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ORE GEOARCHAEOLOGY OF THE URALS METALLOGENIC ZONES

Рудная геоархеология исследует минерально-сырьевую базу древних обществ с помощью различных геологических дисциплин. Использованы данные по 3 металлогеническим зонам: Приуральской, Главного Уральского разлома и Магнитогорской. По составу хромитов определены источники сырья для ряда металлургических центров. Выявлены расплавные включения меди, халькозина и оловосодержащих фаз. Для определения источников золота важно изучение имеющихся в нем включений минералов группы осмия. Даны задачи дальнейших исследований.

The ore geoarchaeology studies the mineral base and metallurgical products (slags, bars, and metallic items) of ancient societies, using various geological disciplines and methods: economic geology, mining, ore mineralogy and petrography, geochemistry (including isotope geology), analytical researches, ore geophysics, and paleometallurgy. Our geoarchaeological research is based on proper geological and geoarchaeological data (slags, copper, bronze and gold items) from 30 archaeological monuments of the South Urals and those provided by colleagues from industrial and scientific organizations and universities.

The main objects (ancient mines) are located in the Cis-Urals, Main Urals Fault and Magnitogorsk metallogenic zones of the South Urals (Vorovskaya Yama, Ishkinino, Dergamish, and Ivanovka) and some of them were found by authors. The mines and ore-bearing areas were mapped and studied using geological, geochemical and micromagnetic surveys. We took part in excavations of the Arkaim, Alandskoye, Sintashta, and Kuysak ancient settlements and Bolshe-Karagansky, Alexandrovsky, and Kamenny Ambar burial mounds.

The mineral composition of the artifacts was studied on an Olympus BX-51 and Axiolab, Carl Zeiss optical microscopes and the chemical composition was analyzed on a REMMA 202M electron microscope and JEOL-733 microprobe, Perkin-Elmer 3110 atomic adsorption and INNOV-4000 X-ray fluorescent analyzers. The using of the compact non-destructive INNOV analyzer is very important for archaeological studies. The results of these works with descriptions of ancient mines, concentrating mills, and metallurgical kiln relics were included into geoarchaeological database. The composition of ores, mineral and melt inclusions in slags, and metallic items are shown in tables. These data show the distribution of the base metals in the ancient society at the studied territory.

Mining and extraction of copper ores. The ancient copper mines represent the open pits 80 m in diameter with vertical and inclined mines. The oxidized ores with malachite, azurite, bornite,

Table 1

Type of inclusions in slags and ores from the settlement the South Urals

Type	Malachite ores in ultramac rocks	Chalcocite ores in sulfide deposits	Sn-bearing ores
Mineral inclusions	Chromite in slags and clasts of ultramafic rock	Chalcocite and clasts of covellite	–
Melt inclusions	As- and Ni-bearing bronze regulus	Chalcocite-bearing regulus	Sn-bearing regulus
Compositions of ore	Azurite-malachite: Cu 3–8 %; Ni 0.1 %; Co 0.1%; As 1–3 %	Chalcocite Cu 5–20 %	Sn mixtures

tenorite and other minerals were mostly exploited. The sulfide ores were rare that is concluded from the compositions of the melt drops in the slags and mineral inclusions (covellite). Three main types of copper objects distinct in geological setting, structures of the orebodies, mineral and chemical composition, and mineral resources are distinguished in the South Urals:

1. Mines in the ultramafic rocks with Cu-, Ni-, Co- and As-bearing ores (Vorovskaya Yama, Ishkinino, Dergamish, Ivanovka);2. Mines in the rhyolite-basalt complexes of the VMS deposits and destroyed by the modern mining (e.g., Bakr-Usyak deposit); and

3. Mines at the contacts with granite intrusions (Elenovka tourmaline-malachite deposit).

Based on the composition of ore, mineral and melt inclusions, we can distinguish three main copper types, which were used during the Bronze Age at the South Urals: malachite ores in ultramafic rocks, chalcocite ores in sulfide deposits, and tin-bearing ores (table 1). The copper-tourmaline ores is a rare ore type.

The estimated resources of copper in the South Urals ancient mines are 70 thousand tons [Yuminov and Zaykov, 2010]. The Cu contents in ores (3–5 % for different mines) and coefficient of metallurgical extraction (min 50 %) are important for approximate estimation of the metal production [Kozlovsky, 1987]. Using these parameters, we may conclude that 1400 tons of copper were extracted from ores.

Ancient metallurgical slags and metallic items. We have studied the compositions of slags from 16 South Urals settlements. Several groups of slags are distinguished on the basis of composition, mineral and melt inclusions. According to XRF data, the main types are Cu-, Cr-, Co-, and Sn-bearing slags.

Chromite, chalcocite and covellite compose the major mineral inclusions in slags. A refractory mineral chromite (the melting temperature is 2180 °C) poorly reacts with a melting slag. The composition of chromite allows determination the source of the ore, which was used in different metallurgical centers. Chalcocite and covellite were found in slags from the Arkaim, Kamennyi Ambar and Konoplyanka settlements.

A few amounts of copper and As- and Sn-bronze melt inclusions were found. The first one is related to arsenide ores from the ultramafic-hosted Co-Cu-VMS and fahlore-bearing deposits (table 1). The Sn-bronze occurs as drops in the slags. Previously, these inclusions have not been revealed in the Urals metal-working products and their presence indicates exploitation of the Sn-bearing ores. According to geological data, Sn deposits of Kazakhstan could be the possible sources for Sn-bearing ores.

Mining of gold ores and jewel industry. The evidences for exploration of gold-quartz deposits and placers in the ancient mines are observed in the Kyzyl and Sakmara river basins in the Baymak ore region, Republic of Bashkortostan. The small ancient pits are characterized by the soot on walls. The stone stamps and mortars (stone plates 30 cm in diameter with a hollow in the centre) were found near the pits. The findings of the bronze and stone picks in the gold-bearing sands of the Miass, Kochkar and Berezovsk ore regions point to the exploration of placers.

The ancient jewelry was found in the Urals archaeological monuments in Orenburg and Chelyabinsk districts and Republic of Bashkortostan. The Filippovka, Perevolochan I, Magnitnyi, and Kichigino are the richest burial mounds. The gold deer and jewelry collection from the Filippovka burial mound, storing in the museums of Ufa and Orenburg, are most expressive [Yablonsky, 2008]. All items were made with a “Siberian animal style”. Various jewelry pieces and wire balls were found in the Middle Age workshop at the Ufa II settlement.

The composition of the archaeological gold is different. Three groups of gold fineness (high 980–860 ‰, intermediate 840–600 ‰, and low 550–370 ‰) are distinguished that may indicates the

Table 2

Composition of inclusions of osmium minerals in ancient gold products (South Urals)

№	**Place of sampling**	**No. of samples**	**No. of analyses**	**Artifacts**	**Average content (wt %)**			**Formula**
					Os	**Ir**	**Ru**	
1.	Filippovka II, burial mound № 4	№ 7–1	6	Cover plates	45.76	36.10	17.45	$Os_{0.40}Ir_{0.31}Ru_{0.29}$
2.		№ 7–2	10		34.54	29.30	27.66	$Ru_{0.42}Os_{0.28}Ir_{0.24}Pt_{0.06}$
3.		№ 7–3	7		35.28	29.20	27.63	$Ru_{0.42}Os_{0.29}Ir_{0.23}Pt_{0.06}$
4.		№ 7–4	1		57.58	14.82	27.02	$Os_{0.47}Ru_{0.41}Ir_{0.12}$
5.		№ 7–5	8		56.88	17.04	25.57	$Os_{0.47}Ru_{0.39}Ir_{0.14}$
6.		№ 7–6	7		55.07	8.97	35.42	$Ru_{0.51}Os_{0.42}Ir_{0.07}$
7.		№ 7–7	5		32.67	53.85	3.43	$Ir_{0.53}Os_{0.32}Pt_{0.09}Ru_{0.06}$
8.		№ 7–8	6		45.03	20.56	33.93	$Ru_{0.49}Os_{0.35}Ir_{0.16}$
9.		№ 7–9	7		37.23	29.91	26.88	$Ru_{0.41}Os_{0.30}Ir_{0.24}Pt_{0.05}$
10.		№ 7–10	5		35.12	58.52	2.26	$Ir_{0.57}Os_{0.35}Ru_{0.04}Pt_{0.04}$
11.		№ 7–11	5		56.53	10.16	32.78	$Ru_{0.48}Os_{0.44}Ir_{0.08}$
12.		№ 7–12	5		37,74	56,05	5,87	$Ir_{0.55}Os_{0.37} Ru_{0.08}$
13.		№ 7–13	3		79.45	12.64	7.58	$Os_{0.75}Ru_{0.13}Ir_{0.12}$
14.		№ 7–14	2		73.36	16.17	10.09	$Os_{0.68}Ru_{0.17}Ir_{0.15}$
15.		№ 7–15	3		72.60	16.83	10.29	$Os_{0.67}Ru_{0.18} Ir_{0.15}$
16.		№ 7–16	6		40.32	38.13	17.28	$Os_{0.35} Ir_{0.33} Ru_{0.29}Pt_{0.03}$
17.		№ 7–17	5		35.83	53.34	2.85	$Ir_{0.52} Os_{0.36} Ru_{0.05} Pt_{0.07}$
18.		№ 7–18	8		38.99	42.80	17,71	$Ir_{0.37}Os_{0.34}Ru_{0.29}$
19.	Filippovka II, burial mound № 1	103ab	2	Cover plates	13.56	81.25	4.12	$Ir_{0.78}Os_{0.13}Ru_{0.07}Rh_{0.02}$
20.		103de	2		22.93	72.68	2.90	$Ir_{0.70}Os_{0.23}Ru_{0.05}Rh_{0.02}$
21.		103jk	2		58.65	35.02	5.45	$Os_{0.56}Ir_{0.33}Ru_{0.10}Rh_{0.01}$
22.		73	4		38.92	50.23	2.39	$Ir_{0.50}Os_{0.39}Pt_{0.06}Rh_{0.03} Ru_{0.02}$
23.	Perevolo-chan-I	11.5.8	4	Cover plate	71,86	21,15	6,81	$Os_{0.68}Ir_{0.20}Ru_{0.12}$
24.	Yakovlev-ka II	Я-3	6	Pendant	71,85	24,21	3,71	$Os_{0.70}Ir_{0.23}Ru_{0.07}$
25.	Magnitny, burial mound № 21	M2-1	2	Hemisphe-rical plaques	40.06	50.27	7.34	$Ir_{0.45}Os_{0.36}Ru_{0.12}Fe_{0.06} Rh_{0.01}$
26.		M2-1-1	4		32.89	30.06	29.87	$Ru_{.43}Os_{.26}Ir_{.23}Rh_{.05}Pt_{.02}Fe_{.01}$
27.		M2-A	5		46.55	39.29	12.26	$Os_{0.41}Ir_{0.34}Ru_{0.21}Fe_{0.03} Rh_{0.01}$
28.		M-II	5		73.62	14.47	10.41	$Os_{0.67}Ru_{0.18}Ir_{0.13}Rh_{0.02}$
29.		M3-1	5	Triangle plaques	59.86	37.05	2.39	$Os_{0.59}Ir_{0.36}Ru_{0.04}Fe_{0.01}$
30.		M3-1-1	5		42.74	13.01	37.80	$Ru_{0.52}Os_{0.32}Ir_{0.10}Rh_{0.04} Pt_{0.02}$
31.		M-III	6		28.82	60.97	5.68	$Ir_{0.53}Os_{0.25}Fe_{0.13}Ru_{0.09}$
32.	Ushkata, burial mound № 12	Ук7	3	Pendant	64.82	34.11	0.47	$Os_{0.65}Ir_{0.34}Ru_{0.01}$

Low contents of Rh, Pt, and Fe are shown only in formulas. The analyzes were carried out on a REMMA 202 M electron microscope (analyst V.A. Kotlyarov) at the South Urals Center for Collective Use (IMin UB RAS, Miass). The artifacts were provided by L.T. Yablonsky (1–22, Orenburg, temporary storage 419, under restoration in State NIIR), S.V. Sirotina (23, 24), A.D. Tairov (25–31), and V.V. Tkachev (32) different metal sources. According to the chemical composition, the most gold items from Chelyabinsk and Orenburg districts and Republic of Bashkortostan contain 82–87 wt % Au (rare 61–67 wt %).

The wire with 97 wt % Au content was found in the jewel workshop of the Ufa II settlement. The Cu contents less than 3 wt % in the gold items is an alloying result. The items with higher (up to 9 wt %) Cu contents were produced with an artificial addition to the copper melt.

The finding of PGE minerals in the items from several archaeological monuments is the most important result of our study (table 2). The PGE minerals were identified in three groups of monuments: (i) Filippovka I and Ufa II mounds (western group of the South Urals), (ii) Perevolochan I and Yakovlevka II mounds (central group adjacent to the Main Urals Fault zone), and (iii) Kichigino I, Bolshoy Klimovsky, Stepnoy, and Ushkatta mounds (eastern group confined to the East Urals Fault zone in the area of the interfluves of the Ural and Tobol rivers). Three groups of chemical composition of 34 PGE mineral grains were distinguished on the basis of various contents of Os, Ru and Ir [Zaykov et al., 2011]. The most data points on the Os-Ru-Ir plot belong to the field of osmium from the Urals placers. Some compositions of PGE minerals from the studied mounds have no analogues in the corresponding deposits.

We have estimated the possible sources of gold and PGE minerals of the ancient jewelry. According to the round morphology and heterogeneous composition of the inclusions, they were extracted from the gold placers located in the Main Urals and East Urals Fault zones. These tectonic structures host Au-bearing ultramafic bodies with osmium mineralization and related placers. The composition of native osmium from the Urals placers and gold jewelry from all studied objects will be compared in order to identify the areas of extraction of gold for the jewelry.

Problems need to be solved in the future: (i) analysis of the metal resources of the ancient societies of various ages, (ii) study of structure of mines and ore composition from new mines; (iii) searching for the metallurgical workshops, which were operated in the Bronze and Early Iron Age; (iv) finding of mineral and geochemical indicators of sources of mineral deposits in the Urals and adjacent territories; and (v) identification of the boundaries of areas of mineral extraction, mining, and paleometallurgical production.

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