the deposit with insignificant enrichment in the heavy isotope relative to meteorite sulfur. According to classification in [18], such a composition of S isotopes allows the Buchim deposit to be attributed to the category associated with felsite volcanics. As follows from these data, sulfur of the Buchim deposit is either of magmatic origin or was mobilized from sulfides of volcanic rocks. At the same time, the S isotope composition in the Borov Dol deposit is characterized by the dominant light S isotope ranging from 0 to –7 ‰ [14]. Such a difference in the isotope composition of sulfur from closely spaced deposits may be explained by their different geological structures. As was mentioned, the Buchim deposit is located in the Serbo-Macedonian Massif, while the Borov Dol deposit is confined to the Vardar zone. It is conceivable that sulfur of the Borov Dol deposit partly originates from host sedimentary rocks.

The study of $^{13}C/^{12}C$ and $^{18}O/^{16}O$ values in calcite from ores of the Buchim deposit demonstrates that water of the ore-forming fluid originates from several sources, including mainly meteoritic [19]. This inference needs, however, further verification.

The composition of fluid inclusions in quartz from the Buchim deposit indicates that ore-forming hyrothermal solutions were of the chlorite–sodium type with concentrations of salts varying from 10 to
25 wt % equiv. The NaCl and mineralization temperatures ranged from 49 to 200 °C. Ore components were transported in the form of complex ions, which contained Na and K chlorides and less common sulfates and carbonates [20].

In conclusion, an important metallogenic fact should be noted for the Buchim–Borov Dol ore district: lack of economically significant copper mineralization in magnetite–hematite skarns of the Damjan deposit, although they were formed at the contact between carbonate flysch rocks and subvolcanic andesites compositionally similar and coeval with rocks constituting stocks of the Buchim and Borov Dol deposits. It is quite conceivable that the upper part of the ore body with copper mineralization is eroded in the Damjan deposit. This is evident from the study of similar polymetallic skarn deposits in Karamazar [21], which demonstrate distinctly zoned patterns: the upper levels of these deposits host polymetallic mineralization, which is replaced downward by hematite–magnetite ores. This observation confirms the inference by Cifliganec [14], who believed, proceeding from metasomatic zoning, that the Buchim deposit was eroded up to its medium level and no erosion was characteristic of the Borov Dol deposit.

It is conceivable that a primary intrusive center served as a source of copper for the deposits under consideration. At the same time, subvolcanic intrusive bodies of these deposits are insufficiently large for mobilization of a quantity of copper from them by the hydrothermal convective system to provide its present day content in orebodies. Consequently, the magmatic source of copper was likely located at deeper levels and represented a relatively large intrusive body (Fig.7). It may be suggested that the significant volume of orebearing magma that formed the intrusive bode at a deep level could yield copper for a relatively large porphyry deposit, although the latter is missing in the entire Lece–Chalkidiki metallogenic zone, the district under consideration included.

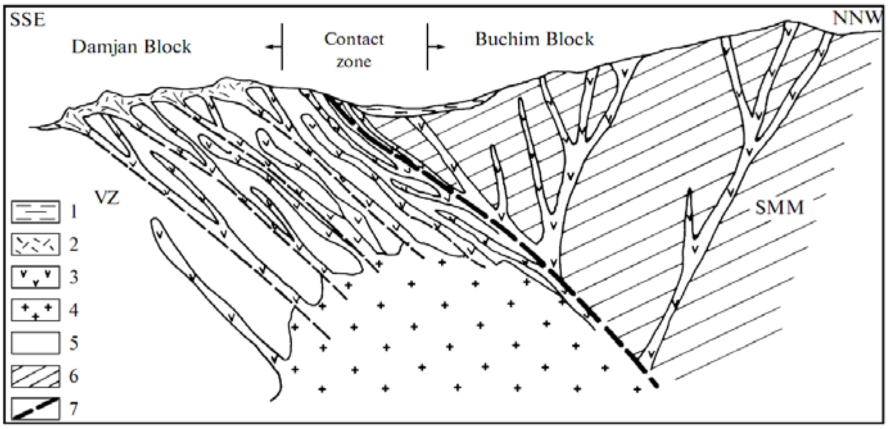

Figure 7. A model of magmatic system in the Buchim–Damjan–Borov Dol ore district. (1) Pliocene–Quaternary rocks; (2) volcanic rocks; (3) subvolcanic bodies; (4) granitoids; (5) ultramafic rocks, granitoids, Cretaceous and Paleogene rocks in rocks in the Vardar Zone (VZ); (6) gneiss, muscovite schist, and amphibolite in the Serbo-Macedonian Massif (SMM); (7) faults.

It is possible that some copper could have been mobilized from ultramafics occurring both in the Serbian–Macedonian Massif (amphibolites) and Vardar zone (peridotites and serpentinites), which were intruded by the Cenozoic magmatic complex. Such a possibility is more real since the Neogene calc-alkaline magmatic complex in the Serbian–Macedonian province is depleted in copper as compared with Cretaceous igneous rocks in the Bor area [16].

CONLUSIONS

The examples cited above demonstrate that the formation mechanism of same Northeast Russia and R. Macedonia porphyry copper-deposits very similar. Bat, the crustal sources of ore matter likely were different.

The hypothesis of copper remobilization from serpentinites and ultramafics of the Vardar zone or massive sulfide deposits of the Cyprus type is also supported by insignificant reserves and low concentrations of ore elements in the studied Cu porphyry deposits, which is characteristic of regenerated deposits [22]. The similar ore forming condition observed in the Lora and outer deposits of the Koni-P'yagina ore districts of the Northeast Russia (Volkov et al., 2006).

This likely represents the main feature, owing to which formation of dwarfish deposits differs from that of their giant counterparts.

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