Genetic model of the Cu-Au skarn mineralization at Karavansalija ore zone, Rogozna Mountain, Southwestern Serbia

ブディノフ, ディミトロフ, ジフコ

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論　文　要　旨

区 分	甲	氏　名	BUDINOV ZHIVKO DIMITROV
論文題名　Genetic model of the Cu-Au skarn mineralization at Karavansalija ore zone, Rogozna Mountain, Southwestern Serbia（セルビア南西部ロゴズナ山地カラバンサリヤ鉱化帯におけるCu-Auスカルン鉱化作用と成因モデル）			

論　文　内　容　の　要　旨

The Balkan Peninsula is an area, which has been a subject for prospecting and mining for more than 6000 years. The abundance and variety of ore deposits and occurrences within it have made mining a principal economic factor for all of the associated countries, since the Roman Empire period. The Cu-Au deposits are of principal significance for the economy of Serbia. Most of them are situated within the Apuseni-Banat-Timok-Srednogorie belt, characterized by Late Cretaceous magmatism. The current study area, however, belongs to another metallogenic belt, namely the Serbo-Macedonian magmatic and metallogenic belt, which is characterized by ubiquitous base-metal economic mineralization and Cenozoic magmatism. The current study focuses on the Cu-Au mineralization within the Karavansalija ore zone with emphasis on the ore mineralogy and paragenesis, the formation conditions and nature of the ore-forming fluid. Furthermore, to elucidate the nature and type of skarn mineralization, geochemical investigation on the related magmatic complex and the host rocks was performed.

Chapter 3 describes the textural, structural and geochemical characteristics of the magmatic complex at Karavansalija ore zone. The observation showed that it displays the typical features of the Cenozoic multi-phase volcanism of the Serbo-Macedonian belt. Two major magmatic units can be distinguished: a thick cover of volcanics and swarms of dykes, which intrude the cover as well as all other underlying lithologies. The Cenozoic magmatic rocks are with volcanic structure and show clear porphyritic character. Large phenocrysts of hornblende, biotite, quartz, plagioclase, pyroxene and quartz comprise up to 50% of the volume of the rocks within the dykes and about 10% of the volume of the volcanoclastics. Often the rocks display some additional textures such as micropoikilitic or dissolution on quartz. All of these textural characteristics imply extrusive to hypabyssal emplacement of the dykes. The geochemical investigation on the magmatic rocks, conducted through XRF and ICP-MS analyses revealed that they are intermediate to acidic with SiO_2 content in the range 53 to 69 wt% and are enriched in K_2O and depleted in Na_2O. Investigation of the results has shown that the studied rocks have quartz-trachytic to quartz-latitc character and are shoshonitic, demonstrate strong depletion of Nb, Ta and Ti, and enrichments in K, and Rb, and show high LILE (large-ion lithophile elements)/HFSE(high-field strength elements). While negative Eu anomaly is obvious within the dykes, the tuffs show controversial results regarding Eu. XRD analyses on oriented samples from the rocks reveal clay mineral assemblage composed predominantly by chlorite and illite and to lesser degree smectite and kaolinite. The chlorite is dominant in the magmatic rocks from the shallower levels, while in the deeper parts of the complex the illite becomes dominant.

Chapter 4 presents data related to the geochemistry and the nature of the skarn. XRD and EPMA analyses were used to define the mineralogy. The skarn mineral composition is represented by garnet, pyroxene (hornblende), epidote, actinolite, tremolite and chlorite. Based on the proportions of these minerals throughout the volume of the rock several types of skarn can be outlined: garnet, garnet-pyroxene, pyroxene and pyroxene-epidote skarn. The garnet is semi-transparent with dark core and sectorial darkening in the rims, likely due to later changes in its chemistry. The garnet is defined as grossular, with chemical composition grossular 42-77%, andradite 2-39% and almandine 18-20%.

Chapter 5 describes in detail the metalliferous mineralization. The targeted Cu-Au sulfide mineralization at Karavansalija ore zone proved to have more complex mineralogy than thought before. A typical gold-bearing skarns Cu-Fe-Zn-As-Bi metalliferous mineral assemblage was outlined with predominantly arsenopyrite, pyrrhotite, chalcopyrite, galena, sphalerite and pyrite recognised. The Cu-Au mineral occurrence can be divided into three groups: 1) unevenly spread concentrations of sulfide aggregates within the skarn, 2) vein-stockwork and/or disseminated form in epidosites adjacent to the skarn and 3) massive sulfide veins within the overlying tuff. The ore mineralization within the skarn and the epidosite is closely associated with the cobalt-nickel-bearing and bismuth-bearing sulfides. The EPMA results show that the cobalt-nickel-bearing minerals are represented mainly by gersodorffite, krutovite and cobaltite, as well as intermediate phases of the gersdorffite-krutovite mineral series. The bismuth-bearing phases are represented by bismuthinite and cosalite within the skarn and tsumoite in the epidosites. Gold is present both as native and as invisible within arsenopyrite. The relationship between the separate sulfide phases is quite complex. They belong to a single continuous ore-forming stage, which commenced with the formation of the sulfides within the epidosite before reaching the main stage, during which the aggregates, growth of Cu-Fe-Bi-As sulfides and gold were formed.

Chapter 6 presents fluid inclusion microthermometry data, arsenopyrite geothermometry data and sulfur isotope data with the aim to outline the temperature constraints of the ore precipitation and the origin of the ore-forming fluid. Fluid inclusions from druzy quartz (second generation quartz) paragenetically associated with the sulfides within the epidosites demonstrating homogenization temperatures of 276-386°C and fluid inclusions within calcite associated with the skarn sulfides show homogenization temperatures of 187-287°C. Fluid inclusions from rock-forming massive quartz from the epidosites have homogenization temperatures of 430-480°C, demonstrating that the ore-mineralization is post-skarn. These temperatures constrains are confirmed by the formation temperature for arsenopyrite, obtained through arsenopyrite geothermometry, indicating 255-360°C. The magmatic origin of the hydrothermal fluid(s) is confirmed by the relatively low values (-0.4‰ to +3.9‰ $\delta^{34}S_{CDT}$) of the sulfur isotope data for the major sulfide minerals.

Chapter 7 summarizes the results, obtained throughout the research and gives thorough discussion, based on them. The ore mineralization is strictly post-skarn, being precipitated in the temperature range of roughly 170-400°C, while the metasomatic alteration took place in the range of 400-500°C. In the targeted study area some of the characteristics of the ore mineralization, obtained through the fluid inclusion microthermometry data, such as the presence of several types of fluid inclusions and the absence of clear zonation patterns through the studied discrete crystals suggest that the most probable mechanism for the formation of the ore mineralization is mixing of at least two fluids. Boiling cannot be excluded as a secondary precipitation mechanism, but characteristics of the fluid inclusions, such as decreasing salinity with decreasing homogenization temperature and lack of low density fluid inclusions (the vapor phase within the studied fluid inclusions is rarely over 40%) suggest that it was not a primary precipitation mechanism. Within the span of the Serbo-Macedonian magmatic and metallogenic belt the ore mineralization from the studied area and the associated lithologies show a number of similarities with the well-known Pb-Zn-Ag and Fe deposits. Other than the presence of bismuth and gold minerals in economically potential quantities, the rest of the described mineral assemblage within the current study area is typical of the other deposits and furthermore good correlation of the sulfur isotope data was confirmed. Therefore, the source or the hydrothermal fluid and the associated to these deposits magmatic complexes and the current study area are likely the same. The Cu-Au skarn mineralization of Karavansalija ore zone can be classified as an oxidized gold skarn. This is based mainly on the relatively high grade (for skarn deposits) of Au (up to 4ppm), the presence of characteristic Py-Po-Aspy sulfide mineralogy, together with base-metal sulfides and chalcopyrite, high garnet/pyroxene ratio, has shown that the mineralization is strictly post-skarn.