

THE METAL AGES AND MEDIEVAL PERIOD

doi:10.17746/1563-0110.2024.52.3.047-055

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Slag Inclusions in Iron Artifacts from Cemeteries at Kichigino I and Krasnaya Gorka, and the Metallurgy of the Early Iron Age Itkul Culture

Silicate slag inclusions in iron artifacts from the Trans-Urals and in iron slags from sites of the Itkul culture were analyzed to assess the geochemical characteristics of iron ore sources exploited during the Early Iron Age. Slag inclusions were found in 19 out of 25 samples from Kichigino I and Krasnaya Gorka. For comparison, we used 12 iron slag samples from Early Iron Age and medieval sites near Lake Irtysh and from Zotino mine. Via statistical analysis, four geochemical groups were separated, each including one or more Kichigino artifacts, which suggests a variety of iron ore sources used by the nomads. Slags and artifacts of the first group are associated with infiltration-sedimentary ironstone ores of the Middle Trans-Urals. Smelting slag from the Itkul site of Shatanov V suggests that these ores were already smelted in the Early Iron Age. The fact that group 1 includes only one artifact from Kichigino I demonstrates that the nomads of the Southern Trans-Urals obtained iron mainly from other sources. Group 2 is characterized by a higher content of Mn and sometimes Ba and S in inclusions. This may attest to the use of Fe-Mn ironstone associated with barite-polymetallic deposits of Central Kazakhstan. Group 3 shows an elevated content of CaO and MgO, indicating the use of ironstone from platform carbonate strata. In the fourth group, the content of K₂O is high, and that of MnO, low.

Keywords: Kichigino I cemetery, Itkul culture, iron, silicate slag inclusions, Early Iron Age, bloomery slags.

Introduction

Nomadic communities of the Scytho-Sarmatian circle provide the earliest example of wide use of iron products in ancient times. However, in most cases, the sources of ore for iron smelting are still unknown, which is caused

both by the absence of traces of metallurgical production at nomadic sites represented by burials, and the difficulties in identifying and analyzing slag inclusions in iron items (Buchwald, Wivel, 1998; Leroy et al., 2012; Stepanov et al., 2020). This study analyzes silicate slag inclusions in corroded iron items to establish ore sources and/or, if the

exact source cannot be determined, geochemical features of ore used for iron smelting.

This study was carried out both because of complete lack of information on the sources of iron in the nomadic communities of the Early Iron Age in the Steppe Eurasia* and because of poor knowledge of iron ore raw materials of that mega-region, including raw materials used by the carriers of the Itkul culture of the Urals, who are believed to be one of the main suppliers of pure copper and iron to the nomads of the Ural-Kazakhstan region (Beltikova, 2005; Tairov, 2019: 194–196). Even though the Itkul people specialized in copper production, it is unclear whether they had any knowledge of iron smelting (Beltikova, 1993; Koryakova, Epimakhov, 2007: 196–197). This is due to the relatively small number of iron products found at the Itkul sites (about 30 items). In addition, metallurgical products (slag and blooms) rarely occur at single-layered Itkul sites. Examination of Early Iron Age assemblages belonging to this culture found at the sites on Lake Irtyash (Irtyashskoye I and Shatanov V) revealed fragments of iron-smithing slag (Stepanov et al., 2021). Smithing slag and blooms were also found at the Zotinskoye III and Krasny Kamen fortified settlements on the Bagaryak River (Beltikova, 2005; Borzunov, 2018; Stepanov, Blinov, Artemyev, 2023). Slag discovered at the settlements resulted mainly from secondary metallurgical processing and was formed during the forging of blooms.

Ore sources for bloomery iron that the Itkul metallurgists received for processing, as well as primary slag formed during ore smelting, have not been clearly identified. Despite the location of the Itkul area near rich deposits of ironstone ores in the Middle Trans-Urals (Artemyev, Stepanov, Ankusheva, 2022), the fact of iron smelting in the Early Iron Age has not been confidently verified, since the sites with primary iron-smelting slag are frequently multilayered (Irtyashskoye II, VIII, Guseva Gora, Zotino mine, Zotinskoye III, Palatki, Verkhnyaya Makusha, and Gora Petrogrom), where the Early Iron Age layers are overlapped by the medieval layers with the evidence of the Petrogrom or Bakal cultures (Beltikova, 2005; Naumov, 2016; Borzunov, 2018).

Study methods

The origin of the ore used to create ancient iron items can be determined by analyzing the chemical

composition of silicate slag inclusions within the metal or the corroded matrix of the iron item, using scanning electron microscopy with energy-dispersive analysis (SEM-EDA). Silicate slag inclusions in iron artifacts emerge in the bloomery process, where iron is reduced to metal in the solid state rather than melted, resulting in a porous mass, i.e. a bloom, which includes a significant amount of slag substrate. Further forging of the bloom and manufacture of an item from it cannot completely remove slag microinclusions from the metal. Since the bloomery process is a relatively low-temperature procedure (within 1100–1300 °C), most of impurities in ore are not reduced to a metallic state, but concentrate in slag, which makes the latter suitable for reconstructing the composition of the ore protolith and identifying iron ore sources. The SEM-EDA method for silicate slag inclusions in iron artifacts reveals the content of main macroelements (Si, Al, Fe, Ti, Mg, Ca, Mn, Na, K, and P) therein. This approach has been widely used in international studies (Buchwald, Wivel, 1998; Charlton, 2015). Since the content of macroelements depends on the composition both of ore and of clay with temper used in making iron-smelting furnaces (source of Si, Al, Ti, Ca, and Mg), charcoal ash (source of Ca, K, Na, and Mg), and fluxes, the ore source can be established only with a certain degree of probability (Blakelock et al., 2009). A further development of this method is its combination with analysis of rare and trace elements using laser-sampling mass spectrometry (Desauty et al., 2009; Stepanov et al., 2020), which involves indicator elements only weakly affected by clay and ash, such as Th, U, Y, Nb, Hf, and rare earth elements. Unfortunately, the small sizes of silicate slag inclusions (<20 µm) in the corroded artifacts under study did not allow for its use.

For SEM-EDA analysis, small pieces of metal were embedded in epoxy resin, and the samples were ground and polished. The samples were analyzed using a Tescan Vega 3 sbu electron microscope Oxford Instruments X-act, with the system of energy-dispersive microanalysis, over the entire area of silicate slag inclusions. Predominantly wustite inclusions were not studied, because of their depletion of Al, Mg, Ca, and K down to values close to the detection limit. Four to fifteen silicate slag inclusions were analyzed for each item. In the corroded items, the size of the unchanged part of silicate slag inclusions usually did not exceed 5–10 µm (Fig. 1). Since most of the studied items have been completely corroded, the inclusions in them also underwent chemical changes (Stepanov et al., 2020). In this regard, the homogeneity of composition in silicate slag inclusions was assessed for each item, and statistical outliers were excluded from the sample. Relics of metallic iron, which were

*Following A.A. Chibilev and his co-authors, the Steppe Eurasia is understood as “a transcontinental geographic space—a mega-region that covers not only the steppe landscape zone of Europe and Asia, but also the forest-steppe and semi-desert (desert-steppe) zones adjacent to it on the north and south” (Chibilev, Levykin, Shcherbakova, 2019: 3).

Fig. 1. Microphotographs of typical silicate slag inclusions in the corroded matrix of iron items from Kichigino I.

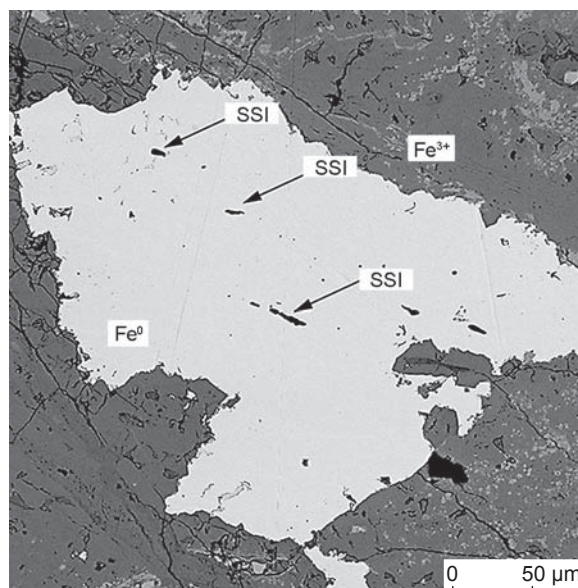
preserved in the matrix of some corroded items, did not contain impurities of other chemical elements. The poor preservation of the items did not make it possible to carry out classic the metallographic analysis used in the study of ancient iron products. Nevertheless, the study of thin sections has revealed the presence of relic carbonized structures in the artifacts, suggesting the use of hypoeutectoid raw iron.

The averaged content values of six main oxides (SiO_2 , Al_2O_3 , MgO , CaO , MnO , and K_2O) for each item were transformed by logarithmic normalization and subjected to statistical processing using principal component analysis according to the common methodology (Charlton et al., 2012; Stepanov et al., 2020). The $\text{FeO}/\text{Fe}_2\text{O}_3$ values were not included in the sample because of significant variations in their concentration due to the capacity of iron oxides to be reduced to a metallic state under bloomery smelting conditions and then re-oxidized during forging processes. The compositions of silicate slag inclusions were compared with those of not only the supposed ore, but also of smelting slag from the sites located on Lake Irtyash and the Bagaryak River, because of the similarity in the nature of their formation. The composition of dumps of smelting slag can be accepted as a geochemical marker of the iron ores used (Disser et al., 2016).

Study objects

The objects of this study were iron products and slag (over 40 spec.) from the Early Iron Age and the Middle Ages sites: artifacts from the South Ural cemeteries of Kichigino I and Krasnaya Gorka, products and slag from single- and multilayered (Early Iron Age and the Middle Ages) settlements on Lake Irtyash (Irtyashskoye II, VIII, Shatanov V) and Lake Kunashak (Kunashakskoye), as well as slag from the recently discovered Zotino mine (Stepanov, Blinov, Artemyev, 2023).

Over twenty corroded iron artifacts were initially selected from the Kichigino I site. However, since most of these were poorly preserved, it was possible to discover silicate slag inclusions in only twelve of them. A comparative analysis of the geochemical signatures of these twelve items originating from mounds 3–6 and 8 is provided herein. Most of the items were attributed to the Early Iron Age, although some of them might have belonged to the Middle Ages (Table 1), which is especially likely for the rod Kich-16 (mound 4), showing good preservation. The materials from Kichigino I have been dated, while the artifacts



from the sites on Lake Irtyash, Krasnaya Gorka cemetery, and Kunashak fortified settlement were surface finds, and many of them are not corroded (Table 1). The composition of silicate slag inclusions in some of these artifacts should probably be considered as an indirect geochemical description of the medieval iron, which, unlike the Early Iron Age items, can be viewed as locally produced.

In addition to our silicate-slag inclusions analysis, the comparison included published data on six samples of bloomery slag obtained from the sites on Lake Irtyash (Irtyashskoye II, VIII, Shatanov V) and the Bagaryak River (Zotino mine) (Stepanov et al., 2021; Stepanov, Blinov, Artemyev, 2023). Two of the samples (from Irtyashskoye II and Zotino mine) have been interpreted as primary slag, since these were obtained during the ore-smelting process, and four samples (from Irtyashskoye II, VIII, and Shatanov V), as secondary, emerging during forging of an iron bloom. According to the common opinion (Dillmann, L'Héritier, 2007), the analysis of smithing slag is considered unreliable for reconstructing the geochemical composition of the original iron ore, owing to the greater contribution of molten clay and ash as compared to primary slag. Nevertheless, according to the studies, four samples of smithing slag from Shatanov V were similar in composition to the primary smelting slag from Lake Irtyash (Stepanov et al., 2021). One of them (Sht-V/5295) is of the greatest interest, since it can be unambiguously dated to the Early Iron Age (7th–3rd centuries BC), which is supported by the accompanying finds (several fragments of iron smithing slag, a completely corroded iron item, pottery from the Itkul and Gamayun cultures, a three-bladed copper arrowhead, and a talc-casting mold) (Ibid.). For this reason, as well as in view of the similar mineralogical and

Table 1. Iron artifacts from the Kichigino I and Krasnaya Gorka cemeteries, and from the Early Iron Age and medieval sites

Sample (lab code)	Site	Context	Artifact	Dating
Kich-1 (P2.41k1-6/1)	Kichigino I	Mound 6, grave 1, burial 1	Spear	4th century BC
Kich-2 (P2.41k1-6/3)	"	"	Dagger	4th century BC
Kich-4 (P1.41k1-5/64)	"	Mound 5, grave 2	"	Second half of the 6th – first half of the 5th century BC
Kich-7 (P2.41k1-8/1)	"	Mound 8	Ring	4th century BC
Kich-8 (P1.41k1-5/77)	"	Mound 5, grave 2	Bridle bit	Second half of the 6th – first half of the 5th century BC
Kich-9 (P2.41k1-6/5)	"	Mound 6, grave 1, burial 2	Knife	2nd–3rd centuries AD
Kich-10 (P2.41k1-8)	"	Mound 8	Item (?)	4th century BC
Kich-13	"	Mound 5, grave 1	Dagger	Second half of the 7th century BC
Kich-14 (41k1-4/10)	"	Mound 4, southeastern sector	Ring	Middle Ages (?)
Kich-18	"	Mound 5, grave 2	Dagger	Second half of the 6th – first half of the 5th century BC
Kich-19	"	Mound 3, grave 1	Bridle	First half of the 4th century BC
Kich-16 (41k1-4/7)	"	Mound 4	Rod	Middle Ages (?)
KrG-1	Krasnaya Gorka	Surface finds	Hook/bridle bit	Second half of the 6th – first half of the 5th century BC
KrG-2	"	"	Chisel	"
KrG-3	"	"	Saw	"
KunashG-1	Kunashak fortified settlement	"	Hook	Early Iron Age / Middle Ages (?)
Irt-2/20	Irtiyash II fortified settlement	Sq. A/2	"	Middle Ages / 17th–19th centuries (?)
Irt-2/22	"	Surface finds	Knife	"
Irt-2/23	"	"	"	"
Irt-2/24	"	"	Axe	"
Sht-2/10	Shatanov V settlement	"	"	"
Irt-8/001	Irtiyash VIII fortified settlement	"	Forge slag	Possibly, Early Iron Age or Middle Ages (?)
Irt-8/002	"	"	"	"
Irt-2/001	Irtiyash II fortified settlement	"	Smelting slag	"
Irt-2/002	"	"	Forge slag	"
Sht-5/5295	Shatanov V settlement	Exploratory pit	"	7th–3rd centuries BC
Zot-3/SmSl1	Zotino mine	"	Smelting slag	Early Iron Age

Note. The preservation of items from Kichigino I, with the exception of the rod (Kich-16), was poor (completely corroded). Preservation of items from the rest of the sites was good.

geochemical composition of smithing slag Sht-V/5295 and probably medieval smelting slag from the multilayered sites of Irtyashskoye II and VIII, this sample became the first reliable evidence on the use of the local infiltration-sedimentary ironstone ores in the Early Iron Age.

The dating of slag and iron items found at Irtyashskoye II, VIII, and the Zotino mine is less clear, because of the good preservation of many items and the presence of the medieval Petrogrom pottery along with Itkul pottery (Naumov, 2016). Moreover, single-layered medieval sites (Uzhovy Ostrov I, II, Kirety I) with a large amount of bloomery iron slag are also known on Lake Irtyash.

Results and discussion

The results of our study of the composition of silicate-slag inclusions and subsequent statistical principal component analysis allowed the classification of the sample of iron artifacts from the Early Iron Age and Middle Ages with slag data into four main chemical groups, which were further subdivided into subgroups depending on the P_2O_5 content (Fig. 2; Table 2). Subgroup 2.3 was identified on the basis of the increased concentration of BaO and S. The absence of P_2O_5 in the initial statistical sample resulted from its high heterogeneity in the bloomery-iron slag (Dillmann, L'Héritier, 2007). The identified groups show different types of iron ore sources, which differ significantly in chemical composition depending on the geological origin of iron ores and the associated rocks. In addition, these subgroups may reflect process conditions of smelting and the composition of fluxes used. Since the division based on statistical analysis with a small number of elements is to some extent arbitrary, some of the identified subgroups can be refined if rare element or isotopic data become available.

The principal component analysis has shown that the increased MnO content significantly affected the identification of clusters in statistical groups 1 and 2. In both cases, manganese-containing iron ores were probably used: those weakly enriched in combination with Al_2O_3 , SiO_2 (group 1), and those high-manganese in combination with CaO and MgO (group 2). Group 1 is the easiest to interpret, since it includes six samples of iron slag, three iron

items from the sites on Lake Irtyash, one sample from the Kunashak fortified settlement, and the Kich-10 item from mound 8 in Kichigino I (4th century BC). The fact that group 1 includes both slag and items from the sites on Lake Irtyash makes it possible to link it with ironstone ores of the infiltration-sedimentary type associated with karstified limestones and dolomites of the volcanogenic-sedimentary strata of the Middle Trans-Urals. Such an ancient mine (Irtyashskoye IX (Naumov, 2016)) is known near the Irtyashskoye II fortified settlement. The presence of the Irt-2/22 item (subgroup 1.2) with silicate slag inclusions enriched in P_2O_5 (up to 4.7 wt%) in this group is generally consistent with phosphorus-containing ironstone ores of Irtyashskoye I (Stepanov et al., 2021).

Given that ironstone ores were the predominant raw material used in the Middle Urals from the Early Iron Age to the Modern Age, it is interesting to note that the population associated with the Kichigino I cemetery

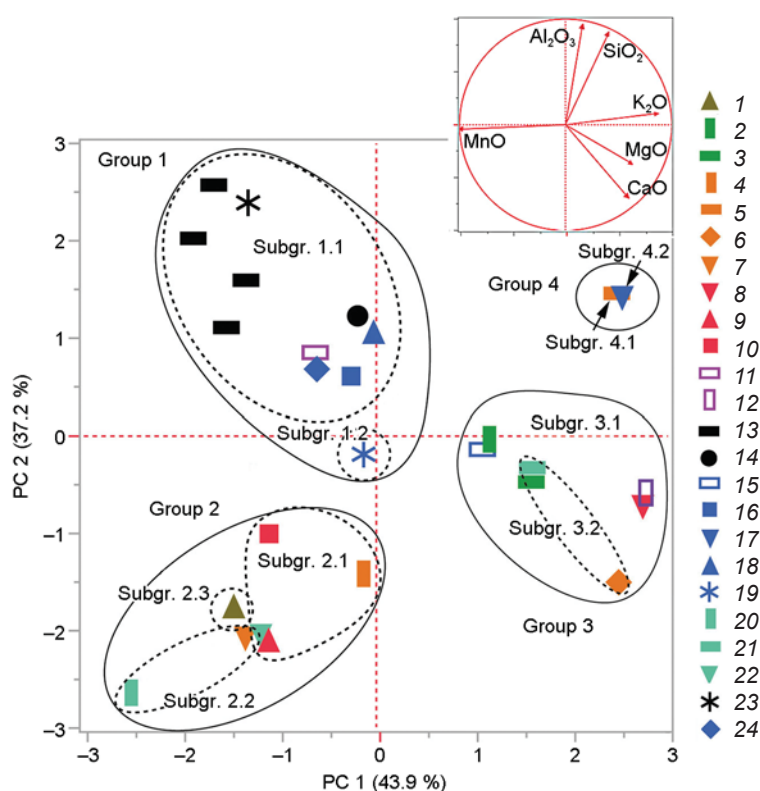


Fig. 2. Principal component analysis of chemical composition in silicate slag inclusions.

1–12 – items from Kichigino I: 1 – Kich-19, 2 – Kich-14, 3 – Kich-16, 4 – Kich-4, 5 – Kich-8, 6 – Kich-13, 7 – Kich-1, 8 – Kid-9, 9 – Kid-2, 10 – Kid-1, 11 – Kid-10, 12 – Kid-7; 13 – bloomery slag from Irtyashskoye II and VIII; 14 – smithing slag from Shatanov V; 15 – item from Shatanov V; 16–19 – items from Irtyashskoye II: 16 – Irt-2/23, 17 – Irt-2/20, 18 – Irt-2/24, 19 – Irt-2/22; 20–22 – items from Krasnaya Gorka: 20 – KrG-1, 21 – KrG-2, 22 – KrG-3; 23 – bloomery slag from Zotino mine; 24 – item from Kunashak. Ellipses mark statistically identified groups, as well as subgroups standing out by their phosphorus content. The inset shows the distribution of elements in the principal component analysis.

Table 2. Chemical composition of silicate slag inclusions in iron artifacts and slags (wt%) and their classification based on principal component analysis

Sample	n	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	MnO	FeO	Group	Subgroup
Kich-10	8	2.5	1.5	12.5	57.1	0.1	1.3	7.6	0.3	2.4	13.9	1	1.1
KunashG-1	4	0.5	2.7	11.6	48.9	1.0	1.4	3.2	0.5	3.1	26.9		
Irt-2/23	6	1.2	3.0	15.1	66.4	0.1	1.7	7.1	0.6	2.4	2.1		
Irt-2/24	7	1.5	3.8	19.9	62.8	0.1	1.4	5.3	0.8	1.6	3.2		
Irt-8/001*	8	0.1	0.6	7.3	25.2	0.5	0.4	1.0	0.2	2.6	62.3		
Irt-8/002*	5	0.3	0.5	9.4	25.0	0.2	0.3	1.0	0.4	1.6	61.3		
Irt-2/001*	6	1.4	1.1	6.7	19.9	0.2	0.5	0.9	–	2.6	66.7		
Irt-2/002*	5	0.1	1.0	10.0	26.4	0.2	0.9	0.9	0.3	3.2	56.9		
Sht-5/5295*	5	0.7	0.5	4.2	13.6	0.2	0.4	1.5	0.1	0.4	78.6		
Zot-3/SmSl1*	5	0.3	0.5	7.7	29.4	0.4	0.6	1.3	0.2	1.8	58.0		
Irt-2/22	5	0.8	2.2	10.0	43.3	4.7	1.1	10.6	0.5	1.4	25.2	2	1.2
Kich-1	2	0.2	2.6	7.3	46.8	0.1	1.7	8.4	0.4	6.6	25.9		2.1
Kich-2	4	0.5	2.8	8.9	43.5	0.2	2.6	23.5	0.5	8.3	9.2		
Kich-4	2	1.1	2.7	12.0	33.5	0.3	1.1	29.5	0.4	1.6	18.0		
KrG-3	6	0.5	4.0	5.0	45.0	0.1	1.5	9.8	0.3	9.0	24.4		
Kich-18	7	0.3	2.4	7.7	30.8	5.3	1.7	19.1	0.4	5.5	27.0		2.2
KrG-1	6	0.3	2.5	6.3	30.9	1.2	0.9	16.2	0.4	18.2	22.2		
Kich-19**	3	0.9	2.8	5.6	28.2	0.3	0.9	6.9	–	6.3	46.8	3	2.3
Kich-7	5	1.0	7.7	13.0	52.7	0.1	2.8	17.2	0.6	0.2	4.6		3.1
Kich-9	5	1.1	5.3	8.9	44.4	0.3	2.9	26.1	0.4	0.1	10.7		
Kich-14	7	0.9	3.5	14.0	57.1	0.1	3.2	12.7	0.5	0.9	7.1		
Sht-2/10	2	1.7	2.9	8.6	38.1	0.2	1.5	7.6	0.4	0.5	38.3		
Kich-13	3	0.5	1.4	2.7	20.6	1.6	1.5	15.2	–	0.1	56.3		3.2
Kich-16	8	0.6	7.0	14.0	58.9	0.1	2.8	12.7	0.6	0.6	2.8		
KrG-2	4	–	1.4	2.0	13.7	10.8	0.3	2.4	–	0.1	69.1		
Kich-8	9	0.7	1.6	12.4	52.0	0.1	2.5	10.3	0.7	0.1	19.6	4	4.1
Irt-2/20	6	0.2	1.0	10.1	32.9	3.4	2.7	6.9	0.4	0.1	42.3		4.2

*Data from (Stepanov et al., 2021; Stepanov, Blinov, Artemyev, 2023).

**As established, SO₃ = 0.4 wt% and BaO = 0.9 wt%.

appears to have used them so little. The inclusion of smithing slag Sht-V/5295 from the Itkul site of Shatanov V in subgroup 1.1 is indirect evidence of the use of these ores in the 4th–3rd centuries BC, which corresponds to the previous assumption by G.V. Beltikova (2005) about the development of iron technology by the Itkul population at the final stage of this culture's existence. However, it is difficult to assess the scale of iron smelting in the Early Iron Age in the Urals because of the limited archaeological data.

The similarity of the chemical composition of slag samples from the Zotino mine and from the sites on Lake Irtyash, as well as the similarity of the mineralogical composition of the ancient slag and bloomeries of the 18th century from Lake Shuvakish (Erokhin, Zakharov, Erokhina, 2021), located next to the Iset cluster of the Itkul sites, confirms the uniformity of infiltration-sedimentary ironstone ores of the Middle Trans-Urals. In all the cases, slag consisted of manganese-containing fayalite, wustite/magnetite, and hercynite, and was

enriched by Al_2O_3 . The inclusion of item Irt-2/20 into group 4, which is distinguished by increased content of Al_2O_3 and SiO_2 , may indirectly indicate the use of another type of ironstone ore by the ancient population of the Lake Irtyash area. Thus, despite the fact that the composition of infiltration-sedimentary ironstone ores of the Middle Trans-Urals corresponds to group 1, artifacts of group 4 may also reflect an unidentified Trans-Ural source of iron ore.

Group 2 is distinguished by correlation and increased contents of MnO, CaO, and MgO. It includes five items from Kichigino I (two from mounds 5 and 6; one from mound 3) and two items from the Krasnaya Gorka cemetery. The inclusion of five items dated to the 6th–4th centuries BC into this group may indirectly indicate the prominence of group 2 in the iron metallurgy of the nomads of the Southern Trans-Urals over a long period. The source of iron ore for this group was ironstone deposits with an increased concentration of Mn. An example of such sites is the Zhayrem ore cluster in Central Kazakhstan, which includes the stratiform Zhayrem and Ushkatyn iron-manganese and barite-polymetallic deposits in sedimentary carbonate strata (Brusnitsyn et al., 2017). Notably, subgroup 2.3 with increased content of Ba and S in silicate slag inclusions also confirms the association of manganese-iron ores with barite.

Group 3 is distinguished by increased content of CaO, MgO, and K_2O , and includes five items from Kichigino I (two items from mound 4; one each from mounds 5, 6, and 8), and artifacts from Krasnaya Gorka and Lake Irtyash. The interpretation of this group is ambiguous. Despite the unclear archaeological context of the artifacts, the similarity of the composition of silicate slag inclusions and the good preservation of one of two items from mound 4 (Kich-16 and Kich-14) suggest that these artifacts could have belonged to the Middle Ages. This is indirectly supported by the discovery of an iron buckle from the Kimek-Kipchak period (10th–11th centuries) in mound 4 and the presence of item Kich-9 (mound 6) of the Xiongnu-Sarmatian period (2nd–3rd centuries AD) in group 3. Thus, the fact that four out of seven items from this group may possibly date back to the Middle Ages, when iron became a common and easily accessible material, points to their non-local origin due to increased migration and exchange processes, and the engagement of many iron ore sites into the set of available ore raw materials. The probable source of this iron could have been ironstone ores in platform calcite-dolomite-siderite carbonate strata, which are known in the Urals or Volga-Kama region.

Two artifacts from group 4 show low concentrations of MnO and higher values of K_2O . However, the interpretation of their source is problematic, owing to the small number of items and the small amount of chemical macroelements studied.

Note that the items from Kichigino I and Krasnaya Gorka do not gravitate to any particular part of the plot (Fig. 2), but are distributed throughout the entire field, entering each of the four groups. This suggests that the early nomads of the Southern Trans-Urals obtained iron of different origin. This allows us to doubt their independent development of any particular deposit. Most likely, ferrous metal was regularly supplied by different manufacturers, or could have been obtained accidentally (for example, during military operations).

Conclusions

The main result of this study is the conclusion about the diversity of ore sources for iron items from the Kichigino I and Krasnaya Gorka cemeteries, which correlates well with the high mobility and specific features of the nomad economy. In the Early Iron Age, when ferrous metal was in high demand among the nomads for producing tools, weaponry, and horse equipment, its supplies were most likely ensured in different ways, possibly including collection of tribute from the sedentary population familiar with the technology of bloomery smelting.

In addition, an important result of this study is the confirmation of the hypothesis of G.V. Beltikova (2005) about the development of iron metallurgy in the Middle Trans-Urals at the final stage of the Itkul culture (4th–3rd centuries BC). The totality of the results points to the use of infiltration-sedimentary ironstone ores associated with karst limestones of volcanogenic-sedimentary strata during that period. These deposits are the dominant type of ore in the Middle Trans-Urals, where their area coincides with the territory of the Itkul culture. The Itkul metallurgists might have been the first in the Urals to exploit these resources for iron production. The fact that only one out of twelve items from Kichigino I can be associated with these ores suggests that the nomads of the Southern Trans-Urals obtained iron mainly from other sources. This is especially noteworthy given that a significant part of the non-ferrous metal items of the nomads from the South Urals were made from the Itkul “chemically pure” copper (Tairov, 2019: 196, 262; Artemyev et al., 2024). The presence of iron artifacts from Kichigino I in the sample, which are distinguished by an increased concentration of Mn in silicate slag inclusions, indicates another, earlier, pre-Itkul source, which could have been ironstone ores from deposits in Central Kazakhstan, associated with barite-polymetallic mineralization. It is difficult to establish the source of ore for iron items of group 3 from macrocomponents, but the increased content of elements such as Ca, Mg, and Fe might have resulted from the use of ironstone

ores from stratiform carbonate strata of platform structures of Eurasia. The orientation of the early nomads (7th–4th centuries BC) of the Southern Trans-Urals toward other iron suppliers was possibly caused by very late adoption of the bloomery smelting by the Itkul metallurgists. The finds of bloomery slags are also known from the layers of the 5th–3rd centuries BC in the Kama region, and smithing slag was found at the Early Iron Age fortified settlements in the Bashkir Cis-Urals (Zavyalov, Rozanova, Terekhova, 2009: 69–72; Oborin, 1960: 40; Grigoriev, 2016). This indicates that these regions could have been the centers of iron production for the nomads of the Southern Trans-Urals. Notably, the conclusions of this study are based on a small sample, and require verification by further systematic archaeological research using radiocarbon dating.

Acknowledgment

This study was supported by the Russian Science Foundation, Project No. 21-18-00576.

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Received March 15, 2023.

Received in revised form October 3, 2023.