ISSN 1075-7015, Geology of Ore Deposits, 2015, Vol. 57, No. 2, pp. 133–137. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © V. Stefanova, A.V. Volkov, T. Serafimovski, A.A. Sidorov, 2015, published in Geologiya Rudnykh Mestorozhdenii, 2015, Vol. 57, No. 2, pp. 148–153.

Native Gold of the Borovik Ore Field, Republic of Macedonia (FYROM)

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Received July 17, 2014

Abstract—Mineralogical and geochemical study has shown that native gold from the Borovik ore field, Republic of Macedonia (FYROM) is homogeneous in composition, high in fineness, and contains appreciable admixtures of Fe and Cu. The chemical composition of native gold does not depend on the morphology of gold grains that indicates closeness of primary source. The results are similar to previous data on gold geochemistry from the Borov Dol porphyry copper and the Plavica high sulfidation epithermal deposits. Electrum was found in placer gold neither in the Borovik ore field nor at the adjacent Plavica deposit. Pan sampling within porphyry copper and silver–gold high sulfidation epithermal deposits and ore fields allows identification and detailed study of the chemical composition and morphological features of native gold from deposits of these types. This procedure is recommended to be applied at prospect and prospect-and-evaluation works. The composition of native gold and morphology of gold grains predict high sulfidation epithermal mineralization in the Borovik ore field.

DOI: 10.1134/S1075701515020063

INRODUCTION

Mineralogical and geochemical study of native gold from impregnated porphyry copper and high sulfidation (HS) epithermal ores at most deposits is hampered because of the fine, frequently micron-scale grains and low (0.1 to 2.0 g/t) grades of this metal. Previous publications reported the results of the study of typical features of native gold from the Borov Dol porphyry copper and Palvica HS epithermal deposits in the Republic of Macedonia (Volkov et al., 2008; Stefanova et al., 2013). Native gold in pan samples selected from small ravines and creeks draining stockworks was studied at these deposits. This paper is focused on the results of studies of gold sampled by this procedure within the Borovik ore field.

GEOLOGY OF ORE FIELD

The Borovik ore field is located in the central Kratovo–Ztetovo ore district 60 km east of Skopje and 5 km northwest of the Palvica HS epithermal deposit (Fig. 1, insert). Base-metal mineralization was found within it in 1974–1975 as a result of areal prospecting by the Belgrade Geological Institute (Bogojevski, 1967).

The Kratovo–Zletovo ore district, spatially related to the homonymous volcanic area (1200 km^2), located at the boundary between the Serbo–Macedonian Massif and Vardar ophiolite zone (Dumurdzanov et al., 2005), is distinguished by the zoned distribution of various type base-metal and precious metal mineralizations (Cifliganec et al., 1997). This volcanic area comprises products of Oligocene–Miocene calc-alkaline magmatism (andsite, dacite, and their tuffs are predominant), which were intruded by the Pliocene basalt dikes.

The Borovik ore field is a part of large volcanic structure (Turalevo caldera), within which a few volcanic edifices are located (Borovik, Golak, Gradiste) (Fig. 1). Andesite flows are intercalated with thin tuff beds. This sequence is intruded by dikes and necks of augite andesite and porphyrytic diorite. All volcanic rocks are strongly altered to form hydrothermal quartzite, argillic rocks (illite, kaolinite, sericite), and jarosite rocks. Quartz–alunite lithocap covers hilltops composed of hydrothermal quartzite.

The ore field is located in the zone of the Balkan deep NNW-trending lineament separating the Vardar ophiolite zone and Serbo–Macedonian intermediate massif (Cifliganec et al., 1997). Therefore, faults of a similar trend are predominant within it. Some faults are indicated by the bodies of hydrothermal quartzite. Numerous thermal springs located along the Povisnica Valley (borehole no. 3 has a debit of 50 L/s and temperature of 50.8°C) are caused by recent tectonic activity along feathering faults. According to chemical analysis, water is sulfate–hydrocarbonate. The ther-

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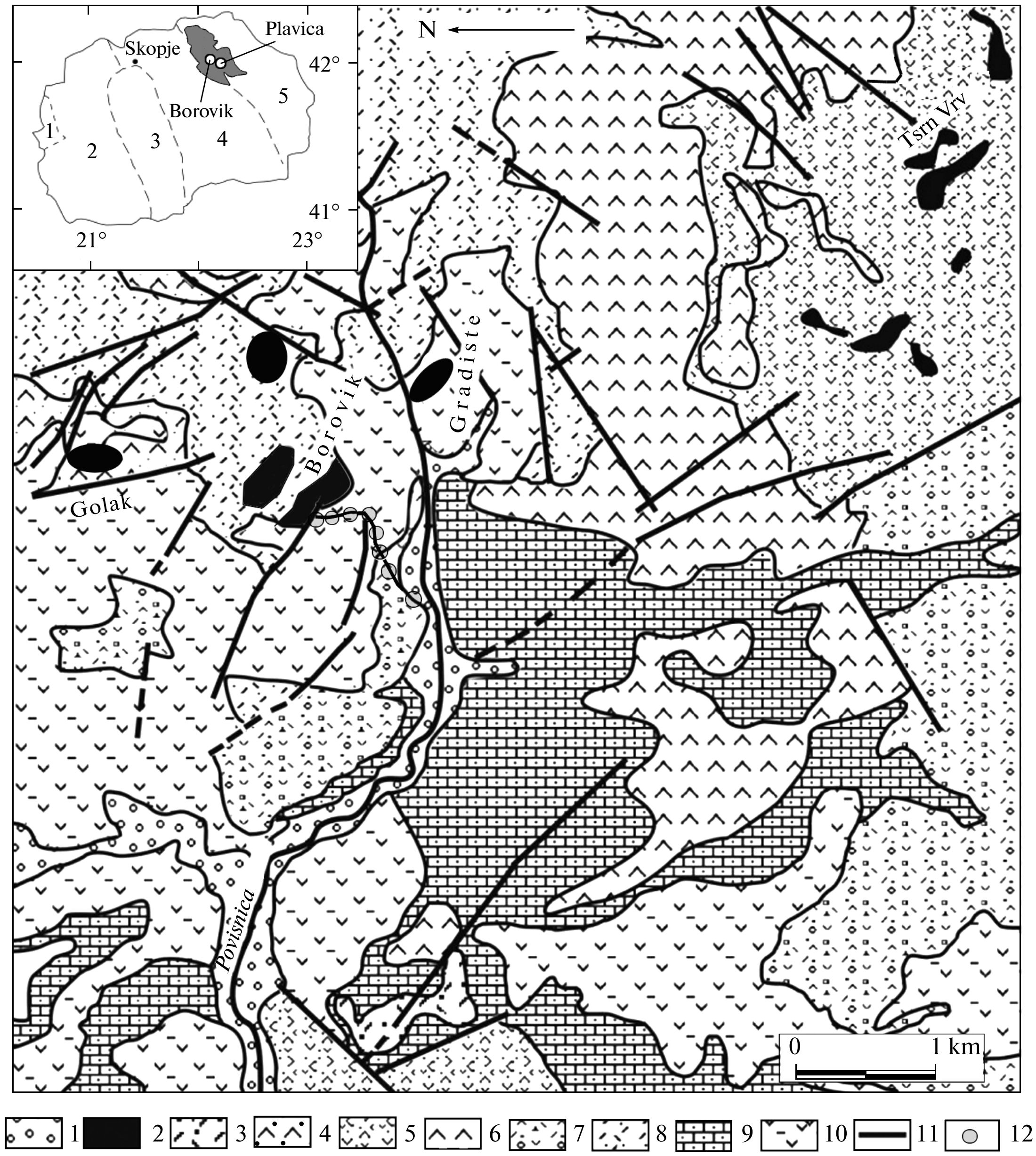

Fig. 1. Geological map of the Borovik ore field. Location of the Borovik deposit within the Kratovo–Zletovo volcanic field in the territory of Macedonia is shown in the insertion. (1) Alluvium, (2) hydrothermal quartzite, (3) hyaloandesite tuff, (4) hornblende–augite–biotite andesite, (5) andesite-dacite ignimbrite, (6) augite–hornblende–biotite–labradorite andesite, (7) volcanic breccia, (8) breccias and tuffstone, (9) green tuffstone, (10) hornblende–biotite–augite andesite, (11) faults, (12) location of pan sampling. In the insertion, numbers of zones correspond to the geological terranes of Macedonia, after Dumurdzanov et al. (2005): (1) Shukali–Krasta, (2) West Macedonian, (3) Pelagon Massif, (4) Vardar, (5) Serbo–Macedonian Massif.

mal springs are accompanied by the occurrences of native sulfur.

Pyrite is the most abundant ore mineral. It occurs in thin quartz veinlets of stockwork and altered wall rocks. In addition, chalcopyrite, galena, sphalerite, magnetite, hematite, molybdenite and occasional enargite, tetrahedrite, pyrrhotite, bornite, tenorite, cuprite, covellite, chalcocite, tennantite, cubanite, martite, malachite, and azurite were indentified in altered wall rocks.

According to the sampling of hydrothermal quartzite in the Borovik ore field, average Cu and Mo grade of is 0.1 and 0.025%, respectively, and that of Au is 0.19–0.49 g/t (Bogojevski, 1967). The highest gold grade (1.5 g/t) was identified in a sample from quartz–sulfide stockwork.

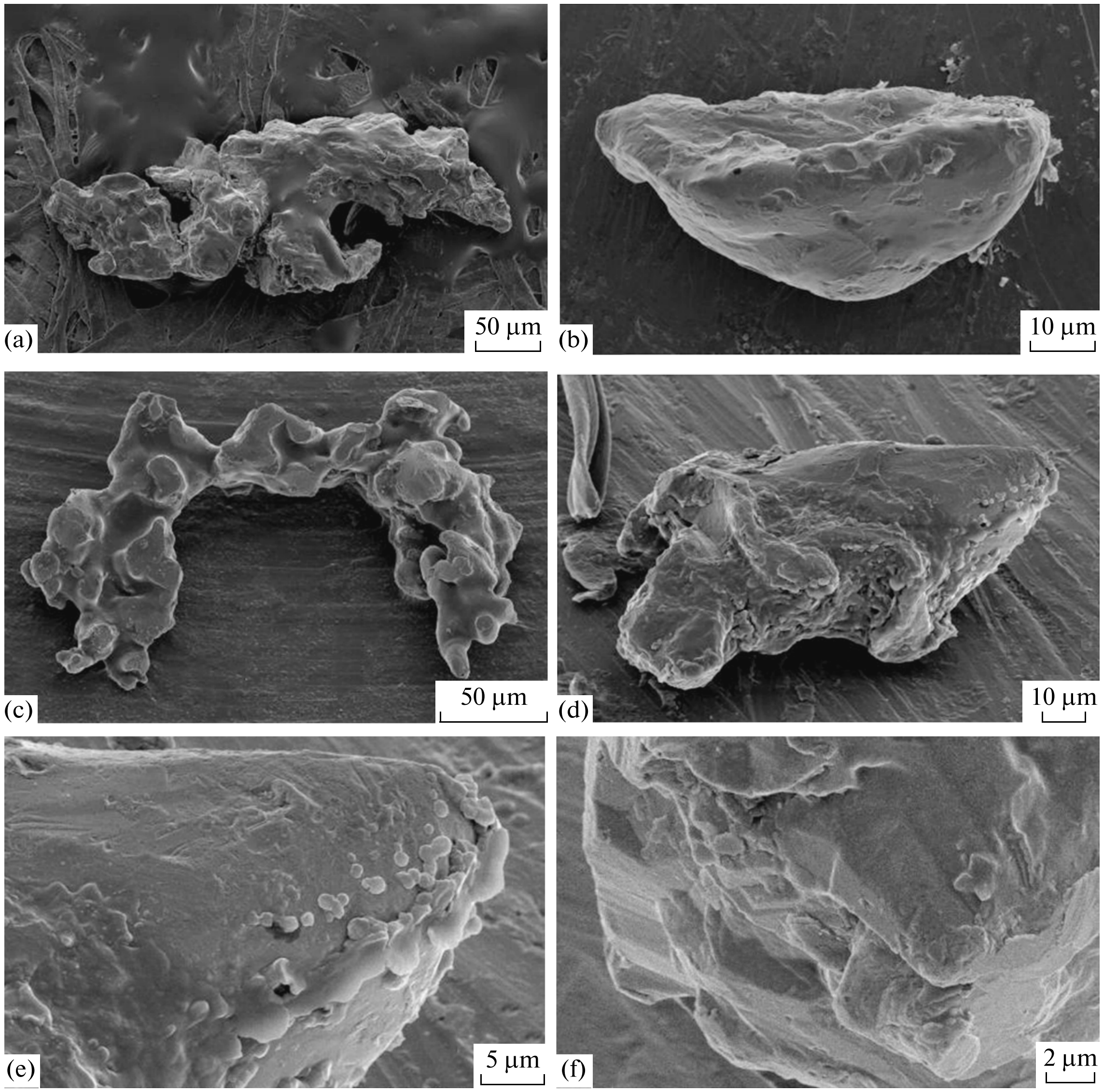

Fig. 2. Morphology of gold grains and their fragments from the Borovik ore field. (a) Crescent-shaped grain of native gold, (b) isomeric subrounded native gold, (c) dendritic native gold, (d) common elongated–isometric gold grains, (e) spherical aggregates of secondary minerals of the surface of the grain, magnified fragment of image d, (f) layered structure of native gold.

MORPHOLOGY, COMPOSITION, AND STRUCTURE OF NATIVE GOLD

The study of native gold from the Borovik ore field involved field and laboratory work. The former was pan sampling (according to the conventional procedure) of the creeks draining the ore field (Fig. 1). Eight pan samples were selected. Sixty-four grains of native gold were found in seven samples taken from the creek crossing the body of hydrothermal quartzite. In addition, feldspar, quartz, muscovite, epidote, abundant pyrite, and less frequent magnetite and chalcopyrite were identified in the pan samples. The number of native gold colors in the pan samples from the Borovik ore field is much higher than that at the other deposits studied in the Republic of Macedonia (Volkov et al., 2008; Stefanova et al., 2013).

The morphology of gold grains was studied on a JMS JEOL-5510 scanning electron microscope at the Electron Microscopy Laboratory of Chemistry Department, Sofia University, Bulgaria. The chemical composition of gold grains was determined on a JEOL LMS 35 CF electron microscope equipped with an X-Tractor Northern TN-2000 microprobe at the Sofia Institute of Photoprocesses, Bulgaria. The standards of the Jeol Company as pure metals were used for Au, Ag, Cu, and Fe. Detection limits for the elements (Au, Ag, Cu, Fe) are 0.01 wt %.

According to electron microscopy, the grains of placer gold ranges from 30 to 250 μm in size. Three morphological groups of gold grains are distinguished: isometric–elongated, irregular, and dendritic–laminar (Figs. 2a, 2b, 2c, 2d). It should be noted that very

Electron microprobe data of gold from the Borovik ore field, wt %

Number of sample	Point of analysis	Components				
		Native gold	Ag	Cu	Fe	Total
BK-2	1 core	98.52	–	0.71	–	99.23
	2 rim	99.10	–	0.62	–	99.72
	3 rim	99.02	–	0.46	0.28	99.76
	Average content	**98.88**	**0**	**0.59**	**0.28**	
BK-3	1 core	86.02	12.91	0.34	–	99.27
	2 rim	92.34	7.24	0.37	–	99.95
	3 rim	90.22	9.09	0.39	0.10	99.80
	Average content	**89.52**	**9.74**	**0.36**	**0.03**	
BK-4/1	1 core	99.02	–	0.48	–	99.50
	2 rim	99.53	–	0.42	–	99.95
	3 rim	99.41	–	0.56	0.09	100.06
	Average content	**99.32**	**–**	**0.48**	**0.03**	
BK-4/2	1 core	99.43	–	0.54	–	99.97
	2 rim	99.24	–	0.38	0.17	99.79
	3 rim	97.71	–	0.83	–	98.54
	Average content	**98.79**		**0.58**	**0.05**	
BK-4/3	1 core	98.68	–	0.47	–	99.15
	2 rim	99.94	–	0.50	–	100.44
	Average conten	99.46	–	0.77	–	100.23
BK-4/4	1 core	**99.36**		**0.58**		
	2 rim	99.08	–	0.33	0.16	99.57
	3 rim	99.24	–	0.69	–	99.93
	Average content	99.54	–	0.46	–	100.00
BK-4/5	1 core	**99.28**		**0.49**	**0.05**	
	2 rim	98.97	–	0.61	0.13	99.71
	3 rim	98.94	–	0.53	0.18	99.65
	Average content	98.59	–	0.70	–	99.29
BK-5/1	1 core	**98.83**		**0.61**	**0.10**	
	2 rim	99.41	–	0.52	–	99.93
	3 rim	98.72	–	0.78	–	99.50
	4 rim	98.86	–	0.60	0.17	99.63
	Average content	**98.99**		**0.63**	**0.05**	
BK-5/2	1 core	98.73	–	0.59	0.18	99.50
	2 rim	98.45	–	0.53	0.14	99.12
	3 rim	99.35	–	0.51	–	99.86
	Average content	**98.84**		**0.54**	**0.10**	
BK-6	1 core	99.26	–	0.66	–	99.92
	2 rim	98.70	–	0.41	0.10	99.21
	3 rim	98.54	–	0.66	0.23	99.43
	Average content	**98.83**		**0.57**	**0.11**	
BK-7	1 core	99.33	–	0.55	0.10	99.98
	2 rim	98.31	0.25	0.58	–	99.14
	3 rim	99.46	–	0.72	0.11	100.29
	Average content	**97.32**	**1.74**	**0.35**	**0.09**	
Borovik	**Average content**	**97.38**	**1.64**	**0.55**	**0.10**	

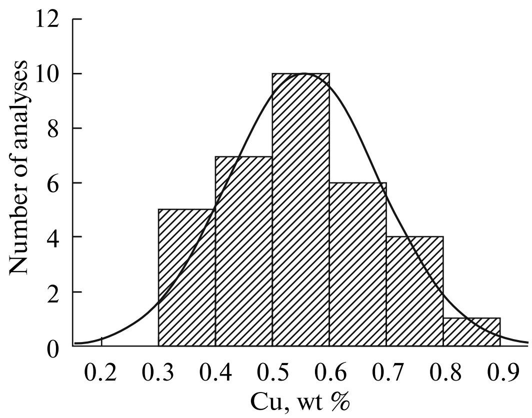

Fig. 3. Histogram of the Cu content in native gold of the Borovik ore field.

fine grains of native gold are irregular-shaped or isometric, and some grains are complex in shape. Native gold of the Borovik ore field is classified as very fine grains (Fig. 2) according to Petrovskaya (1973). Almost all grains of native gold are characterized by the layered structure (Fig. 2f). The morphology of gold grains (Figs. 2a, 2b, 2c, 2d) allows conclusion that the grains input from primary source (Zakharova, 1994).

Chemical composition of native gold. The electron microprobe data given in table indicate that native gold from the Borovik ore field is extremely high-fineness (up to 999, sample BK-4/3, see table) and belongs to the high-fineness variety (Table). The Ag content in native gold ranges from 0.25 (one grain, sample BK-7) to 12.91 wt % (sample BK-3, see table). The distribution of Ag in this grain is zoned: the core is rich in Ag (up to 12.91 wt %) as compared with the rim (7.24–9.09 wt %) (table). The similar zoning was established in the native gold from the Plavica and Borov Dol deposits (Volkov et al., 2008; Stefanova et al., 2013). Average Ag, Cu, and Fe contents in native gold are, wt %: 1.64, 0.55, and 0.1, respectively (see table). The Cu concentration in some grains of native gold ranges from 0.34 to 0.78 wt % and is normally distributed (Fig. 3). The Fe content in native gold is low ranging in some grains from 0.03 to 0.28 wt % (see table).

The results obtained are similar to previously published data on geochemistry of native gold from the Borov Dol porphyry copper and Plavica HS epithermal deposits (Volkov et al., 2008; Stefanova et al., 2013). Native gold of the Borovik ore field is distinguished by higher fineness and higher concentrations of Fe and Cu. Electrum was found in placer gold neither in the Borovik ore field nor at the adjacent Plavica deposit (Dumurdzanov et al., 2005).

CONCLUSIONS

Thus, native gold from the Borovik ore field is homogeneous in composition; it is very high-fineness and contains appreciable amounts of Fe and Cu. The chemical composition does not depend on the grain morphology, which indicates close primary source. The composition and morphology of native gold predict the HS-type epithermal mineralization in the Borovik ore field similar to that at the Plavica deposit. It should be noted that extremely rare published data on typomorphic features of native gold in the ores of porphyry copper and HS-type epithermal deposits (Serafimovsky et al., 2010; Nikolaeva et al., 2008) are consistent with our results.

Pan sampling within porphyry copper and HS epithermal silver–gold deposits and ore fields allows identification and detailed study of the chemical composition and morphological features of native gold from deposits of these types. This procedure is recommended to be applied at prospect and prospect-and-evaluation works.

ACKNOWLEDGMENTS

This study has been supported by the Russian Science Foundation (project no. 14–17–00170).

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Translated by I. Baksheev