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PLATINOID MICROINCLUSIONS OF A NATIVE OSMIUM GROUP IN ANCIENT GOLD ARTIFACTS FROM SIBERIA AND THE URALS AS A SOURCE OF GEOARCHAEOLOGICAL INFORMATION*

An analysis of Early Iron Age gold jewelry from Khankarinsky Dol and Inskoy Dol in the Altai, the Arzhan II royal mound in Tuva, and the Filippovka I and II royal mounds in the Southern Urals, has detected platinoid inclusions similar to those in artifacts from the Near East. Their morphology and composition suggest that gold was mined from placer deposits located near the gold- and platinum-bearing ultramafic belts. Microinclusions consist of solid solutions of osmium, iridium, and ruthenium. Their nomenclature was determined according to the proportion of these components. Triangular diagrams of microinclusions in artifacts from the Urals reveal four clusters: principal (ruthenium and iridium-osmium) and minor (osmium-ruthenium and iridium-ruthenium), with the latter relating to Os-depleted nanoscale particles surrounding larger ones. Their emergence is due to the impact of molten gold on microinclusions. During melting, heated air in micropores could have caused oxidation of osmium with subsequent assimilation of oxidation products by the melt. Micropores, 1–0.4 μm in size, were revealed in 5–10 %. This should be taken into account when comparing the composition of microinclusions and minerals from tentative placer deposit sources. Artifacts from Siberia tend to contain mostly ruthenium. Osmium-ruthenium and iridium-osmium trends have also been detected, but not the iridium-ruthenium trend, possibly due to the small sample size in Siberia. The presence of platinoid microinclusions in ancient gold artifacts may suggest that these were manufactured locally.

Keywords: *Gold, platinoids, osmium, ancient gold jewelry, microinclusions, placer deposits, ultramafic belts, molten gold, nomads, Scythian age*

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Introduction

In recent years, we have identified and studied microinclusions of minerals belonging to a native osmium group from the family of platinoids in ancient gold objects of the Urals and Siberia, comparable with similar inclusions in the artifacts of the Near East (Meeks, Tite, 1980; Williams, Ogden, 1995: 14–15). The Ural findings, which had been discovered before 2009, were described in earlier studies (Zaykov, Zaykova, Kotlyarov, 2010). New materials, substantially enriching the information published (Blagorodnye metally…, 2012: 111–119) were obtained in 2012–2013 by the expeditions of the Institute of Archaeology of RAS (led by L.T. Yablonsky) and Altai State University (led by P.K. Dashkovsky).

This article is a comprehensive and systemic overview of the accumulated data in the context of their value for geoarchaeological reconstruction and identification of the type of gold deposits developed in ancient times. The main objects of research were gold artifacts found in significant amounts in the royal burial mound of Arzhan II (Tuva), as well as burial grounds of Khankarinsky Dol and Inskoy Dol (Altai), Filippovka I and II (Southern Urals). All of them belong to the Early Iron Age.

Microinclusions are represented by minerals of the osmium group—solid solutions of osmium, iridium, and ruthenium (Geologicheskiy slovar, 1973: 49). Their composition is shown in Tables 1 and 2. The numbers of samples used in the text below correspond to the numbers in the Tables. The nomenclature was established by the share of these components in the crystallochemical formulas (Harris, Cabri, 1991). The mineral was named in accordance with the prevailing element in the crystallochemical formula; its varieties were named in accordance with the subsequent elements (in order of content) and impurities (Kobyashev, Nikandrov, 2007: 117). For example, "ruthenium-iridium osmium with an admixture of platinum" would be $Os_{0.42}Ir_{0.37}Ru_{0.17}Pt_{0.04}$; "osmium-iridium ruthenium" would be $Ru_{0.38}Ir_{0.31}Os_{0.27}$.

Genetically, platinoids are associated with ultramafic rock ultrabasites (deposits of the Ural type) and mafic rock basites (the Norilsk type) (Godovikov, 1983: 23). The set of the platinoids and especially their ratios in these types are different. The prevalence of osmium and ruthenium is typical for the Ural-type deposits, which are confined to deep-seated faults also hosting gold deposits. The inclusions of osmium group minerals may indicate the association of the source of these platinoids with ultramafic belts or placer deposits, which emerged from them.

The methodology of the analysis has been previously described (Zaykov, Zaykova, Kotlyarov, 2010). Fineness was used for correlating gold with its sources. Fineness is defined as a ratio of gold content to the sum of all constituent metals (Au, Ag, Cu) and is measured in permille (Petrovskaya, 1973: 94). With some adjustments, the

Table 1. **Composition of platinoid microinclusions in gold objects from the burial mounds of Southern Siberia**

No.	Burial ground, burial mound	Object	Grain no.	Number of tests	Contents, weight percentage						Crystallochemical formula of the mineral
					Os	Ir	Ru	Rh	Pt	Fe	
1	Arzhan II	Inlay of iron sword	Ap-2-3-1	2	72.52	27.48	–	–	–	–	$Os_{0.73}Ir_{0.27}$
2	Khankarinsky Dol, Burial mound No. 15	Torc encasing foil	Xa-15-1a	3	32.24	37.71	24.68	–	5.12	–	$Ru_{0.38}Ir_{0.31}Os_{0.27}Pt_{0.04}$
3			Xa-15-16	3	42.12	46.71	10.68	–	–	–	$Ir_{0.43}Os_{0.39}Ru_{0.18}$
4		Onlay from a headdress	XD-15-2-1	4	59.03	1.94	37.14	–	–	–	$Ru_{0.53}Os_{0.44}Rh_{0.02}Ir_{0.01}$
5			XD-15-2-2	5	39.84	34.47	22.19	1.09	2.15	–	$Ru_{0.35}Os_{0.33}Ir_{0.28}Pt_{0.02}Rh_{0.02}$
6		Fringe of foil from a headdress	Xa-15-6	1	17.28	82.17	–	–	–	–	$Ir_{0.82}Os_{0.18}$
7			Xa-15-7	1	35.75	30.17	30.24	–	3.03	–	$Ru_{0.45}Os_{0.29}Ir_{0.24}Pt_{0.02}$
8		Sewn piece	Xa-15-8	1	45.71	39.83	9.65	–	4.41	–	$Os_{0.42}Ir_{0.37}Ru_{0.17}Pt_{0.04}$
9	Inskoy Dol, Burial mound No. 2	Foil	ID-5	6	51.74	37.47	8.63	0.81	0.81	0.26	$Os_{0.48}Ir_{0.34}Ru_{0.15}Rh_{0.02}Pt_{0.01}Fe_{0.01}$
10			ID-8	1	51.92	38.76	7.86	0.39	–	–	$Os_{0.49}Ir_{0.36}Ru_{0.14}Rh_{0.01}$

Notes: 1) Object No. 1 is from the excavations by K.V. Chugunov, objects No. 2–10 are from the excavations by P.K. Dashkovsky; 2) the analyses were made in the South-Urals Center for Collective Use using REMMA-202M electronic microscope (analyst V.A. Kotlyarov); 3) dash mark indicates the content below the detection limit.

Table 2. **Composition of platinoid microinclusions in gold objects from the burial grounds of Filippovka I and II**

No.	Burial ground, burial mound	Object	Grain no.	Number of tests	Contents, weight percentage						Crystallochemical formula of the mineral
					Os	Ir	Ru	Rh	Pt	Fe	
1	2	3	4	5	6	7	8	9	10	11	12
1	Filippovka I, Burial mound No. 1	Sewn pieces	F-13-2	2	31.03	29.50	33.27	2.48	3.36	–	$Ru_{0.48}Os_{0.24}Ir_{0.22}Rh_{0.04}Pt_{0.02}$
2			F-13-2-1	4	54.25	39.01	5.18	0.45	0.54	0.29	$Os_{0.52}Ir_{0.37}Ru_{0.09}Fe_{0.01}Rh_{0.01}$
3			F-13-2-2	4	18.38	52.09	27.72	0.79	–	0.78	$Ru_{0.41}Ir_{0.41}Os_{0.15}Fe_{0.02}Rh_{0.01}$
4			F-13-2-3	2	31.52	25.87	39.84	1.58	0.70	0.04	$Ru_{0.55}Os_{0.23}Ir_{0.19}Rh_{0.02}Pt_{0.01}$
5			F-13-3	1	41.08	32.30	21.70	1.59	3.02	–	$Ru_{0.34}Os_{0.34}Ir_{0.27}Pt_{0.03}Rh_{0.02}$
6			F-13-3-1	3	33.56	17.33	46.88	1.81	0.11	–	$Ru_{0.62}Os_{0.24}Ir_{0.12}Rh_{0.02}$
7			F-13-3-4	4	39.50	17.76	40.44	1.77	0.26	–	$Ru_{0.56}Os_{0.29}Ir_{0.13}Rh_{0.02}$
8			F-13-3-5-1	2	56.33	21.80	21.04	0.57	–	–	$Os_{0.48}Ru_{0.33}Ir_{0.18}Rh_{0.01}$
9			F-13-3-5-2	1	2.26	62.05	33.99	0.54	1.15	–	$Ru_{0.49}Ir_{0.47}Os_{0.02}Pt_{0.01}Rh_{0.01}$
10			F-13-3-9	4	61.14	13.65	19.65	1.91	3.00	0.14	$Os_{0.52}Ru_{0.31}Ir_{0.11}Rh_{0.03}Pt_{0.03}$
11			F-13-5-1	2	9.725	46.05	43.07	1.16	–	–	$Ru_{0.58}Ir_{0.33}Os_{0.07}Rh_{0.02}$
12			F-13-5-2	2	9.83	6.84	79.70	0.60	0.76	–	$Ru_{0.89}Os_{0.06}Ir_{0.04}Rh_{0.01}$
13			F-13-5-3	1	41.58	15.98	39.62	0.60	0.76	–	$Ru_{0.56}Os_{0.31}Ir_{0.12}Rh_{0.01}$
14			F-13-5-4	4	7.23	20.58	60.91	5.54	5.74	–	$Ru_{0.73}Ir_{0.13}Os_{0.05}Rh_{0.06}Pt_{0.03}$
15			F-13-8-1	1	30.22	28.36	39.46	0.84	0.22	0.68	$Ru_{0.55}Os_{0.23}Ir_{0.21}Rh_{0.01}$
16			F-13-8-2	1	7.09	34.31	57.49	0.49	0.02	0.24	$Ru_{0.72}Ir_{0.22}Os_{0.05}Rh_{0.01}Fe_{0.01}$
17			F-13-8-3	1	36.11	32.80	26.58	0.77	2.78	0.35	$Ru_{0.40}Os_{0.29}Ir_{0.26}Pt_{0.02}Rh_{0.01}Fe_{0.01}$
18			F-13-8-4	1	44.45	22.23	32.32	0.14	–	–	$Ru_{0.48}Os_{0.35}Ir_{0.17}$
19			F-13-8-5	1	34.51	48.43	16.40	–	–	–	$Ir_{0.42}Os_{0.31}Ru_{0.27}$
20			F-13-9-1	2	47.54	8.40	42.21	1.12	–	–	$Ru_{0.57}Os_{0.35}Ir_{0.06}Rh_{0.02}$
21			F-13-9-2	4	42.37	35.88	18.39	0.93	1.94	–	$Os_{0.36}Ir_{0.31}Ru_{0.30}Pt_{0.02}Rh_{0.01}$
22	Filippovka I, Burial mound No. 4	Inlay of iron sword	7-1	6	45.76	36.10	17.45	–	–	–	$Os_{0.40}Ir_{0.31}Ru_{0.29}$
23			7-2	10	34.54	29.30	27.66	–	8.06	–	$Ru_{0.42}Os_{0.28}Ir_{0.24}Pt_{0.06}$
24			7-3	7	35.28	29.20	27.63	–	7.36	–	$Ru_{0.42}Os_{0.29}Ir_{0.23}Pt_{0.06}$
25			7-4	1	57.58	14.82	27.02	–	–	–	$Os_{0.47}Ru_{0.41}Ir_{0.12}$
26			7-5	8	56.88	17.04	25.57	–	–	–	$Os_{0.47}Ru_{0.39}Ir_{0.14}$
27			7-6	7	55.07	8.97	35.42	–	–	–	$Ru_{0.51}Os_{0.42}Ir_{0.07}$
28			7-7	5	32.67	53.85	3.43	–	9.50	–	$Ir_{0.53}Os_{0.32}Pt_{0.09}Ru_{0.06}$
29			7-8	6	45.03	20.56	33.93	–	–	–	$Ru_{0.49}Os_{0.35}Ir_{0.16}$
30			7-9	7	37.23	29.91	26.88	–	5.58	–	$Ru_{0.41}Os_{0.30}Ir_{0.24}Pt_{0.05}$

Table 2 (end)

1	2	3	4	5	6	7	8	9	10	11	12
31			7-10	5	35.12	58.52	2.26	–	3.63	–	$Ir_{0.57}Os_{0.35}Ru_{0.04}Pt_{0.04}$
32			7-11	5	56.53	10.16	32.78	–	–	–	$Ru_{0.48}Os_{0.44}Ir_{0.08}$
33			7-12	5	37.74	56.05	5.87	–	–	–	$Ir_{0.55}Os_{0.37}Ru_{0.08}$
34			7-13	3	79.45	12.64	7.58	–	–	–	$Os_{0.75}Ru_{0.13}Ir_{0.12}$
35			7-14	2	73.36	16.17	10.09	–	–	–	$Os_{0.68}Ru_{0.17}Ir_{0.15}$
36			7-15	3	72.60	16.83	10.29	–	–	–	$Os_{0.67}Ru_{0.18}Ir_{0.15}$
37			7-16	6	40.32	38.13	17.28	–	3.80	–	$Os_{0.35}Ir_{0.33}Ru_{0.29}Pt_{0.03}$
38			7-17	5	35.83	53.34	2.85	–	7.59	–	$Ir_{0.52}Os_{0.36}Ru_{0.05}Pt_{0.07}$
39			7-18	8	38.99	42.80	17.71	–	–	–	$Ir_{0.37}Os_{0.34}Ru_{0.29}$
40	Filippovka II, Burial mound No. 1	Foil	Ф13-103a-e	5	18.28	76.94	3.52	0.94	–	–	$Ir_{0.74}Os_{0.18}Ru_{0.06}Rh_{0.02}$
41			Ф13-103j, k	2	58.65	35.02	5.45	0.47	–	–	$Os_{0.56}Ir_{0.33}Ru_{0.10}Rh_{0.01}$
42			Ф13-73	5	38.92	50.23	2.39	1.40	4.86	–	$Ir_{0.50}Os_{0.39}Pt_{0.05}Ru_{0.03}Rh_{0.03}$

Notes: 1) Materials received from the collections of L.T. Yablonsky; 2) see notes 2, 3 to Table 1.

following types are conventionally used: 1000–920 ‰—high-grade gold, 920–800 ‰—medium-grade gold, and 800–690 ‰—low-grade gold. Optical examination was made by V.V. Zaykov and A.M. Yuminov using an OLYMPUS microscope; the composition of inclusions was determined using REMMA-202M (analyst V.A. Kotlyarov, crater diameter of 2 μm) and JEOL JSM-7001F (analyst D.M. Galimov, crater diameter of 0.5 μm) electronic microscopes.

Background

The first known studies on osmium inclusions in ancient gold artifacts, to the best of our knowledge, were the articles of B. Young and F. Whitmore (Young, 1972; Whitmore, Young, 1973). The studies discussed artifacts from the Near East and suggested that the jewelry was made of gold from the valley of the Pactolus River in Turkey. Later, J. Ogden (1976, 1977) provided a comprehensive overview of inclusions of platinoid group minerals in ancient gold objects. Ogden concluded that it was hardly feasible to correlate the gold of which the artifacts had been made, with its sources. The next important study was the article by N. Meeks and M. Tite (1980), which described osmium minerals in the artifacts of Egypt, Ur, Syria, Palestine, Cyprus, Crete, and Lydia. D. Williams and J. Ogden (1995: 14–15), and N. Meeks (2000) noted the inclusions of these minerals in the ancient objects from Greece. P. Craddock (2000) addressed this topic in respect to gold from Asia Minor.

The study of osmium group minerals in ancient gold objects from the Urals began in 2008 (Zaykov et al., 2008; Zaykov, Zaykova, Kotlyarov, 2010; Shemakhanskaya, Treister, Yablonsky, 2009). The conclusion of Zaykov concerning the possibility of identifying similar microinclusions in the artifacts of Siberia, was confirmed by subsequent research (Dashkovsky, Yuminov, 2012). In 2013, Zaykov and Yuminov began to study osmium platinoids in gold objects from the ancient towns of Gonur (Turkmenistan) and Phanagoria (Northern Black Sea region). The location of archaeological sites, where gold objects with microinclusions of osmium group minerals were found, is shown in Fig. 1.

The common conclusion of all these studies was that gold placer deposits should be recognized as the source of osmium minerals. The Ural experts showed that these placer deposits were confined to ultramafic belts (Blagorodnye metally…, 2012: 93–99). Associational origin from placer deposits was the cause for platinoids of the native osmium group being present in the form of microinclusions in ancient gold artifacts. Owing to very thin fracturing (cleavage) and high fragility of osmium minerals, they break down in placer deposits; during the manufacturing of artifacts, tiny particles with a density of

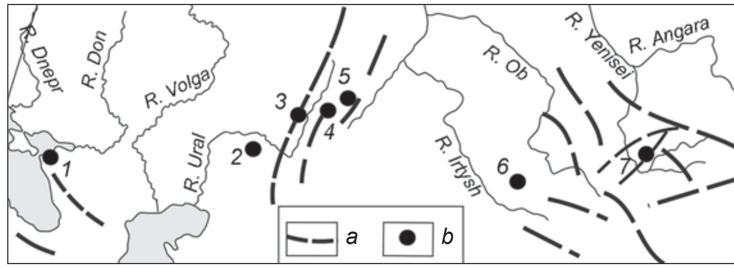

Fig. 1. Archaeological sites with gold objects containing microinclusions of osmium group minerals, in Central Eurasia.
a – ultramafic belts and ophiolite zones; *b* – archaeological sites.
1 – Phanagoria; *2* – Filippovka; *3* – Perevolochan I and Yakovlevka II; *4* – Magnitny; *5* – Kichigino I; *6* – Khankarinsky Dol and Inskoy Dol; *7* – Arzhan.

20–23 g / cm^3 would sink in molten gold, whose density is 16 g / cm^3. As opposed to osmium, platinum is less fragile and therefore it forms larger grains and nuggets in placer deposits, which were easily extracted by ancient artisans.

Thus, the presence of microinclusions of platinoids of the osmium group in archaeological gold is a stable feature of sites located near gold-bearing and platinum-bearing ultramafic rocks which belong to ophiolite zones of fold belts (Platinometalnoye orudneniye…, 2001: 124–142; Geologicheskiy slovar, 1973: 61), enclosing deposits of gold and platinoids. Such structures are known in Russia, including the Altai, Urals, and the Caucasus. To the south of the Caucasus, ultramafic rocks are found in the Sevan-Akerin zone of the Transcaucasia (Magakyan, 1974: 81–91). They expand to the west in the form of the ultramafic belts of Turkey, and to the east—of Iran.

Microinclusions of platinoids in gold objects of South Siberia

Microinclusions of osmium group minerals were found in the materials of three out of nine archaeological sites of Southern Siberia, whose finds have been studied for the composition of the gold, including the royal burial mound of Arzhan II (Tuva), as well as the burial grounds of Khankarinsky Dol and Inskoy Dol (Altai) (see Table 1). They are all dated to the Early Iron Age.

Royal burial mound of Arzhan II (Tuva). The burial of two representatives of high nobility was excavated from underneath a stone embankment, encircled by a sustaining wall. The site is dated to the second half of the 7th century BC. The objects from the burial mound manifest four manners of execution (Chugunov, 2011). The most numerous were mass-produced plaques in the form of profile representations of felines and wild boars, shoulder-belt frames and buckles of a dagger and an acinaces, as well as tassel beads of a belt set. The second group included the plaques of a headdress, representing horses, sheep, and deer. The figures were cut from flat sheets of gold.

Microprobe analysis has shown that the objects were made of native gold of middle fineness. A microinclusion of osmium with iridium—a poorly rounded grain Ar 2-3-1 of angular shape with fracturing pattern, measuring 7 × × 10 μm—was found in the gold inlay of an iron sword (composition, wt. %: Au – 89.72–92.21, Ag – 7.08–9.01, Cu – 0.67–0.89).

Burial ground of Khankarinsky Dol (Altai). It is located in the Chineta archaeological microregion. Objects of gold were found during the excavation of Burial mound No. 15, including an encasing of a torc, zoomorphic onlays, a fringe of foil and a piece sewn on from a female headdress, and a wire earring in the shape of the number eight (Dashkovsky, Yuminov, 2012). The burial mound belongs to the Pazyryk culture, and was dated to the 4th–early 3rd century BC by the burial ritual and inventory (Dashkovsky, Usova, 2011). The gold objects have the following composition (wt. %): Au – 69.50–72.05; Ag – 23.94–26.25, Cu – 2.85–4.26.

Seven platinoid inclusions ranging from 2 to 10 μm in size were discovered in gold foil of five objects. The inclusions have an elongated shape close to lenticular. Three minerals can be identified according to the atomic ratio of Os, Ru, Ir, and Rh in the crystallochemical formulas (see Table 1):

1) ruthenium-iridium osmium (Xa-15-8);

2) two varieties of ruthenium: iridium-osmium ruthenium with the admixture of platinum and rhodium (XD-15-2-1, XD-15-2-2, Xa-15-7) and osmium-iridium ruthenium with platinum (Xa-15-1a);

3) two varieties of iridium: osmium iridium (Xa-15-6) and ruthenium-osmium iridium (Xa-15-1b).

The sample Xn-19 contained inclusions of oxygen copper-ferric compounds. In size they are 20–250 μm, with oval, triangular, or arcuate shape, and are susceptible to fracturing. The size of small blocks ranges from 10 to 60 μm. Judging by the admixtures of Si, P, and Ca, they might have occurred as a technical product when copper and iron sulphides, which were present in the placer deposit, were exposed to molten gold. Such compounds are also formed when iron oxides are exposed to molten copper during the melting of copper—the alloying addition to gold.

Burial ground of Inskoy Dol (Altai). It is also located in the Chineta archaeological microregion. The site was dated to the 4th–early 3rd century BC by the burial ritual and inventory (Dashkovsky, 2014). Burial mound No. 2

contained a wooden structure covered with wooden slabs. Next to the buried person there were found an earthen vessel, an iron knife, a wooden torc covered with gold foil, a heavily corroded iron object, and numerous pieces of gold foil remaining from the headdress.

The gold foil (composition, wt. %: Au – 57–60, Ag – 36–39, Cu – 3) contains oval microinclusions of platinoids from several micrometers to 80 × 120 μm in size. Osmium with iridium and ruthenium has been identified (ID-5, ID-8).

Platinoid microinclusions in gold objects from the Southern Urals

The archaeological materials from the steppe and forest-steppe zones of the region contain microinclusions of osmium group platinoids in gold objects from seven sites of the Early Saka, the Sauromatian, and the Early Sarmatian periods (7th–4th centuries BC): Kichigin I, Bolshoi Klimovsky, Magnitny, Yakovlevka II, Perevolochan I, and Filippovka I and II (Yablonsky, Rukavishnikova, Shemakhanskaya, 2011; Yablonsky, 2013a: 83–110; 2013b). The earliest finds from the burial grounds of Stepnoye and Ushkattinsky date back to the Bronze Age (Blagorodnye metally…, 2012: 145, 153–154). The majority of burial mounds with "osmium-containing" artifacts go back to the Early Iron Age, and the latest finds are dated to the Early Middle Ages (Magnitny, goldsmith workshop of Ufa II).

The largest number of microinclusions containing minerals from the osmium group (42 pieces), was found among the gold objects from the Filippovka burial grounds. They occur in gold of two fineness intervals—650 and 980 ‰.

Burial ground of Filippovka I. Numerous sewn gold plaques containing microinclusions of osmium group minerals were found in Burial mound No. 1 (excavations of 2013 by Yablonsky). The size of the microinclusions ranges from several microns to 100 μm. The host gold has the following composition (wt. %): Au – 93–95, Ag – 3, Cu – 1–2. Three minerals can be identified according to the atomic ratio of Os, Ru, and Ir in the crystallochemical formulas (see Table 2):

1) two varieties of osmium: ruthenium-iridium osmium (F-13-2-1, F-13-9-2) and iridium-ruthenium osmium (F-13-3-5-1, F-13-3-9); in some cases, small amounts of rhodium and platinum (1–3 at. %) are present;

2) two varieties of ruthenium: iridium-osmium ruthenium (markedly predominant, F-13-2, F-13-2-3, F-13-3, F-13-3-1, F-13-3-4, F-13-5-2, F-13-5-3, F-13-8-1, F-13-8-3, F-13-8-4, F-13-9-1) and osmium-iridium ruthenium (F-13-2-2, F-13-5-1, F-13-3-5-2, F-13-5-4, F-13-8-2); the impurities also include rhodium and platinum;

3) ruthenium-osmium iridium (F-13-8-5).

Eighteen inclusions of osmium group minerals were found in the gold inlay of an iron sword from Burial mound No. 4 (excavations of 2006 by Yablonsky) (Blagorodnye metally…, 2012: 111–117). The enclosing gold has the following composition (wt. %): Au – 98, Ag – 1, and Cu – 1. Microinclusions have elongated, triangular, and rounded shapes; their sizes are 40–200 μm. A part of the grains was shattered, and another part of the grains was split along the cleavage. The following minerals can be identified:

1) ruthenium-iridium osmium (7-1, 7-16);

2) iridium-osmium ruthenium, sometimes with the admixture of platinum (7-2, 7-3, 7-6, 7-8, 7-9, 7-11);

3) ruthenium-osmium iridium, which also contains some platinum (7-7, 7-10, 7-12, 7-17, 7-18).

We need to add the information of M.S. Shemakhanskaya on isolated dark inclusions, which look similar to platinoids, on the surface of eleven objects from Burial mound No. 4 (Treister, Shemakhanskaya, Yablonsky, 2012).

Burial ground of Filippovka II. This burial ground is located 11 km to the southwest of Filippovka I. Gold of the objects from the central burial chamber No. 2 in Burial mound No. 1 (excavations by Yablonsky) was examined. Two inclusions were found in gold foil Ф13-103 (composition, wt. %: Au – 74.58, Ag – 22.86, and Cu – 2.12): one inclusion of iridium with ruthenium and osmium had a size of 50 × 110 μm; another inclusion of osmium with ruthenium and iridium had a length 5 μm. Gold foil Ф13-73 (composition, wt. %: Au – 65.66, Ag – 30.57, and Cu – 3.37) contained a grain of iridium with ruthenium and osmium, measuring 10 × 15 μm.

Discussion

Composition of microinclusions of osmium group minerals. The data points in the diagram, showing the composition of microinclusions in the gold of the Ural objects (Fig. 2), are distributed all over the field, but four main trends can be discerned. The ruthenium trend (Ru) is located in the center with a subvertical position from the base (Os-Ir) to the ruthenium top; the iridium-osmium trend (Ir-Os) is shown on the right side and is oriented in the direction from the iridium top to the osmium top parallel to the base (Os-Ir). These two trends comprise the majority of data points, and correspond to the compositions of osmium minerals from the platinoid deposits, which are genetically associated with ultramafic rocks (Tolstykh et al., 2002; Uysal et al., 2009; Agafonov et al., 2005: 88–90).

The iridium-ruthenium trend on the right side of the diagram is typical for nanoscale particles (1–3 μm or less) which surround larger microinclusions and contain smaller amounts of osmium and larger amounts of iridium and ruthenium. The data on the physical and chemical properties of osmium indicate that the change in the composition might have been caused by oxidation processes (Kratkaya khimicheskaya entsiklopediya, 1964: 791–795). It is known that finely shattered particles of osmium oxidize when heated. The fact that this phenomenon might have been the case is confirmed by the presence of micropores 0.1–0.4 μm in size; their amount in the objects reaches 5–10 %. In the process of gold melting, hot air, which was contained in the micropores, could cause the oxidation of osmium with the subsequent assimilation of the products resulting from the oxidation process by the melt. This might have been confirmed by higher content of osmium (2 wt. %) in the gold which enclosed the shattered microinclusions. The emergence of tiny particles around larger microinclusions might have been caused due to two main reasons: mechanical deformations of osmium grains during the manufacturing process of gold foil, and their cracking (desquamation) in molten gold. Since in the first case the composition of microinclusions would have remained the same, the second suggestion is more plausible since desquamation would be accompanied by a decrease in the content of osmium in the rejected particles.

The osmium-ruthenium trend is located in the left part of the diagram in the direction of Os to Ru, and includes a substantial portion of microinclusions with low iridium content.

The data points showing the composition of microinclusions in the gold of Siberian objects in the diagram (Fig. 3) are concentrated near the ruthenium trend; the grain XD-15-2-2 in the gold of a sewn plaque from the burial ground of Khankarinsky Dol shows the osmium-ruthenium trend (Fig. 3, *5*), and the grain Xa-15-6 shows the iridium-osmium trend (Fig. 3, *8*). This situation is similar to the Ural findings. The compositions belonging to the iridium-ruthenium trend have not yet been identified, but this may be caused by the small number of tests.

The correlation between the presence of microinclusions of osmium group minerals and the composition of gold objects is shown in Fig. 4. The histograms were compiled with the step size of 12 and 24 ‰, and reflect the diversity of the metal used. The gold of the objects from Khankarinsky Dol and Inskoy Dol, containing platinoid inclusions, has the fineness of 560 and 770 ‰. The gold objects from Arzhan were made of gold corresponding to fineness ranges of 715–790 and 860–920 ‰; microinclusions were found in the gold of the latter fineness range. Gold objects from the Filippovka burial grounds correspond to the fineness ranges of 620–760 and 790–980 ‰; osmium minerals were found in gold with the fineness of 650 and 980 ‰.

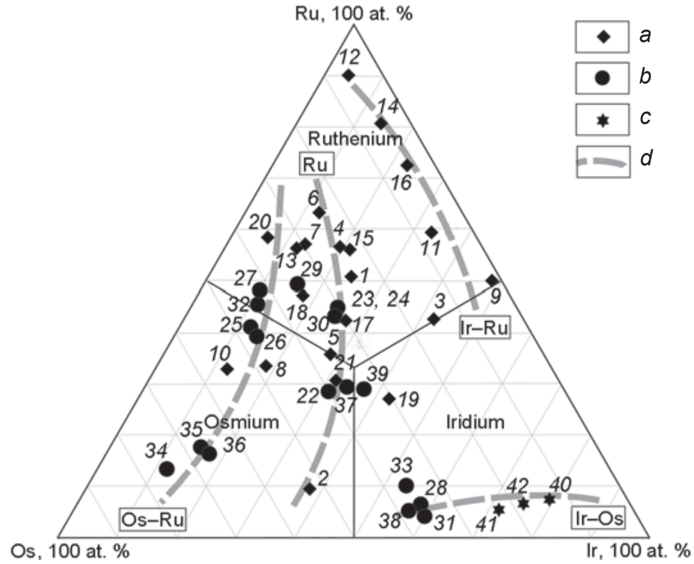

Fig. 2. Composition diagram of platinoid microinclusions in gold objects from the Filippovka burial grounds.
a – Filippovka I, Burial mound No. 1; *b* – Filippovka I, Burial mound No. 4; *c* – Filippovka II, Burial mound No. 1; *d* – composition trends of osmium group microinclusions. The numbers show the sequence numbers of inclusions in Table 2.

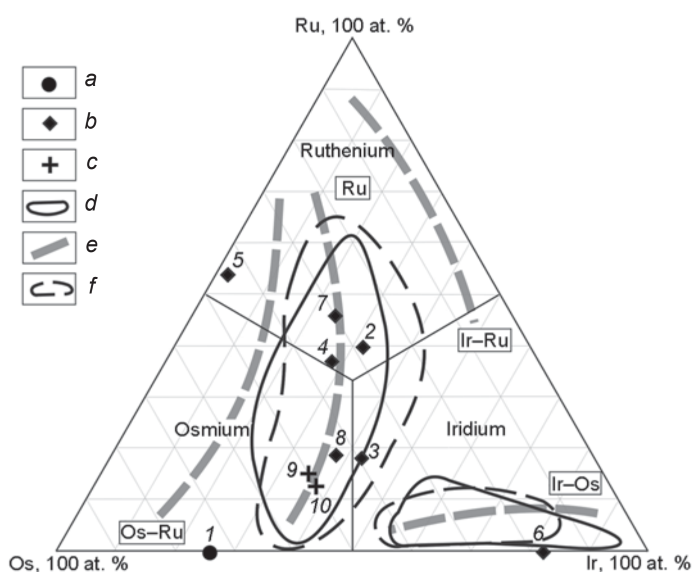

Fig. 3. Composition diagram of platinoid microinclusions in gold objects from archaeological sites and osmium group minerals from the deposits of Siberia and the Urals.
a – Arzhan II; *b* – Khankarinsky Dol, Burial mound No. 15; *c* – Inskoy Dol, Burial mound No. 2; *d* – composition fields of osmium group minerals from gold and platinoid deposits of Siberia; *e* – composition trends of platinoid microinclusions in gold objects from Filippovka burial grounds; *f* – composition fields of osmium group minerals from gold and platinoid placer deposits of the Urals. The numbers show the sequence numbers of inclusions in Table 1.

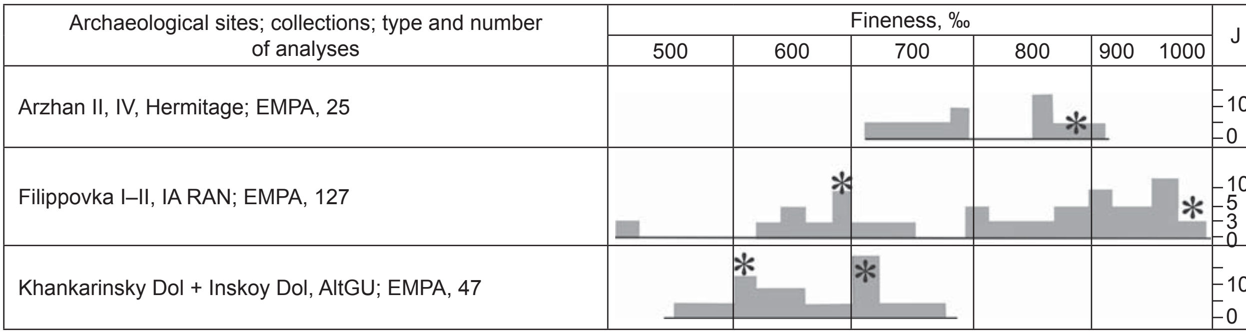

Fig. 4. Comparative chart of fineness of "osmium-containing" archaeological gold from Altai and the Urals. Chronology: Arzhan II и IV – 7th century BC; Filippovka I and II – 5th–4th centuries BC; Khankarinsky Dol and Inskoy Dol – 4th–early 3rd centuries BC.
The asterisk marks the position of inclusions of osmium group minerals in gold objects; J – occurrence frequency; EMPA – electron microprobe analysis (made by V.A. Kotlyarov using REMMA-202M unit).

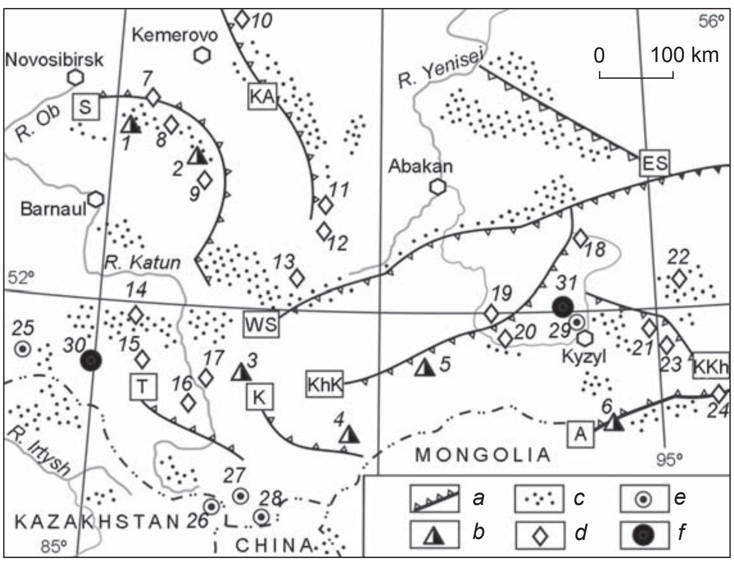

Fig. 5. Archaeological sites with gold objects, gold placer deposits, and the locations where osmium group minerals were discovered in them in the Altai-Sayan region (compiled using the data of Y.G. Shcherbakov and N.V. Roslyakova (2000)).
a – ophiolite zones with bodies of "osmium-containing" ultramafic rock: S – Salair zone, KA – Kuznetsk-Alatau zone, WS – West Sayan zone, ES – East Sayan zone, T – Terekta zone, K – Kurai zone, KhK – Khemchik-Kurtushibinsky zone, KKh – Kaa-Khem zone, A – Agardag zone; *b* – platinoid bedrock manifestations: *1* – Togul-Sungai, *2* – Uksunai, *3* – Kyrkyla, *4* – Uzun-Oyuk, *5* – Kopsek, *6* – Agardag; *c* – locations of gold placer deposits; *d* – locations where osmium group minerals were discovered in placer deposits: *7* – Talovskaya, *8* – Suenga, *9* – Ionikha and Irodov Log, *10* – Kelbes, *11* – Orton, *12* – Balyksa, *13* – Tuenza, *14* – Nikolayevka and Svetlaya, *15* – Kayancha, *16* – Karama, *17* – Aksagyskan, *18* – Algiyak and Chernaya, *19* – Zolotaya, *20* – Sektir and Serlig, *21* – Neozhidannyi, *22* – Kharal, *23* – Kundus, *24* – Emi; *e* – archaeological sites with published information on gold composition: *25* – Bugry, *26* – Berelsky, *27* – Yaloman, *28* – Ak-Alakha, Kaldzhin, Kungurtas, *29* – Dogee Bary; *f* – archaeological sites with gold objects containing the established presence of osmium microinclusions: *30* – Inskoy Dol and Khankarinsky Dol, *31* – Arzhan II.

Sources of osmium group minerals in ancient gold objects. It has been previously shown that placer deposits of geological structures with ultramafic rocks were the source of gold for the objects, which contain inclusions of osmium group minerals (Zaykov, Zaykova, Kotlyarov, 2010). These structures combine the deposits of chromites with the admixtures of platinoids and gold-quartz veins in listvenites (pyrite-mica-quartz rocks formed in ultramafic belts) (Blagorodnye metally…, 2012: 96–102). The resulting placer deposits constitute about a quarter of the total number of placer deposits originating from other sources, including gold deposits in granite and carbonaceous rocks. The variations of gold composition, established during the study of ancient objects, manifest the diversity of formations, which lead to the emergence of placers (Fig. 4).

Burial mounds of the Altai-Sayan region, containing gold objects with osmium group inclusions (Fig. 5), are located near placer gold deposits (Shcherbakov, Roslyakova, 2000). The royal burial mound of Arzhan II is located in the immediate vicinity of the Khemchik-Kurtushibinsky fault with ultramafic belts. This structure accommodates four areas of placer gold deposits with osmium group platinoids: the Algiyak area, Kaa-Khem area, Eilig-Khem area, and the area of the Zolotaya River. The composition of osmium group minerals from the placer deposits of the Zolotaya River and the Neozhidannyi Creek in the Kaa-Khem area have been studied in the greatest detail (Tolstykh, Krivenko, Pospelova, 1997; Agafonov et al., 2005: 114–118, 122–139). Most of the minerals have a composition corresponding to the ruthenium trend.

The burial grounds of Khankarinsky Dol and Inskoy Dol are located on the extension of the Terekta fault zone, which also hosts ultramafic belts. The Kayanchinsky manifestation of chromites with platinoid mineralization in the form of native osmium dissemination reaching 0.5 mm in size, was found 150 km east of Khankarinsky Dol and Inskoy Dol (Gusev, Kukoyeva, 2011). Gold placer deposits containing osmium minerals are located to the west of the area along the Karama, Erusalim, and Baranchi rivers. Burial mounds of high nobility in the South Urals are also associated with sources of placer deposits. The Filippovka burial ground is located to the southwest of the Main Urals Fault zone, which hosts gold deposits of different genetic types; fifteen placer deposits contained admixtures of osmium group minerals amounting to 1.8 % relative to gold. Thus, the proliferation of ancient objects of gold with microinclusions of osmium group minerals both in Siberia and in the Urals shows a direct connection with the presence of placer deposits containing gold and platinoids. All such placer deposits are confined to deep faults with ultramafic belts.

Problem of local goldsmith workshops and cultural relations between the regions. The majority of gold objects under study were made in the Scythian animal style. Some of them were imported and were manufactured in the workshops of Central Asia and the Middle East. However, using the example of Ural gold artifacts it is possible to assume local production.

Many gold objects of high artistic quality, which were found in the burial grounds of the Southern Urals, were made in the traditions of the Achaemenid art (Treister, 2012). However, some details important for the classical artwork of the Achaemenids, are distorted on a number of objects, showing primitive execution. We may add that the gold foil covering the figures of deer from Burial mound No. 1 of Filippovka I was made in a primitive way, and the nomadic artisans were capable of producing gold foil (Yablonsky, Rukavishnikov, Shemakhanskaya, 2011).

Moreover, it is hard to imagine that gold which was mined in the Urals, first “traveled” to the workshops of the Achaemenid satrapies, and then returned in the form of the objects, which have been preserved in the burial mounds. After all, along with osmium-containing Ural placer deposits, in various areas there were many other sources of gold, associated with primary deposits and placer deposits, which did not contain platinoids. Such deposits are known in the Caucasus, the Ukraine, in the Carpathian Mountains, Turkey, and Iran. Thus, it is much more likely that the Ural gold objects with osmium group inclusions were made of gold extracted from the local “ultramafic” placer deposits, which implies that goldsmith workshops must have existed near the burial mounds of the time. In the Urals, they could have been located in the vicinity of the Filippovka and Perevolochan burial grounds, and their discovery becomes a relevant objective of archaeological research.

Cultural ties of the regions are reflected in the borrowing of technologies of metal and jewelry production. Over the vast space of Eurasia, including the Urals and Siberia, the use of gold started from the development of placer deposits. The presence of gold jewelry at the archaeological sites of the Bronze Age in the Urals (Stepnoye, Ushkattinsky) has been conclusively established, and the gold of the objects contains microinclusions of the osmium group. The stylistic features of the animal style in gold objects (Perevodchikova, 2007; Rukavishnikova, Yablonsky, 2008), the typology of weaponry and horse equipment (Shulga, 2007) became similar in the Urals and in Siberia since that period. The paleoanthropological data also support the presence of diverse connections between the population of the Urals and the population of the Altai-Sayan region in the first millennium BC (Chikisheva, 2012: 55–80; Yablonsky, 2013c).

Conclusions

1. The data on the distribution of microinclusions of osmium group minerals in ancient gold objects from the archaeological sites of Tuva (royal burial mound of Arzhan II) and the Altai (burial grounds of Khankarinsky Dol and Inskoy Dol) show that the sources of these minerals were gold placer deposits with platinoids, confined to ultramafic rocks of deep faults.

2. The study of microinclusions of platinoids, which have been recently discovered in gold objects from the Filippovka burial grounds in the Southern Urals, has shown that according to their composition, the majority of microinclusions correspond to osmium group minerals from Ural placer deposits, also associated with ultramafic belts.

3. The following impacts of molten gold on the morphology and composition of microinclusions of osmium group minerals have been identified: the emergence of an aureole of nanoscale particles impoverished of osmium, on the periphery of larger inclusions. This fact should be taken into consideration while comparing the composition of microinclusions and minerals from the supposed placer deposit sources.

4. The presence of platinoid microinclusions of the osmium group in ancient gold objects can serve as a proof that those objects were produced in local goldsmith workshops. For definitive confirmation, it is necessary to identify the isotopic and geochemical differences of platinoids from different regions.

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