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Geoarchaeology and Archaeological Mineralogy

Proceedings of 7th Geoarchaeological Conference, Miass, Russia, 19–23 October 2020

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Preface

The Conference "Geoarchaeology and Archaeological Mineralogy" is dedicated to the famous Russian scientist, Honored Scientist of Russia, Doctor of Geological and Mineralogical Sciences, Prof. Victor V. Zaykov—the founder of geoarchaeology in the Urals. Traditionally, the conference takes place in the Middle September at the South Ural Federal Research Center of Mineralogy and Geoecology of the Urals Branch of the Russian Academy of Sciences in Miass.

The conference is organized by the South Ural Federal Research Center of Mineralogy and Geoecology of Ural Branch of the Russian Academy of Sciences, the South Ural State Humanitarian Pedagogical University, and the South Ural State University.

The multidisciplinary archaeometric research is an important aspect of archaeological surveys. Various mineralogical, chemical, and isotopic research methods that are currently used in the geological study are only just beginning to be introduced into widespread archaeological practice in Russia.

The "Geoarchaeology and Archaeological Mineralogy" is one of the first conferences which provided a successful collaboration of various researchers from both geological and archaeological areas.

The Geoarchaeological Conference is aimed to coordinate and effectively improve the multilevel training of scientists and make linkages between the young scientists and scientific geological and archaeological institutions. The conference aims to accumulate knowledge on new modern geological, geophysical, mineralogical, petrographic, and geochemical methods for searching and studying of archaeological sites and ancient mines. The conference promotes the application of natural scientific methods in archaeology and contributes to the knowledge of the mineral resource base of ancient societies, the analysis of economic relations in antiquity, and a combination of traditions and innovations from a historical perspective. The main social task of the conference is to form scientific linkages between the young scientists from various geological and archaeological scientific institutions of Russia and the international community and to introduce the new generation of students into the field of science.

The conference meetings deal with several topics. The plenary presentations of professors from leading Russian universities and institutions concern the theoretical problems of geoarchaeology and ways to select the best research methods aimed at solving specific multidisciplinary issues.

In the presentations of young scientists and students, the examples of the application of rocks and minerals by ancient societies are considered, indicating the mineralogical, petrographic, and geochemical features of natural rocks, the structure of ancient mines, and composition of metal items and slags discovered during the archaeological excavations.

At the conference "Geoarchaeology and Archaeological Mineralogy-2020," the following topics were covered:

1. General Issues of Geoarchaeology and Archaeological Mineralogy.
2. The Methods of Archaeological Sites and Artifacts Investigation.
3. Extraction of Ores and Minerals in Ancient Times.
4. The Use of Rocks by Ancient Societies.
5. Paleometallurgy, Composition of Products of Metallurgical Manufacturing and Ancient Metallic Items.
6. GIS in Geoarchaeology.

Since 2014, all meetings of the conference have been broadcast live on the Internet at http://video.mineralogy.ru/live/cast/24. A video archive of presentations is posted on the Website of the Institute of Mineralogy of South Ural Federal Scientific Center of Mineralogy and Geoecology of Ural Branch of the Russian Academy of Sciences.

The previous proceedings are available at https://www.springer.com/gp/book/9783030488635.

Miass, Russia

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The board of editors and authors would like to thank twenty-two reviewers whose feedback allowed improving the quality of the manuscript. All mistakes are sole responsibilities of the authors and the board of editors.

About This Book

All papers published in this volume of *Springer Proceedings in Earth and Environmental Sciences* "Geoarchaeology and Archaeological Mineralogy—Proceedings of the 6th Geoarchaeological Conference, Miass, Russia, October 19–23, 2020," were subjected by the editors. The expert reviews were complying with professional and scientific standards expected from a scientific journal published by Springer.

Abstract

The proceedings include the extended abstracts presented at the "VII Geoarchaeology and Archaeological Mineralogy-2020" All-Russian Conference held at the Institute of Mineralogy SU FRC MG UB RAS, Miass, Russia at October 19–23, 2020.

Part I "Ancient Metallurgy: General Issues" is devoted to the general problems of archaeometallurgy of the Bronze and Early Iron Ages, affecting wide regions from the Northern Black Sea coast to China. Here are the authors' concepts on the development of metal production, as well as a series of the latest isotopic–geochemical studies of bronze and iron artifacts.

Part II "Ancient Metallurgy: Case Studies" presents the mineralogical and geochemical characteristics of metal artifacts, ancient ores and metallurgical processing products discovered during archaeological excavations. The results of this part are devoted to the period from the Bronze Age to the Middle Ages.

In the part "Bioarchaeology and Residue Analysis" are the features of the isotopic research of C, N, and Sr in organic and mineral sources from prehistoric sites of Central Eurasia, related to the issues of diet, migration, and individual mobility of people and technologies in antiquity.

The part "Mining of Ores and Minerals in the Past" combines the results of field and analytical studies of the ancient mines. The materials in this chapter are devoted to the Ural region primarily in the Bronze Age.

The part “Archaeological Pottery” is devoted to the features of the chemical and mineral composition of ancient ceramic artifacts originating from archaeological sites in the European part of Russia.

The part “Lithic Tolls and Materials” considers stone raw materials from the Paleolithic, Mesolithic, Neolithic and Bronze Age sites of Eastern Europe, the Urals and Central Asia. Taking into account the analysis of morphological and petrographic features, questions of the origin, the use of stone tools, and their role in the subsistence of prehistoric societies are discussed.

The part “Site Analyses and Geographic Information Systems (GIS) in Archaeology” highlights the application of the complex investigation (GIS, photogrammetry, and remote sensing methods) in the study of archaeological heritage of Eurasia.

The last part “Reviews. Thoughts. Memoirs” brings together historical, social, and methodological reviews related to geoarchaeological problems of different eras and regions. The final part of the section is an article dedicated to the memory of Gennady B. Zdanovich, the famous archaeologist of the Southern Urals, who made a significant contribution to the development of interdisciplinary archeology of the region.

The book is intended for archaeologists, historians, museum workers, and geologists and also would benefit students, graduate students, and specialists—who are interested in the application of minerals at different stages of human development.

Contents

Ancient Metallurgy: General Issues

Internal and External Impulses for the Development of Ancient Chinese Metallurgy

Stanislav A. Grigoriev

Abstract There are two points of view on the origins of Chinese metallurgy. The most widespread idea is that it originated and developed as a result of impulses from the steppe cultures of Southern Siberia. The second point of view: Chinese metallurgy originated in the Neolithic of the Yangtze basin and then spread to the Yellow River basin. This version explains the paradox of Chinese metallurgy better, as copper-tin alloys replaced pure copper. However, the analysis of the Neolithic materials of the Yangtze and Yellow River basins showed that metallurgical production was there in a much-underdeveloped form. The number of copper objects has been exaggerated due to erroneous dating. The earliest well-documented smelting sites appeared in the late 3rd millennium BC in Gansu, but there is no evidence of their connection with Siberian cultures. There is no evidence of Andronovo influences. The Seima-Turbino impulse, which coincided with the beginning of the Shang Dynasty around the 16 century BC, probably, had an impact. But it spread not from the west but the north. This impulse probably stimulated the use of copper-tin alloys, but the use of bronzes in a ritual context was the main reason.

Keywords Bronze Age · Metallurgy · China · Technologies · Socio-economic processes

1 Introduction

In most regions of the Old World (Northern Eurasia, Europe, and the Near East), the development of ancient metallurgy was realized according to one pattern that can be considered universal. With the socio-economic development, the demand for metal increased, which caused a transition to new types of ores and technologies of their smelting. This, in turn, stimulated the transition to new types of alloys. As a result, everywhere there were two interrelated trends: (1) copper-oxidized ore—ore with low-melting gangue–ore with gangue and impurities of arsenic–ore with additions

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of arsenic minerals—copper-iron sulfides and ores in refractory rocks (e.g., quartz); (2) pure copper–arsenic copper–tin bronze (Grigoriev 2017, 2018). However, the dynamics are different in China. Here, after a very limited use of pure copper, there was a sharp rise in production with the transition to the smelting of tin bronzes. Two explanations have been proposed for this paradox. The first is based on the idea that the metallurgy of the Gansu province (between Xinjiang and the Great Plain) was a transmission link between the metallurgy of the Eurasian steppe and the Erlitou culture of the Yellow River, which formed the basis of the subsequent metallurgy of the Shang Dynasty (Mei, 2003). According to the second, Chinese metallurgy formed in the Neolithic of the Middle Yangtze. During this period, the use of sulfides and tin bronzes developed; therefore, it is proposed to consider this period as the Bronze Age (Guo et al. 2019, etc.).

2 Results and Discussion

2.1 Cultural Specificity in Metal Consumption

An important difference between China and other regions is the role that metal played in culture. The bulk of the metal is found in a prestigious ritual context. In comparison with this, the use of metal in warfare was somewhat limited while growing steadily. Despite the rapid development of agriculture and the emergence of large urban centers in the Neolithic, this did not increase metal consumption. Changes begin only with the formation of the Shang State, and the overwhelming mass of metal of this time is represented by ritual bronze vessels. This had a significant impact on the nature of changes in the types of alloys and smelting technologies. But it is also necessary to understand the significant difference in metallurgy in different regions of modern China and different periods. A summary statistical procedure for this entire territory is meaningless, and it is necessary to analyze all these territories separately. However, this requires many analyses, but the number of chemical analyses for China is slightly more than 3000, and the finds of smelting places are extremely rare. Therefore, we can trace only the most general trends.

2.2 Western Periphery

The most straightforward situation is observed in the west of Xinjiang, where during the first half of the 2nd millennium BC, metal objects have analogies in the Andronovo culture, and then in the cultures of the steppe Final Bronze Age (see Mei 2000), and smelting of copper-iron sulfides and tin alloys appeared. In Gansu, the first metallurgical production was formed in the late 3rd—early 2nd millennia BC in the Xichengyi culture (Li et al. 2015), and then in the Qijia and Siba cultures. It is characterized by the smelting of oxidized ore in quartz rock and subsequent remelting of the resulting product together with arsenic minerals. Sometimes tin minerals were used as an alloying component. However, this technology has nothing in common with Eurasian technologies to produce both arsenic and tin alloys. In addition, the parallels proposed in the Qijia and Siba cultures in the metal of southern Siberia (Afanasievo, Okunev, Seima-Turbino, Andronovo) are primarily erroneous. More correct are parallels with the later Karasuk metal, which in China is chronologically comparable already with the Late Shang period (the thirteenth to eleventh centuries BC). Nevertheless, this technology was probably borrowed from an unclear source so far, since it should be preceded by several stages given in the introduction.

About the beginning of the second half of the 2nd millennium BC, this technology, apparently, spread to the southwest of Shaanxi (Chen et al. 2017). Still, we cannot deduce from this its spread to the east and the formation of the Shang metallurgy of the Yellow River basin since the latter was based on copper-iron sulfides and alloying of metallic copper with tin.

2.3 Metallurgy of the Yellow and Yangtze Rivers

Metallurgy in the Yangtze and the Yellow River basins formed already in the Neolithic, during the 5–3 millennia BC (Li 2004, p. 189, 191). However, the number of copper objects from this period is exaggerated. Probably, the total number from the Pre-Shang period does not exceed 150 units. However, it is difficult to calculate due to the erroneous or uncertain context of many finds. Moreover, most objects belong to the final phase, to the late 3rd—first third of the 2nd millennium BC (An 1982–83, p. 69). In the north, the metal is represented mainly by pure copper, and single objects were made of arsenic copper and brass.

In the south, metallurgy remains are associated with the Qiujialing and Shijiahe cultures (Fig. 1). But what is described as copper ingots are pieces of oxidized ore; objects described as metallurgical furnaces are usual pits. The fragments of large "smelting vats" are fragments of vats for making alcoholic beverages. There is no reliable evidence on ore smelting in any of these regions, although some finds (arsenic copper in the north, tuyeres, and ore in the south) suggest this. But even if it is possible to show the existence of metallurgy, it could not be a base for the subsequent Shang production.

The developed metallurgy of the Bronze Age, with tin and tin-lead alloys and smelting of copper-iron sulfides, appeared in the Yellow River Basin during the transition from period 2 to period 3 of Erlitou, and the beginning of the Shang Dynasty can be associated with this transition. In radiocarbon chronology, period 3 is dated between 1610 and 1555 BC (Zhang et al. 2008, 197–210). Chinese scholars see the roots of this dynasty to the northeast from the future core of the Shang state, in Hebei, and the west of Shandong (Chang 1983, p. 500, 501, 509, 510). Significantly, the Seima-Turbino tradition of casting socketed objects from tin bronzes appeared exactly in the area of distribution of ceramics of the Middle Shang period and to the

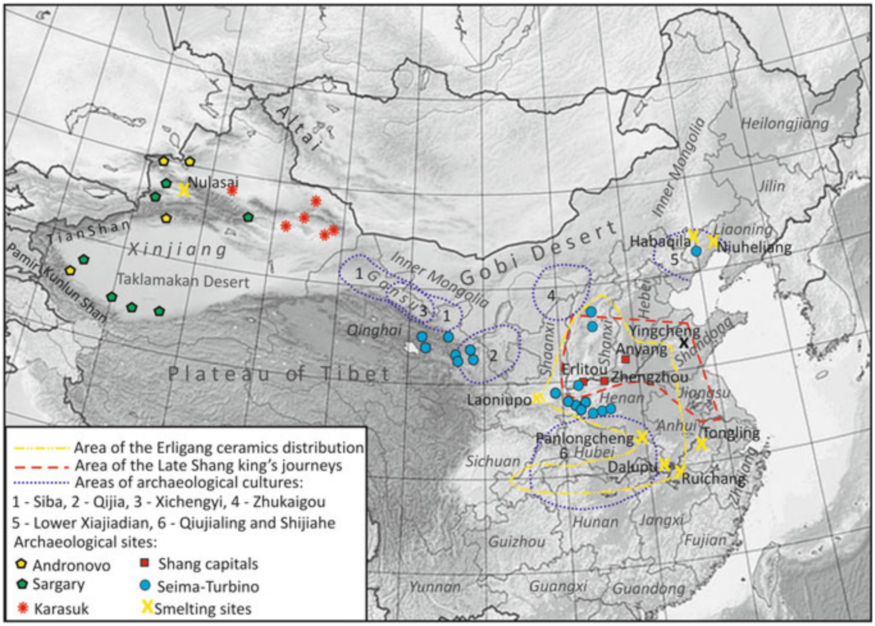

Fig. 1 Map of metallurgical sites and cultures on the territory of the PRC mentioned in the text

northeast of it (Lin 2014). Most of the objects are concentrated in the area of the Early Shang capital, Erlitou. Some objects are also present to the west, in Gansu, but they are cast from pure and arsenic copper, in some instances with minimal tin admixtures (see Fig. 1). The coincidence of these processes suggests that the tradition of these alloys was brought to China by the Seima-Turbino tribes, not through Xinjiang and Gansu, but Liaoning and Hebei. This route is confirmed by the fact that the spearheads in the northeast are morphologically closer to the Seima spearheads and were cast from alloys with a high tin content (Grigoriev 2021). To the south and southwest, this alloy is replaced by arsenic or pure copper. The formation of the Shang state led to a sharp increase in the demand for the metal, and this growth was provided by the classic combination of alloys with tin and smelting of copper-iron sulfides. At the same time, smelting of sulfides was carried out in large volumes in the mining areas, and copper or matte was already delivered to the Shang foundries in the core area.

The increased demand for metal led to the territorial expansion of the ore base. As a result, Shang metallurgical technologies penetrated the Yangtze, where the richest deposits of copper and tin are located. Large centers, for example, Panlongchen, began to function there, providing metal supplies to the north (Liu et al. 2019). These centers mark the distribution of Shang culture and technology, but it does not follow that they were a part of the Shang in a political sense.

In addition, Shang technologies penetrated to the west, to Shaanxi and Gansu, up to the east of Xinjiang, and the north, to Inner Mongolia and Liaoning, forming a broad belt of the Northern periphery of the Shang civilization. About the fourteenth to thirteenth centuries BC, in the late Shang period, on this periphery, Karasuk-type objects of southern Siberia are widespread, and the production of arsenic copper (Li et al. 2013, 4, 6), which is characteristic of Karasuk culture. Thus, the Northern periphery, with its Siwa culture in Gansu, Zhukaigou in the south of Inner Mongolia, and the Lower Xiajiadian culture in the east of Inner Mongolia and west of Liaoning, becomes for many years an area of interaction between steppe and Chinese cultures and a place where steppe and Chinese technologies coexisted.

3 Conclusions

Thus, there are no grounds for the opinion that Chinese metallurgy developed in a somehow unusual way. It was developing according to the same principles as metallurgy in the western regions of Eurasia. The growing demand for metal also stimulated its development, and the latter by the socio-economic development of society. As in the west, we see a strict correspondence of ore and technological schemes to the same types of alloys. Of course, as in the west, there are some deviations from this, caused by the specific raw material situation, trade relations, etc. Sharp technological changes were driven by external technological impulses, which was not unusual in many other regions. Therefore, the opinion about the unique ways of Chinese metallurgy is largely mythologized. It was subordinated to general trends based on universal socio-economic and physicochemical laws and the peculiarities of different types of raw materials in ore deposits.

In the Yellow River and Yangtze basins, metallurgy originated in the Neolithic and existed in a very weak undeveloped form. At the end of the 3rd millennium BC, there was a technological impulse from an undefined western source to Gansu, which spread to the east in the 2nd millennium BC (Fig. 2). For the formation of the Shang metallurgy, the spread of the Seima-Turbino tradition from the north was especially important. Subsequently, we see the influence of the Shang metallurgy to the south, north, and west. In western Xinjiang, during this period, Andronovo impulses are observed, followed by impulses of the steppe cultures of the Final Bronze Age. Finally, in the 2nd millennium BC, there was an interaction between the Karasuk metallurgical traditions from southern Siberia and the Shang tradition along the entire Northern periphery.

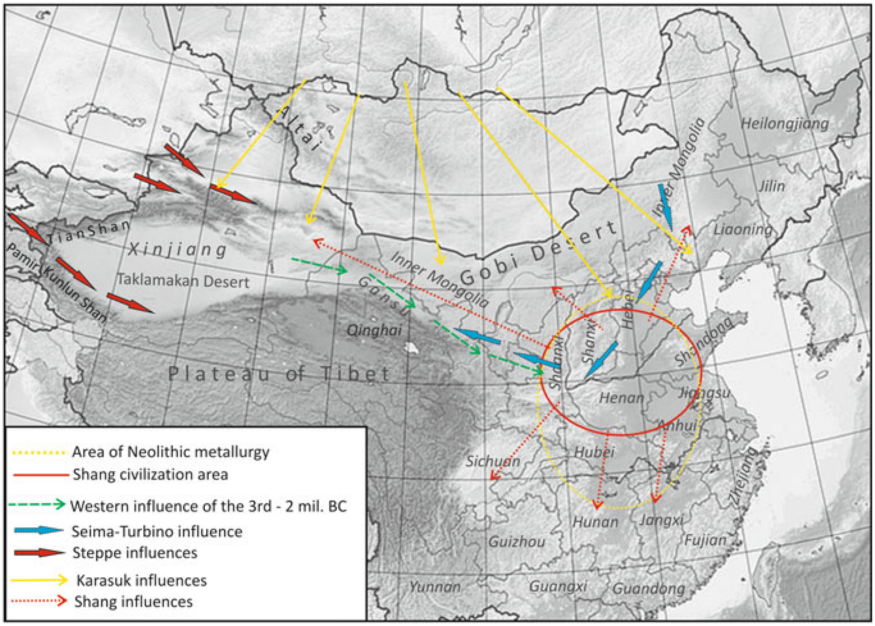

Fig. 2 Cultural impulses influenced the development of Chinese metallurgy

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Iron Sources and Technologies During the Early Iron Age in the Northern Pontic Region

Marianna A. Kulkova, Maya T. Kashuba, Aleksandr M. Kulkov, Tatyana V. Ryabkova, Mariya N. Vetrova, Aurel Zanoci, and Olga V. Bubnova

Abstract The questions about the early stages of development of iron technology (the first millennium BC) in the Northern Pontic region are considered in the article. Three traditions of iron making were identified: the Eastern European, the Caucasian/Ancient Oriental, and the Hallstattian (Carpathian-Danube). It is important to compare geochemical and technological features of the earliest iron items belonging to different iron-making traditions and to determine the iron ore sources. The precise analytical methods (Metallography, SEM–EDX, pXRF, XRD, m-CT) were used for the determination of geochemical and mineralogical composition of iron items and slags from the sites of Saharna Mare (Hallstatt tradition) and Tarasova Balka (the Eastern European tradition). As a result of investigations, various iron manufacturing technologies and used iron ore sources were determined.

Keywords Early iron manufacture · Metallography · SEM-EDX slags · Geochemistry of iron slags · Hallstatt (Carpathian-Danube) iron making tradition · The Eastern European iron making tradition · m-CT of iron items

1 Introduction

One of the innovations in the ancient technologies is the discovery of iron ore mining and iron smelting. This allowed for the development of iron-working. Unlike the

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bronze production where the process of casting was used, the production of iron items required drastically new methods such as hammering. The modern technology of cast iron production was developed only in 18 c. AD after the high-temperature blast furnaces started being used. Therefore, the development of blacksmithing craft in ancient times was a long and multistep process requiring repetitive work and practice. This process lasted from 3 to 1th millenia BC and incorporated the early skills with working of meteoritic iron, ore mining, the production of bloomery iron, and mastering of work with this material.

The process of penetration of iron technology in the societies of Eastern Europe (from the Urals to the eastern Carpathians) was uneven. Primarily it was developed in the societies which previously mastered the bronze making. They were familiar with copper and tin ore mining and the methods of production and working of bronze and copper alloys. Societies of Eastern Europe fully mastered the methods of iron manufacture by the 9th c. BC. The total number of artifacts from the Bronze-Iron Ages transition phase in Eastern Europe consists of more than 100 items. Among them, 20% were found in the kurgans of early nomads and belong to the "Cimmerian" culture. This common occurrence of iron products suggests the existence of iron production technology among the local people of Eastern Europe. At the same time, bronze began to be replaced with iron in two main categories of objects, weapons and tools, which needed to be sharp and hard.

The chronology of Early Iron Age cultures in the Northern Pontic region is currently debated. Mainly it is because of the lack of sufficient number of radiocarbon dates for the Final Bronze age and the Early Iron age. There are about 30 radiocarbon dates for a period of 13/12th–8th c. BC. For this timespan, the distribution of the radiocarbon dates bears uneven character, with existence of chronological lacunas for some archaeological cultures. Based on archaeological collections and radiocarbon dates the transition period (*Ferraeneum*) between Bronze Age and Iron Age was identified (Bochkarev and Kashuba 2018). This period incorporates the later phases of the Late Bronze cultures including Gáva-Holigrady, Bondarikha, Belozerskaya, as well as Visotskaya, Chernolesskaya, Saharna and Holercani-Hanska. It also includes the "Cimmerian" sites of the first phase and earlier sites of the second phase. Iron items were not found during excavations of the sites dated to this time in the eastern part of the Eastern Europe (Kašuba et al. 2019).

On the basis of the investigation of evidence from early iron metallurgy in the region, Terekhova and Erlikh (2002) developed a concept of the appearance of the Eastern European iron technological tradition. The main technical characteristics of this tradition are the use of the heterogenous mixture of soft iron and low carbon steel. The Eastern European tradition was developed in the Belozerskaya culture. This tradition was spread throughout the Northern Pontic region reaching the western part of the forest zone. In the steppe zone of the sites of Belozerskaya culture, the iron products represent items for thrusting and cutting (knives and daggers) and adornments. There are also finds of bimetallic daggers combining bronze and iron metal. The dating of these items is 11th–10th c. BC. In the forest-steppe zone (the Middle Dnieper region), the thrusting and cutting items (knives and awls) were found in excavations of sites of Belogrudovskaya and Chernolesskaya cultures (the right bank of Dnieper) as well Bondarikhinskaya culture (on the left bank of Dnieper). They are dated to the end of 11th(?) and 10th–9th c. BC (Kašuba et al. 2019).

In the area of the Northern Pontic region apart from the Eastern European tradition, N. Terekhova and V. Erlikh also identified the Caucasian (Trans-Caucasus) or Ancient Near Eastern iron-working tradition. Kashuba (2013) identified the Hallstatt (Carpathian-Danube) iron-working tradition. The latter appeared in the Eastern Carpathian region due to the spread of tribes from the Carpathian basin, Middle and Low Danube basin during the final Bronze—early phases of the Early Iron Age (end of 2nd-beginning of 1st millenium BC). The chronological framework of these cultures coincides with the European chronology of the Hallstatt period: HaA–HaD phase (Kashuba, 2012).

The results of investigation of iron artifacts produced via Eastern European tradition were presented in several publications (Shramko et al. 1977; Bidzilja et al. 1983, etc.). The results of investigation of iron products from the Bel'skoe settlement (Fig. 1) are presented in the recent publication by Shramko et al. (2020). The metallography of three knives from the sites of Bondarikhinskaya culture (11th–9th c. BC) showed that one product (knife from the Chervony Shlyakh-1 site) has a poor quality with low level of iron-working skills. However, the other two items (knives from the Oskol site) are characterized by good quality and high level of forge welding and were manufactured from the soft iron and unevenly carburized steel (Shramko and Buinov 2012). Metallography and X-ray analysis of two bimetallic daggers from the Sofievka and Golovjatino sites belonging to Chernolesskaya culture showed that the dagger from the Golovjatino site was produced from the low quality bloomery iron, while the dagger from the Sofievka site was produced from the moderately carburized steel (Shramko et al. 1977). The metallography of two iron knives from burial-1 of Kochkovatoe mound-31 of Belozerskaya culture showed that bloomery iron was used for their manufacture (Vanchugov 1990). In the artefact assemblage

Fig. 1 Map of the location of Saharna Mare (11–10 cc. BC) and Tarasova Balka (7–6 cc. BC) sites

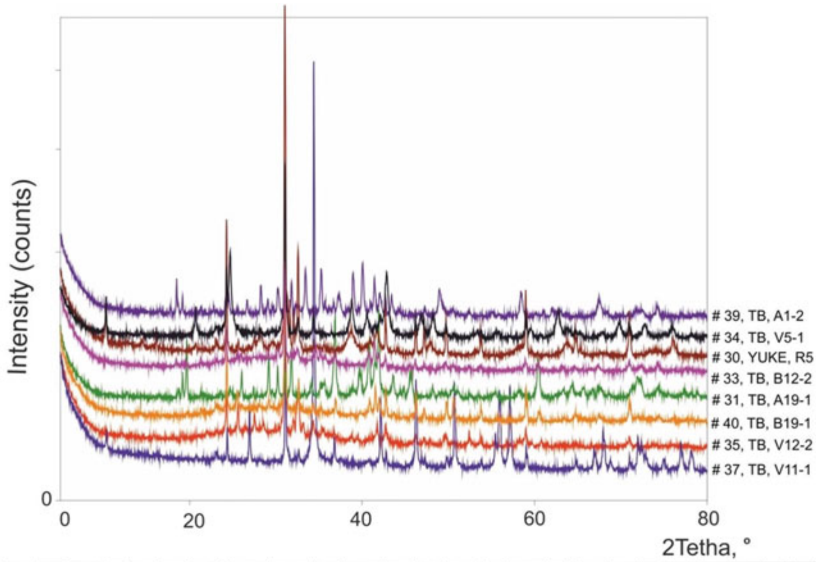
from the burial-2 of Stepnoy/Zapovitne mound-5 a bimetallic dagger dated to 11th c. BC was found (Otroshchenko 2003). Recently, the radiocarbon date of 1375–1131 cal BC was obtained for the bimetallic dagger from burial-3 of Khadzhillar mound-1. This date indicates the use of bronze-iron daggers by people of Belozerskaya culture already at the 12th–11th c. BC.

The above-named iron-making traditions were distinguished mainly based on the investigation of materials from archaeological collections via traditional archaeological methods. The advanced analytical methods have not been applied to most of the archaeological iron artifacts of this period. In this sense, it is important to compare the geochemical characteristics of the earliest iron items belonging to different traditions in order to reconstruct their technologies and to find out about the raw ore sources from which the iron was smelted. The main problem of the researchers is often a small number of iron artifacts from the transition period and the early phases of the Early Iron Age for the considered territory. One of the causes for the lack of iron materials is their bad preservation during burial due to corrosion. Due to these factors, many initially existent objects were not preserved. Almost all iron artifacts of the named period are stored in museums. Therefore very small number of iron fragments was sampled for investigation. Apart from metallography, we used modern high precision analytical methods (e.g. SEM–EDX) for the study of iron pieces of 1–5 mm size. The sampling of this small amount of material largely did not affect the appearance of the museum items. In some cases, just iron corrosion from the item surface was analyzed.

2 Materials and Methods

In this work, we present the first results of multidisciplinary investigation of five archeological iron artefacts belonging to various metallurgical traditions and seven iron slags. The complex analytical methods were applied for the study of (1) iron knives from the Saharna Mare site (11th–10th c. BC) manufactured via the Hallstatt Carpathian-Danube iron-working tradition (Figs. 1 and 2) and (2) steel arrowheads and metallurgical slags from the Tarasova Balka site (Ryabkova 2015) (see

Fig. 2 Iron knives from the Saharna Mare site (**a** 44/4, **b** 65/1, **c** 144/1) and iron arrowheads from the Tarasova Balka site (**d** V11/47, **e** B 11/40)



Mineral	Quartz SiO_2	Na-Ca feldspar $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$	Kaolinite $Al_2Si_2O_5*(OH)_4$	Muscovite	Calcite $CaCO_3$	Goethite FeO(OH)	Cordierite $(Mg,Fe)_2Al_3[Si_5AlO_{18}]$	Mullite from $Al_2O_3*2SiO_2$ to $2Al_2O_3*SiO_2$	Pyroxene (Aegirine) $NaFe[Si_2O_6]$	Pyroxene (diopside) $CaMg[Si_2O_6]$	Olivine (fayalite) Fe_2SiO_4	Leucite $K(Si_2Al)O_6$	Magnetite Fe_3O_4	Rhonite $Ca_4(Mg_8Fe_2Ti_2)O_4[Si_6Al_6O_{36}]$	Molybdenite MoS_2	Olivine (monticellite) $CaMgSiO_4$	Wustite FeO	Sphalerite ZnS	Pentlandite $(Ni,Fe)_9S_8$	Millerite NiS	Pyroxene (jadeite) $NaAl[Si_2O_6]$	Anatase TiO_2	Analcime $Na(Si_2Al)O_6*H_2O$	Hematite Fe_2O_3	Microcline $KAlSi_3O_8$
$2\Theta_{100\%}$, °	26,6	26,93	12,37	35	29,4	21,4	10,46	26,22	29,94	29,95	35,9	27,3	35,5	35,09	14,4	33,6	41,9	28,85	51,5	32,3	30,6	25,5	25,96	33,3	28

Fig. 3 XRD analysis of slag mineralogical composition

Fig. 1). These products are from the early Scythian period (7th–6th c. BC) and were manufactured via the Eastern European iron-working traditions.

Three small iron pieces from three knives (see Fig. 2a, b, c) from the Saharna Mare site were analyzed by SEM-EDX, metallography (Polarizing Microscopy Leica 4005P), and Digital microscopy (Keyence VHX1000) (Fig. 3).

It needs to be noted that only above-listed iron artifacts were found at the site. The remains of slags and other by-production of metallurgical production have not been found during the excavations. Small pieces of iron (2–3 mm) were embedded into epoxy resin and polished. Then, the surfaces were treated with a 10% solution of HNO_3 in ethanol. This pretreatment allowed conducting metallographic investigation on the surface of the fragments (see Fig. 3b).

The rich collection of bronze and iron products was found at Tarasova Balka site located in the North-Western Caucasus region (see Fig. 1). The most interesting are two arrowhead samples (Fig. 2d, e). For their investigations, the methods of SEM-EDX, p-XRF, and m-CT were applied. Slags were dispersed across the whole of Tarasova Balka not concentrating at any specific area of the site. No possible manufacturing zones were identified at the site. Overall, using various analytical methods we investigated seven slag samples and one ore sample. The chemical composition was determined by p-XRF on the polished surfaces three times. The average values of elemental concentrations are presented in Table 1. In accordance with instruction of the pXRF analyzer, standard reference materials were measured after initialization of the system, and before each set of measurement of archeological samples. The detailed geochemical-mineralogical analysis was done using scanning

Table 1 The contents of chemical elements in slags and iron items by pXRF analysis

Sample number	P, ppm	S, ppm	Cl, ppm	K, %	Ca, %	Ti, ppm	V, ppm
#30, YUKE, R5 (ore)	709	373	3262	0.7	1.57	782	66
#34, TB, V5-1 (slag)	n/o	776	2541	0.82	5.39	787	34
#37, TB, V11-1(slag)	n/o	929	2689	0.37	25.08	344	17
#31, TB, A19-1(slag)	n/o	1211	3344	1.56	2.22	934	21
#40, TB, B19-1(slag)	2835	168	2154	1.34	1.43	2290	51
#35, TB, V12-2(slag)	n/o	1033	1437	1.02	1.28	1708	44
#39, TB, A1-2(slag)	n/o	922	1599	4.24	5.21	779	43
#33, TB, B12-2(slag)	n/o	<150	2021	1.36	2	778	29
Б11/40 (arrow)	6610	1092	n/o	1.24	3.09	2337	218
B11/47 (arrow)	10,011	1610	n/o	1.01	3.9	1840	176

Sample number	Cr, ppm	Mn, ppm	Fe, %	Ni, ppm	Cu, ppm	Zn, ppm	Zr, ppm
#30, YUKE, R5 (ore)	27	620	4.29	42	1	5	42
#34, TB, V5-1(slag)	8	65	3.88	55	1	6	45
#37, TB, V11-1(slag)	5	496	0.38	9	3	3	44
#31, TB, A19-1(slag)	23	154	6.27	91	37	2	46
#40, TB, B19-1(slag)	34	129	5.41	83	3	4	50
#35, TB, V12-2(slag)	45	294	1.48	37	16	11	49
#39, TB, A1-2(slag)	<8	156	9.97	176	103	2	42
#33, TB, B12-2(slag)	<9	57	10.65	156	59	2	41
Б11/40 (arrow)	82	231	11.33	n/o	25	22	20
B11/47 (arrow)	101	189	9.16	n/o	37	36	28

Sample number	Pd, ppm	Ag, ppm	Cd, ppm	Sn, ppm	LE, %
#30, YUKE, R5(ore)	4	16	8	5	92.84
#34, TB, V5-1(slag)	56	34	20	55	89.46
#37, TB, V11-1(slag)	56	26	8	51	73.7
#31, TB, A19-1(slag)	n/o	15	14	14	89.36
#40, TB, B19-1(slag)	39	33	5	51	91.03
#35, TB, V12-2(slag)	2	6	6	5	95.76
#39, TB, A1-2(slag)	48	52	33	35	80.18
#33, TB, B12-2(slag)	25	60	34	31	85.67
Б11/40 (arrow)	n/o	159	n/o	36	83.25
B11/47 (arrow)	n/o	156	n/o	44	84.51

electron microscopy (SEM-EDX) on polished section surfaces and XRD analysis of powder probes.

SEM-EDX analysis of samples was carried out at the Hitachi S-3400 N Scanning electron Microscope. The automatic powder diffractometer D2Phaser (Bruker) was applied for XRD analysis of slag mineralogical composition (see Fig. 3). The bulk chemical composition of samples was obtained on p-XRF Innov XSystems. Inner reconstruction of arrowheads was provided by the SkyScan m-CT Scanner 1172 (Bruker). All measurements were carried out at the Centres of RDMI and “Geomodel” in the St. Petersburg State University using standard procedures.

3 Results and Discussion

Saharna Mare site. The samples from three iron knives were analyzed (see Fig. 2a, b, c).

In sample 44/4 (#62 in Database of iron items) in according to SEM–EDX analysis (Fig. 4c) material of light-gray color consists of pure iron (Fe) without impurities. Inclusions of minerals of dark gray color consist of Fe-olivine (fayalite), porous inclusions (grains) of light gray color have a composition of FeO (Mn, Ti) and comprised by goethite and magnetite. The composition of fayalite is close to stoichiometric; admixtures of Mn and Mg are attested. Inclusions of fayalite ($Fe_2(SiO_4)$)

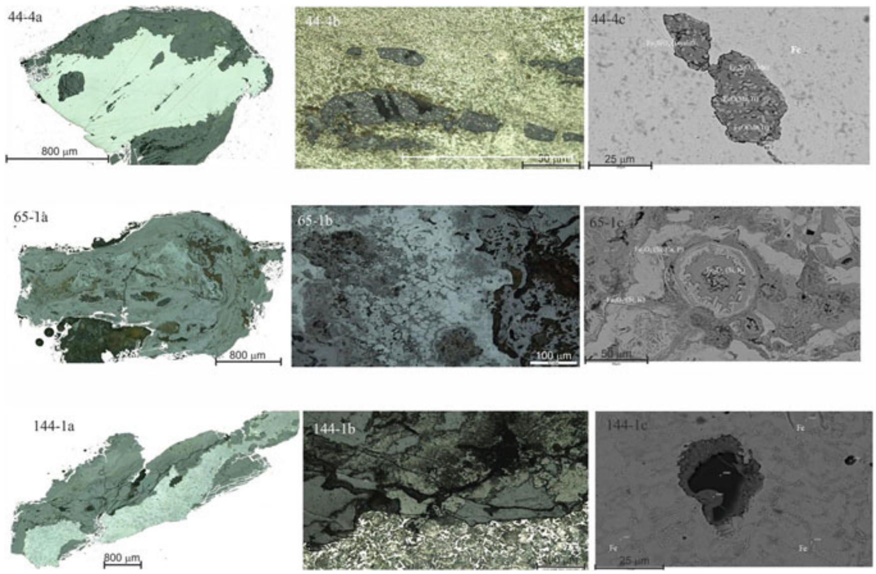


Fig. 4 **a** Digital microscopy of a thin section of knives; **b** Optical reflected microscopy of knives; **c** SEM-EDX microscopy of knives

were formed as a result of the melting of iron ores. In the sample, the presence of Mn, Ti in olivine can be a marker of iron ore type. Such geochemical association and olivine formation during fusion can be evidence of using magnetite-ilmenite ores which are genetically connected with intrusive magmatic rocks (e.g. granite, diorite). At the same time, alluvial deposits of titan-magnetite sands which are known in the coastal part of the Black Sea could have also been used (Inozemtcev et al. 2019).

In the reflected light, the alloy used in the sample 65/1 (#63) (Fig. 4b) is different in comparison to the sample 44/4. The objects mainly consist of secondary minerals (goethite and limonite) and has strongly corroded structure. Individual grains and secondary multilayer oolites with needle crystals were formed during the secondary corrosion. The main mineral of the matrix is hematite (Fe_2O_3) with the presence of elements (Si, P, Ca, K). The most corroded part has a composition of limonite ($FeOOH \times H_2O$) (Fig. 4c). The mineralogical and geochemical composition suggests that the sedimentary ores were used for bloomery iron production. Possibly, it was lake or bog ores. The metal was smelted at the temperature of about 900–1100 °C.

The structure and mineralogy of sample 144/1 (#64) (see Fig. 4) according to optical parameters is close to those of the sample 44/4. Based on the results of SEM-EDX the matrix of the sample consists of pure iron. In the matrix, there are individual grains of silicate minerals (plagioclase) and goethite (FeO (Mn, Ti)), and oxides of iron. Traces of Mn, Ti can be an evidence of the use of magnetite ore.

The mineralogical and geochemical investigation allowed determining two different sources of iron ores which probably were used for the manufacture of iron alloys for knives from the Saharna Mare site. Two of these samples (44/4, 144/1) were made of iron ores of high quality (magnetite-ilmenite composition). Possible sources of these ores are alluvial magnetite sands deposited in the coastal part of the Northern Black Sea. Their use for iron metallurgy was published elsewhere (Inozemtcev et al. 2019). The fusion of these ores was at temperatures about 1100–1200 °C and more. Another source of raw material for the making of 65/1 knife was the lake bog or floodplain limonitic (oolite) ores. Their elaboration for bloomery iron did not require such high smelting temperature as in the first case. The temperature could have reached about 900–1100 °C. Iron is more corrosive and of bad quality. Probably, there were two impulses of receipt of raw material: one way—from the South (Northern Black Sea coast) and another way was from the North. The second source could be presented by local bog iron ores.

Tarasova Balka site. The investigation of slag and ore allowed determining their mineralogical and geochemical compositions and textural features which provides information about ancient technological processes of iron making and raw material sources. The results of XRF and XRD analysis are presented in Tables 1 and 2.

1. *Sample of ore (#30, YUKE, R5). Ferruginous sandstone is bright red color* (Fig. 5a).

Based on SEM-EDX analysis, the structure of the sample is a grainy aggregate consisting of rounded grains of quartz, calcite, angular grains of feldspar, and pyroxene. Quartz is presented by isometric 100–250 μm grains. On the surface of

Table 2 The mineralogical composition of slags and ores on data of XRD analysis

#30, YUKE, R5	#34, TB, V5-1	#37, TB, V11-1	#31, TB, A19-1
Quartz SiO_2	Quartz SiO_2	Quartz SiO_2	Quartz SiO_2
Feldspar $NaAlSi_3O_8–CaAl_2Si_2O_8$	Feldspar $NaAlSi_3O_8–CaAl_2Si_2O_8$	Feldspar $NaAlSi_3O_8–CaAl_2Si_2O_8$	Olivine–fayalite Fe_2SiO_4
Kaolinite $Al_2Si_2O_5*(OH)_4$	Kaolinite $Al_2Si_2O_5*(OH)_4$	Pyroxene-diopside $CaMg[Si_2O_6]$	Leucite $K(Si_2Al)O_6$
Calcite $CaCO_3$	Calcite $CaCO_3$	Calcite $CaCO_3$	Magnetite Fe_3O_4
Hematite Fe_2O_3	Goethite FeO(OH)	Mica	Roenite $Ca_4(Mg_8Fe_2Ti_2)O_4[Si_6Al_6O_{36}]$
Microcline $KAlSi_3O_8$	Mica		Molybdenite MoS_2
Mica			

#40, TB, B19-1	#35, TB, V12-2	#39, TB, A1-2	#33, TB, B12-2
Quartz SiO_2	Quartz SiO_2	Quartz SiO_2	Quartz SiO_2
Feldspar $NaAlSi_3O_8–CaAl_2Si_2O_8$	Feldspar $NaAlSi_3O_8–CaAl_2Si_2O_8$	Olivine (Montichellite-kirschsteinite) $CaMgSiO_4$	Olivine–fayalite Fe_2SiO_4
Olivine–fayalite Fe_2SiO_4	Magnetite Fe_3O_4	Magnetite Fe_3O_4	Magnetite Fe_3O_4
Leucit $K(Si_2Al)O_6$	Mullite (from $Al_2O_3*2SiO_2$ to $2Al_2O_3*SiO_2$)	Wustite FeO	Leucit $K(Si_2Al)O_6$
Magnetite Fe_3O_4	Pyroxene-aegirine $NaFe[Si_2O_6]$	Pyroxene-zhadeit $NaAl[Si_2O_6]$	Analcime $Na(Si_2Al)O_6*H_2O$

(continued)

Table 2 (continued)

#40, TB, B19-1	#35, TB, V12-2	#39, TB, A1-2	#33, TB, B12-2
Mullite (from Al_2O_3*$2SiO_2$ to$2Al_2O_3$*SiO_2)	Cordierite $(Mg,Fe)_2Al_3[Si_5AlO_{18}]$	Anataz TiO_2	
Pyroxene-aegirine $NaFe[Si_2O_6]$		Sphalerite ZnS	
		Pentlandite $(Ni, Fe)_9S_8$	
		Millerite NiS	

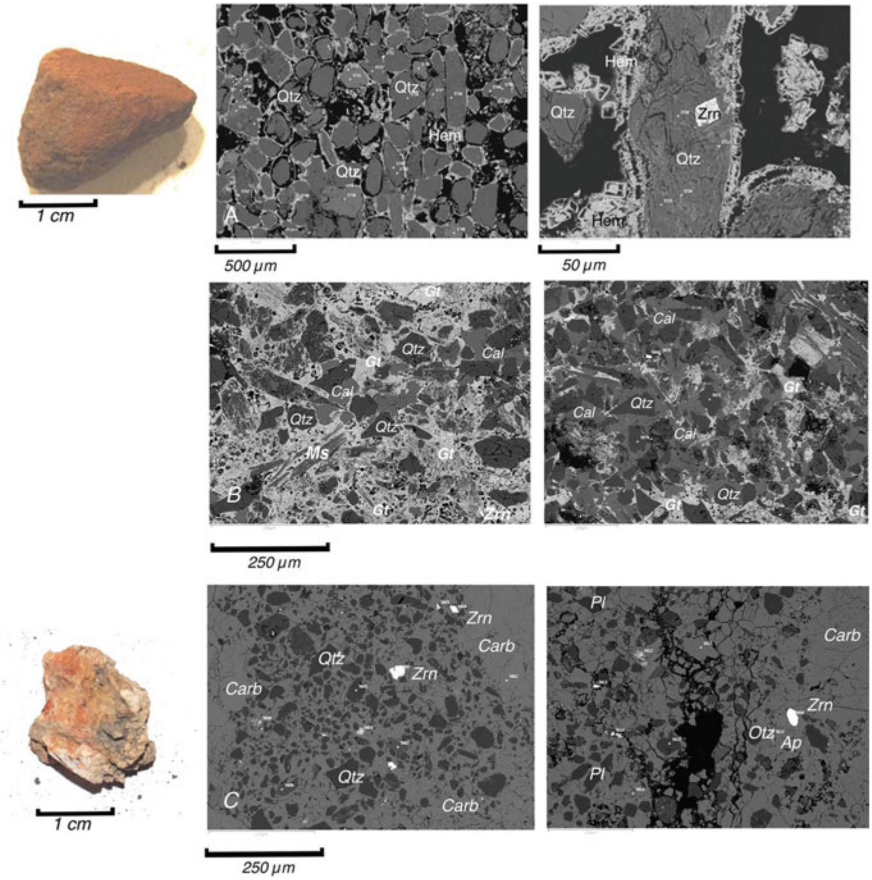


Fig. 5 SEM-EDX of **a** ferruginous sandstone (#30, YUKE, R5) Qu-quartz, Hem-hematite, Zrn-zircon; **b** slag (#34, TB, V5-1) Cal-calcite; Gt-goethite, Ms-mica; **c** slag (#37, TB, V11-1) Carb-carbonate, Ap-apatite, Pl-plagioclase

quartz grains, there are secondary minerals (chlorite and stilpnomelane). The feldspar consists of microcline and albite 100–200 μm grains. The grains of carbonate have a round shape and contain isomorphic admixtures of MgO and FeO. All grains have coats of iron oxides (hematite). Accessory minerals are apatite, rutile, and pyroxene. According to XRD analysis, the main mineral phase is hematite and the ferruginous (hematite) sandstone are known to locally occur.

2. *Sample of slag (#34, TB, V5-1) of red-brown color* (Fig. 5b).

According to SEM-EDX analysis, the matrix consists of iron oxides embedding angular grains of quartz, feldspar, carbonate, and fiber crystals of muscovite. The carbonate grains are eroded and replaced by iron oxides. Accessory minerals are zircon (enriched by Hf, Y), rutile, and monazite. Geochemical and mineralogical compositions of slag (see also Tables 1 and 2) (presence of a sand component of quartz, feldspar, accessory minerals like zircon, rutile, and monazite) show that ferruginous (hematite) sandstone of local origin could been smelted. The chemical composition of slag is close to the sandstone sample. The high carbonate content (as well as Ca) is evidence of carbonate flux addition.

3. *Sample of slag (#37, TB, V11-1) of red-brown color* (Fig. 5c).

The results of SEM–EDX analysis show the matrix consists of iron oxides with inclusions of grains of quartz and K-Na feldspar. The grains have angular shape with sizes from 10 to 100 µm. K-Na feldspar is albite and K-feldspar with an isomorphic mixture of orthoclase ($KAlSi_3O_8$) and albite ($NaAlSi_3O_8$). Accessory minerals are zircon (enriched in Hf), olivine (kirschsteinite), apatite, rutile, and monazite. This slag is similar to the slag (#34).

4. *Sample of slag (#31, TB, A19-1) of black color with gray inclusions* (Fig. 6d).

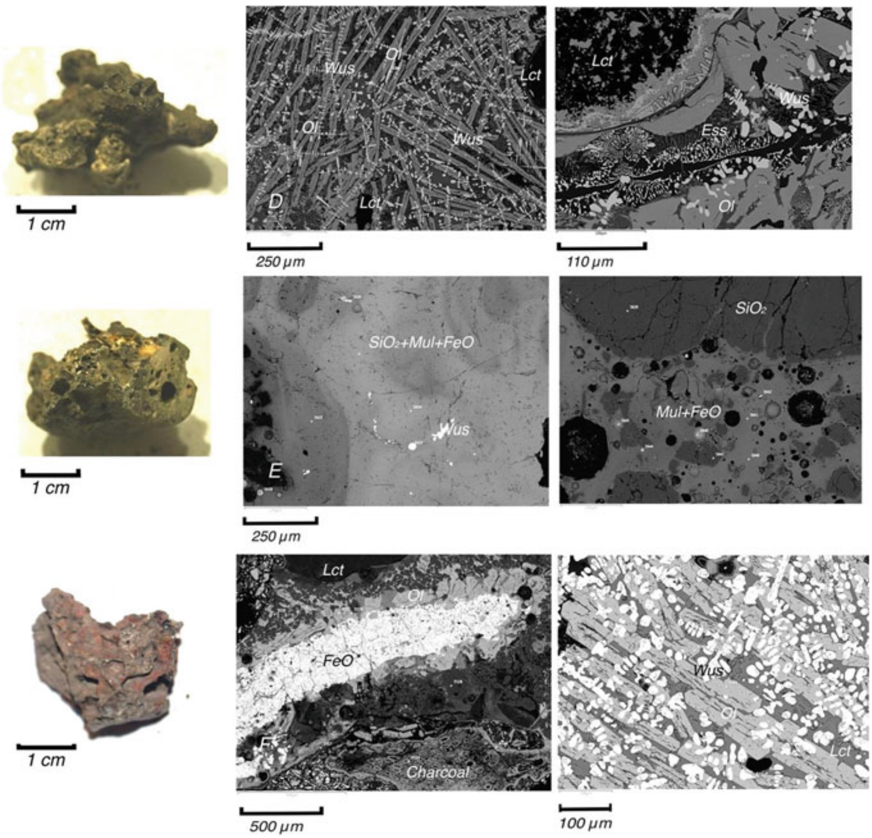


Fig. 6 SEM–EDX of **d** slag (#31, TB, A19-1); **e** slag (#40, TB, B19-1); **f** slag (#35, TB, V12-2)

As the results of SEM-EDX and XRD analysis, the matrix consists of long skeletal crystals of fayalite, dendrites of Iron (wustite), and some leucite and pyroxene esseneite ($CaFe_3$ + ($AlSiO_6$). Crystals of olivine are needles of 250–500 µm in length with an admixture of MgO (0.85–3.9%). Iron oxides formed skeletal crystals and dendrites. There are some admixture of SiO_2 (0.48–8.96%). Esseneite is present as needle crystals between olivine crystals. Leucite fills voids and veins of a matrix. Iron consists of pure iron and wustite. In comparison to samples (#37, 34) this sample has higher concentration of Fe and Ni (Table 1). The smelting occurred at reducing conditions in a furnace at a temperature of about 1100–1200 °C in the presence of carbonate flux (forming esseneite and roenite). The cooling was fast. This is evidenced from the presence of dendrites of wustite and skeletal crystals of olivine. The slag is of a tap type, formed during flow of the melt outside of the furnace. Magnetite ores could be used as raw sources.

5. *Sample of slag (#40, TB, B19-1) of black color with gray inclusions* (Fig. 6e).

The results of SEM-EDX analysis, show that the matrix consists of amorphous silica and mullite with inclusions of iron oxides (FeO = 17–49%). In comparison to samples (#37, 34) this sample contains a higher concentration of Fe and Ni. The smelting happened at high temperature in a reduced atmosphere. Ti-magnetite ores could be used as raw sources. This slag is similar to the slag (#34).

6. *Sample of slag (#35, TB, V12-2) of light-gray color with black inclusions* (Fig. 6f).

According to the SEM-EDX analysis, the matrix has a zonedl structure. The central part consists of iron oxides, the inner zone consists of olivine (fayalite + kirschsteinite) and the outer zone (10–500 µm) is filled by leucite. In the bottom part of the matrix (see Fig. 6F) there is a fragment of charcoal replaced by iron oxides. In the central part of charcoal, there are fragments of olivine + iron oxides. Olivine has some amount of Mg (1.24–3.74%). Accessory minerals are pure copper and cassiterite. Iron oxide phase contain inclusions of chromium oxides. In comparison to other slags, this sample is characterized by a high concentration of Ti (see Table 1). The smelting happened inside of the furnace, at high temperature (1200–1300 °C)—the olivine and mullite were formed in a reduced atmosphere (Table 2). The bottom of the slag characterized by the structure of slow cooling. Ti magnetite ores could have been smelted. Mullite and cordierite formed in presence of clay components from the furnace walls.

7. *Sample of slag (#39, TB, A1-2) of light-gray color with black inclusions* (Fig. 7g).

The matrix consists of species of olivine (montichellite-kirschsteinite) and wustite according the results of SEM-EDX and XRD (see Table 2) analysis. Kirschsteinite contains admixture of MgO (2.61–3.36%). Iron oxide phase contains TiO_2 (1.49–2.21%). Accessory minerals are copper oxides and sulfides (chalcocite). Cuprite contentains isomorphic admixtures of As_2O_3 (2.73–8.16%) and FeO (6.21–7.11%).

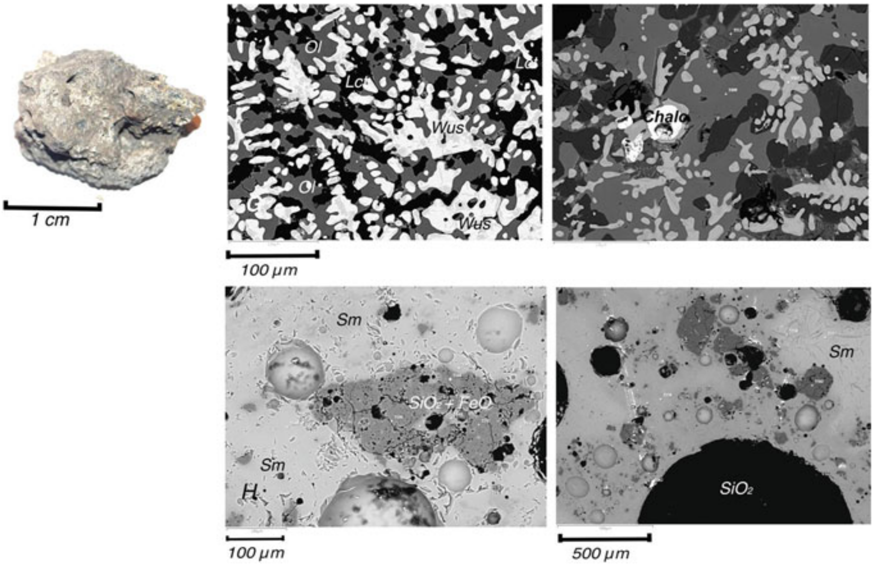


Fig. 7 SEM-EDX of **g** slag (#39, TB, A1-2); **h** slag (#33, TB, B12-2)

Based on the geochemistry and mineralogy of the sample (see Tables 1 and 2), we can suggest that sulfides and fahlore were smelted. The smelting happened in a reducing atmosphere, with fast cooling. The smelting temperature was about 1200–1300 °C.

8. *Sample of slag (#33, TB, B12-2) of dark-gray color* (Fig. 7h).

According to the SEM–EDX analysis, the matrix consists of smectite with some zones of amorphous silica. Accessory minerals are rutile and chrome-rich spinels. The smelting occurred at high temperatures, in an unstable atmosphere without flux. The cooling was fast.

Based on the geochemical and mineralogical study of the slag, four groups can be distinguished.

1st group—hematite-goethite slags (#34, 37) were formed as a result of smelting of local ore (ferruginous (hematite) sandstone (#30)). They have red-brown color and granular structure. In the matrix, there are angular grains of different sand minerals (quartz, carbonates, apatite, rutile, mica, monazite). The smelting occurred in an open furnace, at a temperature of about 900–1100 °C. Carbonates were added as a flux. This is evidenced from the presence of angular grains of carbonates in the matrix and high Ca concentrations.

2nd group—Ti-magnetite slags (#31, 33, 40) have dark-gray and black color. The main part of the matrix consists of olivine (fayalite) with fewer other high-temperature minerals like Ca-pyroxene (esseneiite), and leucite. According to (Olovčić et al. 2014) and (Chuenpee et al. 2014), the presence of Ca-rich pyroxene and Ca-olivine (kirschsteinite) could be the results of the addition of lime-rich flux to achieve minimal temperature melting and facilitate the welding process. Kirschsteinite is not a naturally occurring mineral and commonly forms during smelting. The magnetite is an indicator of an unstable atmosphere inside the furnace with the presence of oxygen and insufficient reduction (Bella et al. 2018). A little amount of carbonate flux was probably added. As a result, these slag samples have a lower contents of calcium in comparison to the first group. The smelting happened in a closed furnace at a high temperature (1200–1300 °C). The cooling was fast and slag is tap-type that has been formed outside of the furnace at a temperature of 1100–1300 °C. The skeletal crystals of olivine and eutectic wustite dendrite are the indicators of this process (Török et al. 2010, 2015). The presence of an amorphous phase of mullite and some Al-rich minerals could occur during the smelting of solution with clay component from clay walls of the furnace (Olovčić et al. 2014). One of the samples (#33) was formed without flux addition.

3rd group—magnetite slags (#35). Slags have a light-gray color with inclusions of black color. The slag formed inside the furnace as deduced from a zoned structure. If the system contains relatively high CaO content, the olivine may become kirschsteinite ($CaFeSiO_4$). Kirschsteinite is not a natural mineral phase. It is typically found in metallurgical slags whose formation requires reducing conditions and high temperature (Bella et al. 2018). These slags are a cintered-type slag formed at the bottom of the furnace during smelting with charcoal (Török et al. 2015; Barros et al. 2020; Veldhuijzen and Rehren 2007). The smelting happened in a reducing atmosphere, at high temperatures (1200–1300 °C). Magnetite ores could have been used as a raw material.

4th group—slag of sulfide and fahlore ores (#39) have a light-gray color with inclusions of black color. The matrix contains inclusions of pentlandite, sphalerite, chalcocite and millerite. The smelting happened in a reduced, unstable atmosphere, with fast cooling. The temperature of smelting was about 1200–1300 °C with the addition of carbonate flux (formation of montichellite–kirschsteinite).

The formation of tap-slag type can occur if the iron production was well-developed where the furnace allowed a slag removal. Such kind furnace construction is characterized by high productivity.

We investigated the mineralogical and geochemical composition of two iron arrowheads (Fig. 2). According to the SEM–EDX analysis (Figs. 8b, and 9b), the sample (#58, V11/47) consists of olivine (fayalite), quartz, phosphates (apatite-vivianite), iron oxides (goethite, magnetite). The composition of the sample (#53, B11/40) is iron oxides (goethite, magnetite), quartz, zircon and traces of phosphates.

The data from SEM and p-XRF analysis shows the varying compositions of alloys. Probably, different types of ores were used. The steel of sample (#58, V11/47) was made of the ore that was more hard to smelt. Steel formed at high temperature (olivine is an indicator of this) and with the addition of flux. The presence of phosphates and high Ca and P concentrations allow assuming an application of crushed bones as a flux. The steel of the sample (#53, B11/40) varies in mineralogical composition. It contains quartz and zircon. The concentrations of calcium and phosphorus lower than in the sample (#58, V11/47). Probably, flux for this sample consisted of sand. It is known that the addition of quartz as flux resulted in a melting temperature decrease

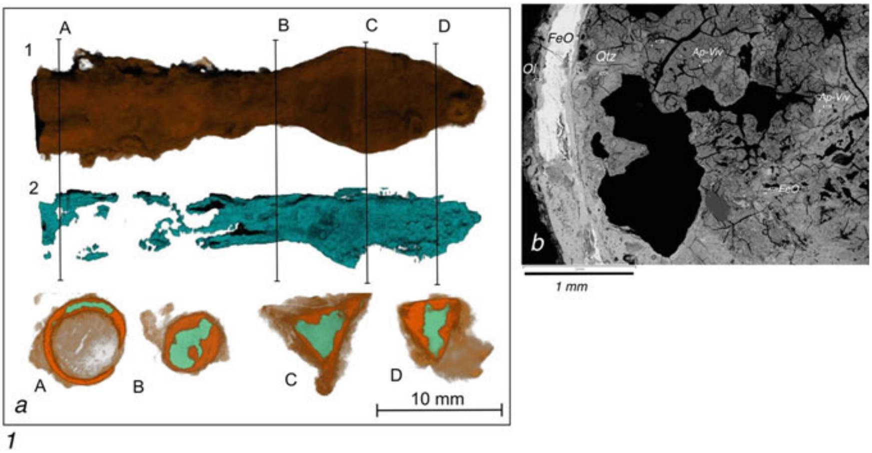


Fig. 8 Iron arrowhead (#58, V11/47) **a** m-CT **b** SEM-EDX analysis

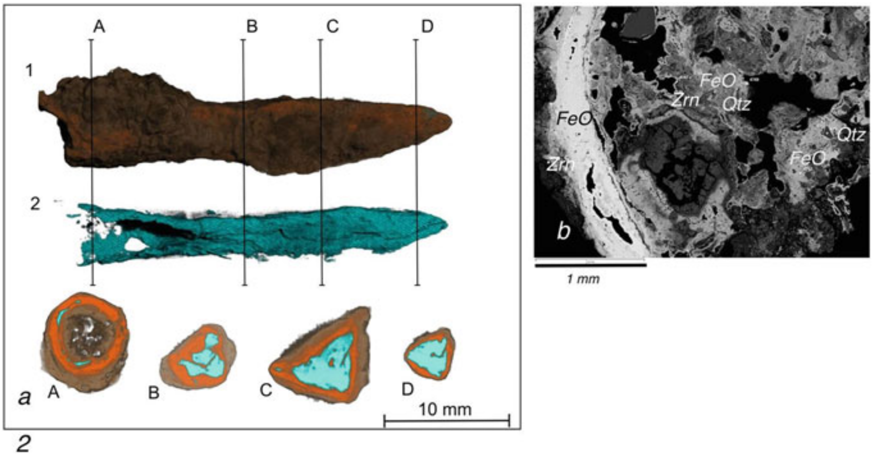


Fig. 9 Iron arrowhead (#53, B11/40) **a** m-CT **b** SEM-EDX analysis

of around 200°C and decrease of the furnace temperature down to 980–1000 °C (Portillo-Blanco et al. 2020). Probably, Ti-magnetite ores were used as raw material for production of metal for both items.

The technologies of manufacture of arrowheads show variation. This is seen from the results of m-CT analysis (Figs. 8a, and 9a). The sample (#53, B11/40) could have been made from a steel plate by curving and twisting in a spiral shape. To be used by such a technique the steel must have been ductile. The presence of high phosphorus concentration in steel alloy promotes brittleness increase. The sample (#58, V11/47) has a high P concentration and was probably brittle. Therefore arrowhead was made using another technique. The steel rod could have been flattened to form a blade.

Therefore, in the Tarasova Balka site several types of iron ore could have been used for iron making: local ferruginous sandstones, Ti-magnetite ores, sulfide and fohlore (polymetallic) ores. Several types of smelting technologies can be considered: the smelting in a close furnace at high temperature (1200–1300 °C) with high yield and smelting in an open furnace at low temperature (900–1200 °C). Techniques of arrowhead making vary and probably depended on the quality of steel.

4 Conclusions

The consideration of geochemical and mineralogical data of the ancient iron items and slags from the sites of Northern Black Sea cost dated to 11th–6th c. BC and belonging to different iron-making traditions allowed to identify several technological processes that used different types of iron ores. In the Early Iron Age the iron technology began to be rapidly adopted in the different parts of the Northern Pontic Sea region. It can suggested that these processes happened independently from each other.

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Lead Isotope Analysis of the Bronze Age Metal in the Steppe Cis- and Trans-Urals

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Abstract The Southern Urals in the 4th-2nd millennium BC was a key mining and metallurgical region of Eurasia with hundreds of copper deposits and thousands of ore occurrences developed from the beginning of the Bronze Age to the Iron Age, where three major (the Trans-Urals, Cis-Urals, and Ural-Mugodzhary) mining and metallurgical centers were located. Lead isotope ratios are used in archaeology to identify raw materials for the production of metal in antiquity. The lead isotope composition does not change during metallurgical processes and remains constant regardless of the ore roasting temperature or Red-Ox conditions of smelting this work aims to identify the potential sources of ore raw materials for the production of many copper artifacts of the steppe Cis-Urals and Trans-Urals of the Bronze Age by multicollector inductively coupled plasma mass spectrometry (MC-ICP-MS) lead isotope analysis. The results of lead isotope analysis made it possible to obtain new data for many copper artifacts (products and ingots) of various periods of the Bronze Age (4th-2nd millennia BC). The detected variations in lead isotopes indicate a rather clear connection between copper artifacts and the original ores of the Trans-Urals or Cis-Urals.

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Keywords Lead isotopes · Copper ingots · Copper ores · Provenance · Late Bronze Age · Cis- and Trans-Urals

1 Introduction

The Southern Urals in the 4th-2nd millennium BC was a key mining and metallurgical region of Eurasia with hundreds of copper deposits and thousands of ore occurrences developed from the beginning of the Bronze Age to the Iron Age (Chernych 1970). Three mining and metallurgical centers (MMC) were distinguished on the territory of the Southern Urals in the Bronze Age: the Trans-Urals, Cis-Urals, and Ural-Mugodzhary (Chernych 1970; Tkachev 2011; Tkačev u.a. 2013; Zaikov et al. 2013; Yuminov et al. 2013, 2017; Bogdanov 2017). Ancient mines confined to sulfide and quartz-azurite-malachite ore deposits in copper sandstones and conglomerates of the Late Permian served as the raw material base of the Cis-Urals MMC (Bogdanov et al. 2018). The Cis-Urals MMC is the largest historical and metallurgical formation in Eurasia regarding its scale of mining and metallurgical activities, the extraction volume of copper ores, and areal characteristics (Kargaly I 2002, Kargaly II 2002, Kargaly III 2004, Kargaly IV 2005, Kargaly V 2007). The Trans-Urals MMC is associated with the development of zones of secondary enrichment and oxidation of volcanogenic massive sulfide (VMS), skarn, hydrothermal quartz vein, and porphyry copper deposits localized in volcanic and ultramafic rocks. In the Ural-Mugodzhary MMC, ancient mines are found in ultramafic and talc-carbonate rocks, pyroxenites, basalts and jaspers, granitoids, and in contact zones.

Lead isotope analysis (LIA) is based on the use of lead stable isotopes resulting from the radioactive decay of uranium and thorium (Faure and Mensing 2005). Due to different half-lives of ^{235}U, ^{238}U, and ^{232}Th, decaying to ^{206}Pb, ^{207}Pb, and ^{208}Pb, respectively (while Pb^{204} is non-radiogenic and its content is constant and corresponds to its initial content in lead at the moment of the start of U and Th decay), it is possible to determine the Earth's age and geological developments, which have led to the emergence of ore deposits (Hauptmann 2007). Lead isotope composition remains constant regardless of the ore roasting temperature or Red-Ox conditions of smelting (assuming a sole ore source and no mixing or recycling) (Pernicka et al. 1984); although several factors complicate the interpretation of LIA results of ancient metal. For example, ore deposits may have identical or partially overlapping lead isotope composition, ~~even at significant distances from each other~~; moreover, the remelting of metal scrap, as well as the use of raw mixtures from two or more ore sources with different lead isotope ratios might complicate the correct assignment of metal products to ore sources (Hauptmann 2007). The using of chemical composition to assign metal objects with a particular ore deposit is subject to criticism due to the geochemical variability of ore deposits and the fractioning of trace elements during metallurgical processes from ore to metal (Hauptmann 2007). The lead isotope composition of metal can be influenced by silicon, calcium, and other fluxes used in melting copper, as well as ligations in alloys. However, with careful consideration of the above factors, lead isotope ratios can be successfully used in archaeology to identify raw materials for the production of metal, glass, ceramics, pigments, etc.

The measurement of Pb isotopes stands to gain the most from MC-ICP-MS (Multi-collector Inductively Plasma Mass Spectrometry) techniques because there is no suitable isotope ratio against which instrumental mass bias can be corrected on a TIMS (Thermal Ionization Mass Spectrometry) (Kamber and Gladu 2009). Although this issue can be overcome using double or triple spike techniques (labor and cost-intensive) yielding the most precise and accurate data, the analytical resolution of multi-collector MC-ICP-MS without double-spiking appears more than sufficient to explore a large number of geochemical tasks (Kamber and Gladu 2009).

This work aims to identify the potential sources of ore raw materials for the production of copper artifacts of the steppe Cis-Urals and Trans-Urals of the Bronze Age by multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) lead isotope analysis.

2 Materials and Methods

The fragments of copper ingots and metal artifacts originating from archaeological sites and accidental finds in the Trans-Urals (Ustye, Kamenny Ambar) and the Cis-Urals (Turganik, Ordynsky Ovrag, Usolka in the center of the Kargaly ore field, Tokskoe, Kyzyloba, Kurganny burial ground near the Baryshnikov hamlet and Ileksky burial ground, ingot hoards near the Novo-Privolny, Almala, Belousovka, and Mayorskoye villages, in the Sol-Iletsk town, near the Verkhneozernoe village) located, respectively, on the territory of the Chelyabinsk and Orenburg regions, are studied. The geographical locations of the studied objects are shown in Fig. 1. The cultural and chronological features of the analyzed metal products and the products of metallurgical processing are different. The Cis-Urals series is represented by the samples of metal from various tools and two crude copper ingots from the Yamnaya (Pit Grave) culture of the Early Bronze Age (4th millennium BC—first half of the 3rd millennium BC), as well as by 12 plano-convex discoid, or "bun" crude copper ingots from the Srubnaya and Alakul cultures of the Late Bronze Age (2nd millennium BC). The Trans-Urals sites comprise the materials from the Sintashta culture of the early phase of the Late Bronze Age (early 2nd millennium BC), the early (Petrovka) stage of the Alakul culture, and syncretic Srubno-Alakul complexes of the Late Bronze Age (second and third quarters of the 2nd millennium BC). An impressive series of sulfide ores and products of pyrometallurgical processing obtained from the Mikhailovsky, Belousovsky, and Karpovsky mines and associated mining metallurgical complexes with fire pits and sludge dumps located in the south-western outskirts of the Kargaly ore field (Bogdanov et al. 2018; Bogdanov 2019) dated by the middle of the 2nd millennium BC, was studied.

Sample preparation and analysis were carried out in cleanrooms (classes 1000 and 10,000) and laminar flow boxes (class 100) at the IGG UB RAS, Ekaterinburg

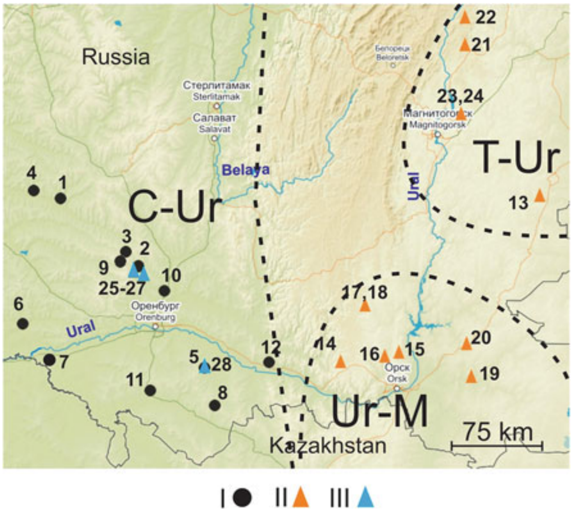

Fig. 1 The key archaeometallurgical and geoarchaeological sites of the Southern Urals. I—Archaeological sites of the steppe Cis-Urals: 1—Turganik settlement, 2—Ordynsky Ovrag settlement, 3—location of a copper ingot in the south of the Kargaly ore field near the Uranbash village, 4—Tokskoe settlement, 5—mining and processing complex at the Kyzyloba mine, 6—Kurganny burial ground near the Baryshnikov hamlet, 7—Ileksky burial ground, 8—hoard near the Novo-Privolny village, 9—hoard near the Almala village, 10—hoard near the Mayorskoe village, 11—hoard in the Sol-Iletsk town, 12—hoard near the Verkhneozernoe village. II—VMS deposits of the Southern Urals and ore from archaeological sites: 13—ore from the Kamenny Ambar settlement, 14—Yaman-Kasy, 15—Gai, 16—Ishkinino, 17—Ivanovskoye, 18—Dergamysh, 19—Barsuchii Log, 20—Dzhusa, 21—Molodezhnoe, 22—Uchaly, 23—Babarik, 24—Alexandrinskoe. III—key copper mines and mining and processing complexes of the south-western outskirts of the Kargaly mines: 25—Mikhailovsky mine and Mining processing complex, 26—Karpovsky mine, 27—Belousovsky mine and Mining processing complexes №1–№2, 28—Kyzyloba mine. The dotted line shows the boundaries of mining and metallurgical centers and the main cultural and historical communities in the Southern Urals (Artemyev and Ankushev 2019): C-Ur—Cis-Urals MMC; T-Ur—Trans-Urals MMC; Ur-M—Ural-Mugodzhary MMC

(Kiseleva et al. 2021). Each of the items was mechanically micro-sampled. The dissolution of metal samples (0.01 g) was carried out in closed PFA vials using a mixture of concentrated HNO_3 (1 ml) and HCl (3 ml) on a hot plate at 120 °C until complete dissolution (several hours). After evaporation to dryness, 0.1 ml of concentrated HBr was added and evaporated again. The residue was then redissolved in 0.5 ml of 0.05 M HBr, placed in microtubes, and centrifuged for 15 min at 6000 rpm.

Although MC-ICP-MS has transformed the field of isotope ratio determination for Pb-isotope determination, the optimistic early hope that isotope ratio determination by ICP-MS might overcome the need for labor-intensive, costly, and failure-prone element purification has largely evaporated and given way to a more cautious view that precise and accurate determinations require very careful separation of the element of interest from the geological, biological or environmental matrix (Kamber and Gladu 2009).

The conventional ion-exchange chromatography technique proposed by (Kamber and Gladu 2009) was used for lead isolation. Bio-Rad AG 1×8 resin (100–200 mesh) was loaded into pre-cleaned polypropylene funnels (Vitlab) fitted by chemically resistant glass wool (11 μm, Carl Roth). The parameters of the resin layer and the elution protocol are given in (Kiseleva et al. 2021). A fresh portion of resin was used for each sample, thus eliminating the memory effects of the resin. The purified lead fraction was evaporated to dryness and dissolved in 2 ml of Tl-containing 3% (v/v) HNO_3.

Lead isotopes were measured on a Neptune Plus multicollector ICP mass spectrometer (Thermo Fisher Scientific) with an ASX 110 FR automatic sample introduction system (Teledyne CETAC) fitted by PFA micro-flow nebulizer (50 $\mu l \cdot min^{-1}$) connected to a quartz spray chamber. A blank correction was obtained using a 3% (v/v) HNO_3 washing solution. Detailed operational conditions of Neptune Plus are given in (Kiseleva et al. 2021). Lead isotopes were measured using the Tl-normalization technique (Woodhead 2002) with the correction of ^{204}Pb isobaric interference by $^{202}Hg/^{204}Hg = 4.350370$ and normalization according to the exponential law. The accuracy and long-term reproducibility of the lead isotope ratio measurements were evaluated using NIST SRM-981 ($n = 63$): $^{208}Pb/^{206}Pb = 2.1681 \pm 0.0008$, $^{207}Pb/^{206}Pb = 0.91452 \pm 0.00036$, $^{204}Pb/^{206}Pb = 0.059059 \pm 0.000042$ (Kiseleva et al. 2021).

3 Results and Discussion

Determined lead isotope ratios in comparison with the ores of the VMS deposits of the Trans-Urals and the northern outskirts of the Ural-Mugodzhary region (Tessalina et al. 2016) are shown in Fig. 2. The clusters of archaeological samples from the Trans-Urals and Cis-Urals are located, respectively, at the beginning and end of the plots, which may be associated with the geochemical features of the ore-bearing complexes of the Upper Permian (copper ores of the Cis-Urals) and deposits of various formations within the ophiolite belt of the considered part of the Urals, associated with Devonian geological structures. The relative range of the sample points with a grouping in the central part of the plot indicates a fairly wide development of all available ore occurrences in the Cis-Urals and Trans-Urals differing in genesis and chemistry, by ancient metallurgical miners. Relatively rich deposits of various types were developed with Cu content in the ore protolith of 15–20% and higher.

Two Early Bronze Age artifacts belonging to the Yamnaya culture of the steppe Cis-Urals fall into the cluster of the Trans-Urals and Ural-Mugodzhary samples. These are a battle hammer axe from mound No. 2 of the Ileksky burial ground and a razor blade from mound No. 6 of the burial ground near the Baryshnikov hamlet, dating back to the first half of the 3rd millennium BC (Bogdanov 2004). That data could be the first evidence of ore development in the zones of secondary enrichment and oxidation of the VMS deposits in the Trans-Urals and the northern part of the Ural-Mugodzhary region, as well as the presence of probable traffic of ore materials

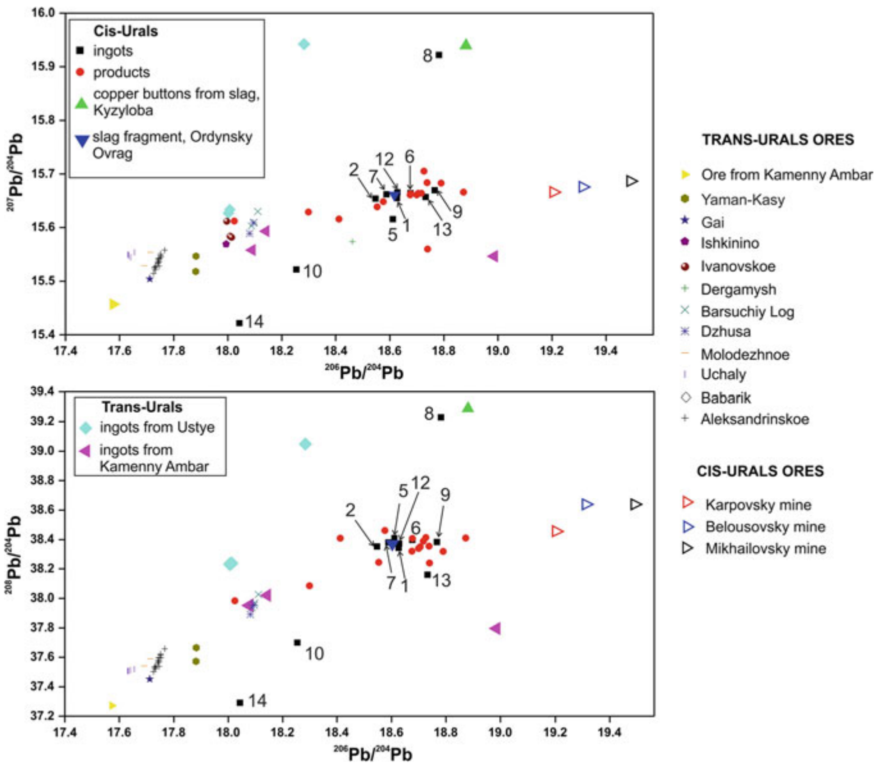

Fig. 2 Lead isotope ratios in the studied samples of copper ores, ingots, and Bronze Age artifacts from the Cis-Urals and Trans-Urals in comparison with the VMS ores of the Southern Urals (Tessalina et al. 2016). Numbers correspond to the sample codes for copper ingots. The error bars are smaller than symbols

and metal between the Trans-Urals and the Cis-Urals. Still, the trade of metallic items or metal recycling cannot be excluded.

A dramatic scatter of lead isotope ratios is observed for the drops and ingots of crude and refined copper from the settlements of Kamenny Ambar and Ustye (the first half–mid-2nd millennium BC). Such a scatter in the samples of the Southern Trans-Urals may indicate the use of various types of deposits (skarn, VMS) and copper ores (quartz-azurite-malachite and sulfide), which is confirmed by the study of metallurgical slags (Ankushev 2019; Artemyev and Ankushev 2019). Since the Kamenny Ambar is a two-layer monument, the Trans-Urals copper ore sources confined to ultramafic rocks could probably have been used at the Sintashta stage of the settlement at the beginning of the 2nd millennium BC, while the other sources of sulfide ores could have been exploited in the Srubno-Alakul times.

Two Cis-Urals bun ingots of crude copper of the Srubnaya culture (the ingot No. 10 (P-22-42 m) from an ancient mine dump in the outskirts of the Late Bronze Age Ordynsky Ovrag settlement dated by the middle of the 2nd millennium BC, and the ingot No. 14 (P-25 m) from the southern outskirts of the Kargaly mines (accidental find near the village of Uranbash)) refer to the field of the Trans-Urals and Ural-Mugodzhary MMC on the graphs. Late Permian sulfide and quartz-azurite-malachite ore occurrences in clay rocks, sandstones, and conglomerates were the main raw material for 14 bun ingots of the crude copper from the steppe Cis-Urals. Nevertheless, the isotope signature of ore originating from the minerals from the zones of secondary enrichment of VMS deposits was objectively recorded in the metal of the two ingots under discussion. This fact indicates the possibility of the existence of traffic of ore materials and the products of pyro-metallurgical processes between the Cis-Urals and the Trans-Urals. The archaeological complexes of the steppe Cis-Urals generally confirm this conclusion. According to the settlement and burial sites of the Kargaly ore field and its steppe outskirts, a significant mixing of ceramic, funeral, and other traditions is noted for synchronous cultures—the Srubnaya culture of the steppe Cis-Urals and the Alakul culture of the Cis-Urals and Trans-Urals (Kargaly I 2002, Kargaly II 2002, Kargaly III 2004, Kargaly IV 2005, Kargaly V 2007).

Alakul ingot No. 8 (P-94 m) from the hoard near the Verkhneozernoe village is close in the lead isotope composition to a copper button from the metallurgical slags of the mining complex of the Kyzyloba mine (Orenburg region), which reflects the use of copper ore sources with a close geological position by metallurgists of the Western Alakul cultural group. They are characterized by the maximum lead isotope ratios, but, in general, they are in the trend of the Cis-Urals samples. The separation of these two samples is probably due to the chemical features of the original ore protolith (sulfides and silicates of the Kyzyloba mine), apparently associated with different geological formations of the Late Permian ore occurrences of the steppe Cis-Urals developed in the Bronze Age.

4 Conclusions

The implemented method of lead isotope analysis made it possible to obtain new data for many copper artifacts (products and ingots) of various periods of the Bronze Age (4th-2nd millennia BC) of the steppe Cis-Urals and Trans-Urals. The detected variations in lead isotopes indicate a rather clear connection between copper artifacts and the original ores of the Trans-Urals or Cis-Urals, at least within the confines of the reference materials (VMS ores) used. The interpretation of results is difficult for several samples. Further, more precise comparisons will become possible only after the implementation of a large-scale program of isotopic analyses of ore deposits and occurrences of all mining and metallurgical centers of the Bronze Age in the Southern Urals.

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Ancient Metallurgy: Case Studies

Metalworking and Metallurgical Slags in Tokskoe Late Bronze Age Settlement

Maksim N. Ankushev, Ildar A. Faizullin, Dmitry A. Artemyev, and Ivan A. Blinov

Abstract The paper is devoted to the copper ore sources and the peculiarities of the metallurgical process in the Tokskoe Late Bronze Age settlement (first half of 2nd millennium BC). The results of archaeological excavations of past years are briefly described. House structures with pit-wells were found at the settlement; stone works related to metallurgy; a large number of copper ore fragments, metallurgical slags, metal artifacts. The mineralogy of slags and the composition of minerals were established by optical microscopy and SEM-EDS. Trace elements in sulfides and copper droplets were determined by LA-ICP-MS. As a result of the interpretation of mineralogical and geochemical data, it was established that rich chalcocite-covellite ores were exploited at the Tokskoe settlement. This is evidenced by the confinement of the settlement to copper sandstone deposits, the presence of relict and newly formed sulfides in slags, impurities of Ba and Cl in slag glass, as well as S, Ag, and Pb in copper droplets. The use of copper sandstones as raw materials and the technology of the metallurgical process at Tokskoe settlement are typical for the Late Bronze Age Srubna assemblages of the Southern Cis-Urals.

Keywords Metallurgical slags · Late Bronze Age · Kargaly · Copper sandstones · Southern Cis-Urals · Srubna culture

1 Introduction

The Cis-Urals copper sandstones, due to the near-surface location of stratiform and rich sulfide ore bodies, were a large copper ore base in the Bronze Age. The development of these deposits dates back to the beginning of the 3rd millennium BC the Yamna population, which was later replaced by the Abashevo, Srubna, and the Final Bronze Age assemblages (Chernykh 2008). At the largest Kargaly ore field and

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a specialized settlement of miners-metallurgists Gorny, large-scale archaeological work was previously carried out with subsequent analytical studies (Kargaly 2004).

To date, traces of metallurgical activity have been found in twelve settlements in the Western Orenburg region (Koryakova and Epimakhov 2007). Previously, only metalworking was noted at them, which includes the redistribution of finished ingots and billets, the casting of future products in molds, as well as their subsequent processing with a whole set of forging operations. Metal products are not very diverse and are most often represented by tools: tip, awls, knives, and tool blanks. However, in the Late Bronze Age burial sites and hoards of the Western Orenburg region, the amount of copper and bronze artifacts is quite large, which indicates the widespread use of metal items among the population.

Today, the technologies of ore mining, metal smelting, and alloying seem to be much more interesting. The Late Bronze Age settlements in the Western Orenburg region, which are located near Kargaly, allow a more detailed study of the metallurgical production in the region. Copper smelting at each specific settlement and the raw material base is a rather interesting question, and it can be answered by applying analytical methods to the products of metallurgical processing—slags. The main object of study in the article was the metallurgical slags from the Tokskoe Late Bronze Age settlement.

2 Materials and Methods

The Tokskoe settlement is located 6 km south of the Ivanovka village and 1.5 km northeast of the Yulty village of the Orenburg region. The settlement is located on the terrace of the right bank of the Tok River. During two field seasons (1979 and 1990), an area of 220 m^2 was excavated at the settlement. The materials from the 1979 excavations were briefly published (Morgunova and Porokhova 1989; Faizullin 2012, 2015). The results of the study of the osteological material are given just as briefly (Kosintsev and Varov 1992). Bone artifacts have been examined in the most detail, traceological analysis of all artifacts has been carried out (Usachuk and Faizullin 2016). The settlement dates back to the Late Bronze Age and was founded by the Srubna assemblages.

One house structure specializing in metalworking has been investigated in the settlement area. The excavation covered part of the house structure and a small area around it. A pit well with stonework was revealed in the center. It had a rounded shape with dimensions of 1.97×2.27 m and vertical walls. Filling strengthened the stonework in the center of the pit—the mouth of the well. The stonework began at the level of the house-structure floor; it was laid out of rough stones of various sizes, tightly packed in a circle.

In the southeastern part of the house structure, an oval depression was found in the sterile soil, 2×2 m in size and 13–26 cm deep. It had a bright brown color, apparently from burning. Separate blocks and accumulations of sandstone were found along the edges of the depression, without traces of thermal effects. Among the stones and in

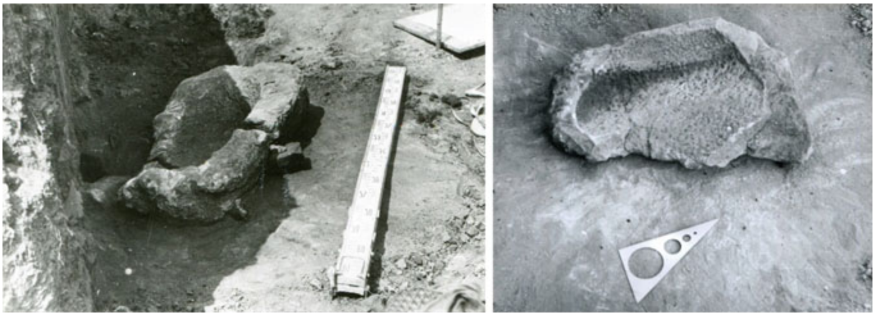

Fig. 1 Stone baths from Tokskoe Bronze Age settlement

the filling of the depression, many fragments of coal, several samples of slag, droplets of copper, and two fragments of ceramics that had undergone thermal action were found. The house structure described is probably associated with metallurgy.

Traces of metallurgical activity were also recorded around the well. A large number of copper ore fragments, metallurgical slags, animal bones with copper mineralization, melted blocks of sandstone were found here. Near the well, four fragments of pottery with a slagged inner surface were found.

Two baths were found near the stonework of the well (Fig. 1). One of them was a monolith with a hollowed-out depression. The dimensions of the bath are 0.6 × 1 m, the depth is up to 17 cm, and the walls are 8–10 cm thick. Nearby, a smaller bath was found, 0.3 × 0.56 m, with walls up to 8 cm thick, also made of a stone monolith. Similar finds were found at the Bronze Age metallurgist settlement in the Donbas (Tatarinov 1988). Usually, they are interpreted as baths for washing and enrichment copper ore (Khalyapina 2000).

At the bottom of the house structure, human bone remains from at least 10 individuals were found in random clusters around the pit-well and the northwestern part of the house structure. The position of the skeletons was recorded only in three places (Faizullin 2012). The interpretation of burials can be varied. Those buried could have been victims of ritual activities or part of the abandonment process practiced in traditional societies. The mass ‘burial’ of people in the Tokskoe settlement of Chemyakin (2015) refers to the traces of a military conflict. Citing as an example a whole series of Andronovo sites, on which, in his opinion, because of the sudden attack and the destruction of the settlement, people were not buried.

Two metal tools were found in the excavation: a four-sided awl, sharpened on both sides, and a needle, hollow and round in cross-section. Metallurgical slags from the Tokskoe settlement are represented by fragments of 4–7 cm, brown and black; oxidized regulus of copper are observed on the surface of the sample (Fig. 2). On the chip, the slag is glassy, with a large number of pores and secondary copper mineralization. The mineralogy of slags and the features of the composition of minerals were established in 3 samples by optical (Olympus BX 51, analyst M. N. Ankushev) and electron microscopy (Tescan VEGA 3 SBU, analyst I. A. Blinov). Trace elements in sulfides and copper droplets were determined by laser ablation on an Agilent 7700

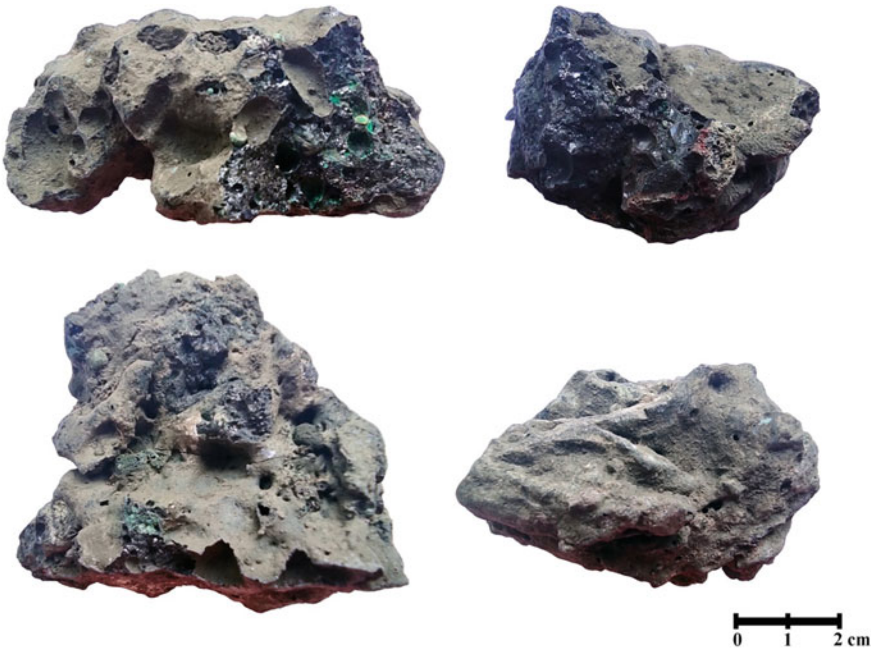

Fig. 2 Metallurgical slags of Tokskoe settlement

× inductively coupled plasma mass spectrometer and an NWR UP-213 attachment using NIST SRM-500, NIST SRM-610, USGS GSD-1 g, USGS MASS-1 standards. All analyzes were carried out in the Institute of Mineralogy SU FRC MG UB RAS laboratories.

3 Results and Discussion

Metallurgical slags from Tokskoe settlement belong to the glassy sulfide-containing mineralogical type (Ankushev et al. 2021a). The main slag component is glass, which corresponds to intermediate composition rocks and normal, rarely sub-alkaline petrochemical series (Table 1). A specific feature of the glass composition is also the increased content of BaO (up to 9.5 wt %) and the presence of Cl (up to 1.4 wt %) in almost all analyses.

Quartz is widespread in slags, represented by small (1–10 μm) grains distributed in the glass matrix and large relics of various morphologies. As single inclusions, there are relics of serpentinite, minerals of the serpentine group have the following composition (wt %): MgO 44.38; SiO_2 48.24; FeO 3.24; Al_2O_3 1.43; CuO 0.43; K_2O 0.33; Na_2O 0.17. Also in the glass matrix, we recorded a 30 μm single grain of Cr-rich spinel, partially destroyed. The composition (wt %): Cr_2O_3 49.09; FeO

Table 1 Composition of a glass of metallurgical slags of Tokskoe settlement

№	Sample	Content, wt %												Summary
		SiO_2	Al_2O_3	CaO	Na_2O	K_2O	MgO	BaO	FeO	TiO_2	CuO	P_2O_5	Cl	
1	Tok 1-1	60.7	11.9	6.4	1.8	1.6	0.9	6.4	7.8	–	0.9	–	0.3	98.5
2		57.1	7.3	9.6	1.4	1.1	1.4	4.8	12.0	0.2	5.4	0.4	0.4	101.0
3		61.6	11.3	5.5	2.1	2.0	0.7	5.2	7.6	–	2.7	–	0.4	99.1
4		54.3	6.2	13.2	1.2	1.0	1.1	4.7	11.6	–	4.7	0.4	0.3	98.7
5	Tok 1-2	56.3	7.1	14.0	1.5	0.6	1.8	9.5	7.7	–	0.6	–	1.4	100.4
6		59.5	6.5	16.1	1.2	0.7	2.7	4.6	5.7	0.5	0.8	0.6	0.7	99.5
7		56.0	11.6	18.3	3.7	1.4	2.1	–	3.8	0.8	2.0	0.3	–	99.9
8	Tok 1-3	57.7	3.7	16.3	0.9	0.7	2.2	4.5	12.8	–	0.3	0.9	0.4	100.3
9		57.1	3.3	16.4	1.0	1.2	1.5	4.4	13.6	–	0.5	0.7	0.5	100.3
10		62.2	13.3	8.3	2.1	2.0	1.6	4.7	5.0	0.4	–	–	0.2	99.8
11		58.2	5.8	14.9	1.0	0.8	2.2	3.7	11.2	0.5	0.3	0.5	0.7	99.7

Note Dash—below the detection limit

28.64; MgO 9.72; Al_2O_3 6.93; CuO 3.61; MnO 0.81; CaO 0.49; TiO_2 0.31. More common are relic inclusions of bornite, which retained the angular shape and texture of the primary ore fragments. Sometimes bornite relics are partially melted and have around the drop-like shape. Newly formed non-stoichiometric Ba-Al-Si-O phases are rarely found in slags.

Metal inclusions in the slags of Tokskoe settlement are widespread, forming rounded single- and multiphase droplets of various sizes. The most common are single-phase drops of copper and two-phase inclusions, where the copper droplet is bordered by a chalcocite "jacket" (Table 2). Cuprite develops along the periphery of copper droplets, as well as in voids, in which submicron inclusions of native silver are frequent (Fig. 3).

The LA-ICP-MS method was used to study the composition of newly formed sulfide and copper droplets in slags from the Tokskoe settlement (Table 3). The newly formed sulfides contain high concentrations (average over 24 analyzes, ppm): Ag—509, Ba—534, Pb—182 (Table 4). Copper droplets contain high concentrations (average over 17 analyzes): Fe—0.58 wt %, S—0.46 wt %, Ag—912 ppm, Pb—269 ppm, As—248 ppm.

Glassy sulfide-containing slags from Tokskoe settlement are products of metallurgical processing of copper sandstone ores. This is indicated by a large number of quartz grains in the slag, the presence of Ba and Cl impurities in the glass, and the high Ba and Pb concentration in the newly formed sulfide and copper droplets. The high sulfur content in the copper droplets indicates the processing of predominantly secondary copper sulfides. The high iron content also indicates the use of bornite ores, which is consistent with the bornite relics in the slag. Similar mineralogical and geochemical features were noted in slags from other Cis-Urals Late Bronze Age

Table 2 SEM-EDS data of metal and sulfide inclusions in metallurgical slags from Tokskoe settlement

№	Sample	Content, wt %			Summary
		Cu	Fe	S	
1	Tok 1-1	100.8	–	–	100.8
2		80.2	0.3	19.4	99.9
3		100.3	–	–	100.3
4		100.6	0.3	–	100.9
5	Tok 1-2	100.3	0.3	–	100.6
6		100.1	0.3	–	100.4
7		79.8	0.2	19.8	99.8
8	Tok 1-3	99.7	0.4	–	100.1
9		77.6	2.3	20.6	100.5
10		99.7	0.8	–	100.5
11		79.1	0.7	20.4	100.3

Note Dash—below the detection limit

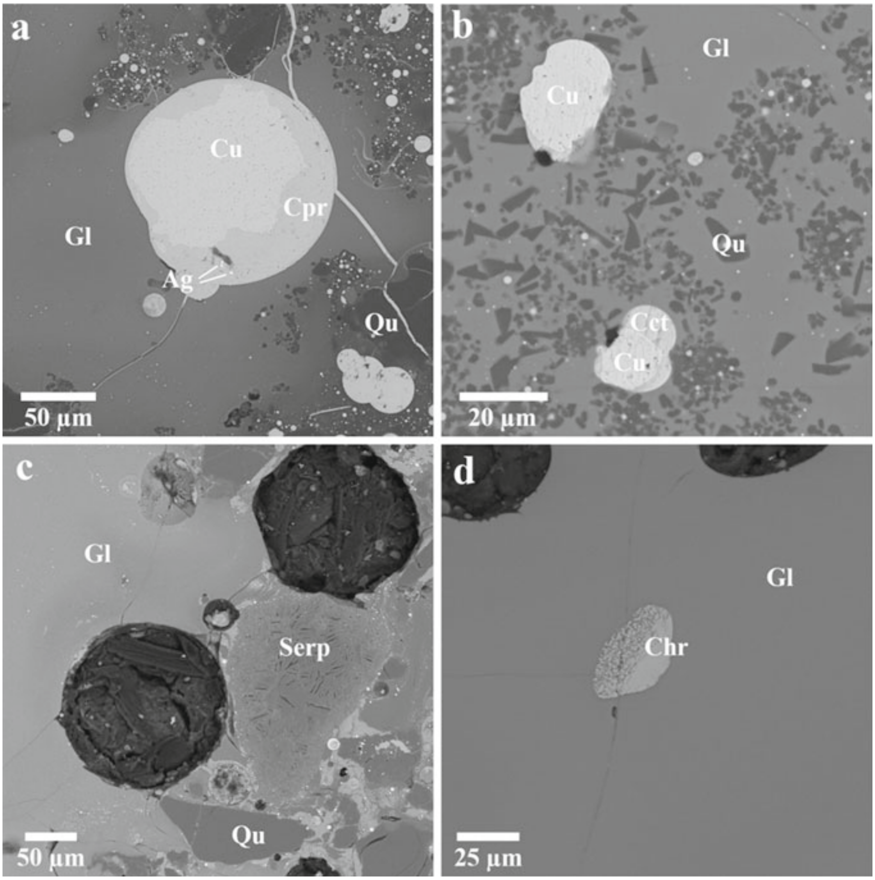

Fig. 3 Mineralogical composition of Tokskoe settlement metallurgical slags. **a**—partially oxidized copper droplet in a glass matrix; **b**—copper droplets in a newly formed chalcocite "jacket"; **c**—relic fragments of serpentinite and quartz grains in slag glass; **d**—partially destroyed single grain of Cr-rich spinel. Cct—chalcocite, Chr—Cr-rich spinel, Cpr—cuprite, Cu—metallic copper, Gl—glass, Qu—quartz, Serp—serpentinite

settlements, for example, Gorny and Rodnikovoe, for which Kargaly also served as a source of copper raw materials (Kargaly 2004; Ankushev et al. 2021b). The presence of serpentinite relicts in the slags, as well as a slightly increased As content in the metal, in contrast to sulfides, may indicate the use of a mixed ore charge. In this case, ores associated with copper deposits in ultrabasites are added to the concentrate of copper sandstone sulfides. Previously, the use of a mixed charge was recorded during the analysis of metallurgical slags at the nearby Turganik settlement (Artemyev and Ankushev 2019). Another source could be As-enriched interlayers in copper sandstones (Blinov 2020).

In the Late Bronze Age, about 1700–1500 BC, numerous deposits of copper sandstones of the Western Orenburg region were located in the area of the Srubna

Table 3 Composition of metal inclusions in slags from Tokskoe settlement (according to LA-ICP-MS data)

№	Sample	Cu	Fe	S	Co	Ni	Zn	As	Se	Ag	Sn	Sb	Te	Au	Pb	Bi
		%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	Tok 1-2	98.0	1.02	0.623	28.9	35.0	1110	258	8.8	1290	7.1	19.3	3.0	1.34	336	3.89
2		98.6	0.95	0.29	23.8	76.7	170	347	10.3	636	0.23	5.44	<3.0	0.16	225	0.05
3		98.5	0.90	0.44	17.9	26.8	84	292	6.9	1144	1.17	14.1	0.52	0.21	335	1.06
4		98.7	0.75	0.35	24.2	24.4	45	256	6.2	997	4.2	17.9	1.5	0.22	214	2.91
5		98.6	0.88	0.35	26.3	33.5	75	174	7.9	1060	<5.8	11.8	1.5	0.24	356	2.20
6		98.9	0.72	0.27	14.8	19.0	18.2	149	6.5	1122	<0.79	7.05	<0.6	<0.1	258	0.14
7		98.9	0.64	0.26	13.0	19.2	8.2	156	<4.9	1188	<0.62	7.4	<0.6	<0.1	299	0.12
8		98.9	0.67	0.35	13.1	23.1	11.1	200	3.3	773	<0.51	9.6	<0.7	<0.1	240	0.07
9		98.9	0.49	0.37	12.1	22.1	12.8	208	4.7	1269	0.47	8.85	<1.5	0.10	402	0.10
10		99.0	0.47	0.33	12.5	21.7	8.8	139	3.9	1170	0.47	6.87	<0.47	<0.1	370	0.05
11		99.0	0.48	0.41	10.6	20.6	8.3	114	3.9	969	0.41	5.35	<0.91	<0.1	188	0.02
12	Tok 1-3	99.7	0.011	0.234	1.40	15.6	88	111	148	392	<0.85	4.44	<4.8	0.40	16.2	0.93
13		99.7	0.017	0.260	0.61	49.0	124	160	28	300	<0.84	10.7	0.35	<0.1	11.7	1.08
14		99.6	0.011	<0.41	25.3	61.6	86	924	57	1559	7	44.3	7.6	1.08	367	19.3
15		96.6	1.52	1.86	19.1	40.1	20	181	92	258	2.4	17	<7	<0.1	64	8.6
16		99.1	0.25	0.47	17.9	56.2	7.1	213	14.8	742	<0.86	18.6	<4.7	0.10	684	1.81
17		99.8	0.018	<0.03	10.4	15.6	35	342	56	635	<4.7	7.6	1.0	<0.1	209	2.87
Minimum		96.6	0.011	0.23	0.61	15.6	7.1	111	3.3	258	0.23	4.44	0.35	0.1	11.7	0.02
Maximum		99.8	1.52	1.86	28.9	76.7	1110	924	148	1559	7.1	44.3	7.6	1.34	684	19.3
Average		98.9	0.576	0.46	16.0	33.0	112	248	28.6	912	2.61	12.7	2.2	0.43	269	2.66
Median		98.9	0.641	0.35	14.8	24.4	35.0	200	8.4	997	1.17	9.6	1.5	0.22	258	1.06

Table 4 Composition of sulfide droplets in metallurgical slags of Tokskoe settlement (according to LA-ICP-MS data), ppm

№	Sample	Cu, %	S, %	Fe, %	V	Cr	Mn	Co	Ni	Zn	Ga	As	Se	Mo	Sb	Ag	Pb	Bi	Ba
1	Tok 1-2	69.1	30.5	0.237	14.7	<3.5	<3.2	0.246	5.35	37	0.294	28.5	66.2	1.72	0.83	434	2.44	0.34	9.4
2		69.4	30.4	0.132	6.2	<2.3	<3.5	0.332	13.1	3.3	0.291	6.35	63.8	1.75	0.64	519	10.5	0.23	15.2
3		67.4	32.0	0.484	38.5	<2.7	<2.5	0.318	22.5	95	0.65	38.6	72.7	7.93	0.59	334	1.9	0.17	21.7
4		72.6	27.1	0.188	29.7	<2.2	3.3	1.71	117	70	0.95	20.8	67.4	3.02	0.84	247	48.4	1.11	33.9
5		72.9	26.1	0.95	11.4	6.9	4.1	3.23	1.23	45	3.06	136	40	31.2	1.88	35.5	81	<0.21	156
6		74.6	21.9	3.39	28.8	3.7	16.9	10.6	2.22	9.8	2.38	104	34.6	52.2	2.45	67.5	258	<0.01	97.5
7		79.0	20.8	0.034	23.7	49.8	<4.6	0.254	1.00	3.2	1.18	6.4	46.1	326	0.4	206	4.2	<0.01	34.7
8		81.2	18.6	0.002	2.77	13.7	<3.6	0.31	1.16	0.1	18.8	14.1	48	144	1.15	1370	32.5	<0.26	1007
9		75.6	24.2	0.033	16.2	13.9	<4.0	0.51	1.4	1.3	8.5	12.6	39	598	0.44	225	624	<0.12	420
10		80.0	19.7	0.178	10.9	22.2	<5.2	0.2	0.56	2.9	11	12.1	45	296	14.4	439	308	<0.09	239
11		83.6	16.1	<0.008	5.6	20.5	<11	0.41	<3.0	<18	27.8	23	37	354	0.06	1680	4.1	<0.16	1650
12	Tok 1-3	65.3	27.6	7.07	111	48	178	34.4	6.0	400	121	24.3	202	18.7	7.1	36.1	101	3.8	6600
13		55.6	34.2	9.98	17.7	72.5	18.4	9.8	2.38	9.5	3.76	21.1	936	206	2.96	144	225	1.66	93
14		55.5	33.8	10.51	13.1	79.7	20	9.89	1.6	557	2.54	19.1	850	201	1.28	155	226	0.84	105.9
15		58.4	31.4	9.99	13.2	71.9	20	10.1	1.04	110	1.71	18.4	860	189	0.64	152	205	0.42	104.9
16		54.0	39.9	5.96	17.3	49	15.4	6.8	0.3	61	6.5	23.3	679	75.6	0.96	502	248	0.21	392
17		72.8	25.1	1.68	4.4	26	93.9	5.6	10.7	78	8.6	41	790	34.5	2.02	2380	283	0.75	24.1
18		80.7	19.0	0.02	1.37	8.5	9.1	1.02	1.9	17	1.71	8.2	301	3.1	0.62	1817	330	0.17	<1.4
19		74.9	23.0	2.04	1.24	12.4	27.6	18.6	1.9	<10	0.27	25	169	9.3	1.94	102	522	0.1	<1.3
20		50.6	40.0	9.25	0.61	7.4	8.6	15.7	0.6	2.9	1.66	19.4	725	22.9	0.34	353	168	0.12	106.1
21		53.5	37.7	8.78	1.96	10.3	7.6	14.8	1.14	3	2.12	24.2	669	81	0.65	353	161	0.07	160

(continued)

Table 4 (continued)

№	Sample	Cu, %	S, %	Fe, %	V	Cr	Mn	Co	Ni	Zn	Ga	As	Se	Mo	Sb	Ag	Pb	Bi	Ba
22		54.9	36.1	8.92	1.51	8.6	8.52	18.5	2.1	5.6	2.02	26.3	653	81.9	0.58	344	147	0.08	127
23		66.7	27.6	5.63	11.6	70.5	<3.5	18.9	4.3	4.7	0.57	49.2	446	112	1.37	257	114	0.07	16.5
24		76.0	22.6	1.38	0.66	5	8.3	5.59	0.73	<4.0	5.49	20.9	117	51.2	1.28	70.1	258	0.05	342
Minimum		50.6	16.1	0.002	0.61	3.7	3.3	0.2	0.3	0.1	0.27	6.35	34.6	1.72	0.06	35.5	1.9	0.05	9.4
Maximum		83.6	40.0	10.5	111	79.7	178	34.4	117	557	121	136	936	598	14.4	2380	624	3.8	6600
Average		68.5	27.7	3.8	16.0	30.0	29.3	7.8	8.7	72.2	9.7	30.1	332	121	1.9	509	182	0.6	534
Median		71	27.4	1.7	11.5	17.2	15.4	6	1.9	9.8	2.25	22.05	143	63.9	0.9	296	165	0.21	106

Note The values of Ge, Cd, In, Sn, Te, Au, Tl are below the detection limit population, which provided them with rich sulfide ores (Kargaly 2004). Ore-bearing siltstones and marls made it possible to mine near-surface deposits with relatively low labor costs. At the same time, to the east was the area of the Alakul population, and to the south-east—the Kozhumberdy population (Tkachev 2017). There are rare, poor on the surface volcanic massive sulfide and skarn copper deposits of the Southern Trans-Urals and Mugodzhary (Yuminov et al. 2013). Ore-bearing rocks here are strong serpentinites, granites, and volcanites (basalts and rhyolites), which significantly complicated the establishment of mine workings. These factors determined the formation, development of mining and metallurgy technologies, and the general scale of metal production in various regions.

4 Conclusions

In the Late Bronze Age, at Tokskoe settlement, rich chalcocite-covellite ores were exploited. This is evidenced by the confinement of the settlement to the Kargaly copper sandstone deposits, the presence of relict and newly formed sulfides in slags, impurities of Ba and Cl in glass, as well as S, Ag, and Pb in copper droplets. These impurities are typical for the products of metallurgical redistribution of copper sandstones, which was also noted in other Cis-Urals Late Bronze Age settlements (Kargaly 2004; Ankushev et al. 2019). The revealed relics of serpentinites and increased As contents in copper droplets may indicate the use of a mixed ore charge. The use of copper sandstones as raw materials and the technology of the metallurgical process in the settlement are typical for the Srubna population of the Late Bronze Age of the South Urals.

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Arrowheads from Two Sarmatian Burials of the One Mound: Metal Composition and Shape Relation

Ivan A. Blinov and Alexander D. Tairov

Abstract The arrowheads from Mound 3, Burial pit 1 (240 items), and Burial pit 2 (130 items) of the Kichigino I Burial Ground were subjected to the XRF analysis. In both burials of Mound 3, the arrowheads have a similar chemical composition. The admixtures are Ni, As, Sb, Pb, and Bi with contents that do not exceed 1 wt%. In individual cases As content can reach 34.2%. The arrowheads metals are divided into 7 groups. Metal groups are distributed unevenly. Pure copper arrowheads prevail, then As minor admixture items follow them in numbers. The items with a high concentration of Sb and As are rare. Other metals are found in low quantities. Communities conducted burying in the burials 1 and 2 of mound 3 used mainly copper and its alloys of local manufacture. They did not practice copper alloying for arrowheads production.

Keywords Kichigino I · Early iron age · Pre-Sarmatian · Bronze arrowheads · Trans-Urals

1 Introduction

Bronze arrowheads are commonly found in the southern Urals Pre-Sarmatian burial grounds. In our opinion, these are expended supplies: being often lost while shooting, its functioning time most likely was short. To manufacture an ample quantity of the arrowheads, the most accessible material was used; therefore arrowheads could be presented as an indicator of such material sources. An important key in the understanding of both the sources of raw materials and the ancient metal makers' knowledge on metal characteristics is the alloying components such as Sn, As, Pb, Zn, and rarely such elements as Sb, Bi, Ag, Ni.

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The Kichigino I burial ground is situated on a flattened area Tushkanskaya Mountain in the South Urals, on the left bank of the Uvelka River, 1.5 km west of Kichigino village, Uvelsky area, Chelyabinsk region (Tairov et al. 2008).

The Necropolis consists of 10 mounds spread in an irregular chain from WNW to ESE along the hill slope. Its dirt fills diameter ranges from 14 to 35 m with 0.1–1.5 m high. The burial ground was completely excavated in 2006–2011 in the course of the protective work conducted by the South Urals State University in cooperation with the Institute of History and Archeology of UB RAS, and the Chelyabinsk Regional Museum (nowadays—South Urals State Historical Museum). In the graves nos. 1 and 2 of Mound 3, as well as in the underside entrance hole untouched Pre-Sarmatian male martial burials were found.

In Burial pit 1, the burial was conducted in a plank coffin located in the central part of the burial. A deceased male individual aged 25–30, was positioned supinely with his head oriented to the West. In the left part of the chest, in the heart area, a heavily corroded bronze arrowhead was found. To the left from the bones, between the coffin and the burial wall, there was a long iron sword with arcuate crossing. Upon its grip, a foreleg bone of a sheep/goat was laid. To the left of the crossing, there was a big spotted glass bead. A bead of the same type was laid left to the sword-blade under the crossing. A similar bead was found near the right bone wrist (Fig. 1).

Upon the middle and lower parts of the sword-blade, quiver's pieces were found. That contained the 247 bronze socketed arrowheads (240 of them were analyzed). The 70 of 247 items had raised sockets and the 177 had hidden sockets (Fig. 2).

All the arrowheads with raised sockets were three-bladed, their length varies from 2.3 to 3.9 cm, but the vast majority has average size, varying from 2.7 cm to 3.4 cm. Most of them have an arched head and almost one-third of them have a triangular head, or the head close to this form.

The arrowhead's size varies from 2.7 cm to 4.1 cm; predominantly, the item's size is 3.2–3.7 cm. Most of the arrowheads with the hidden socket are three-bladed.

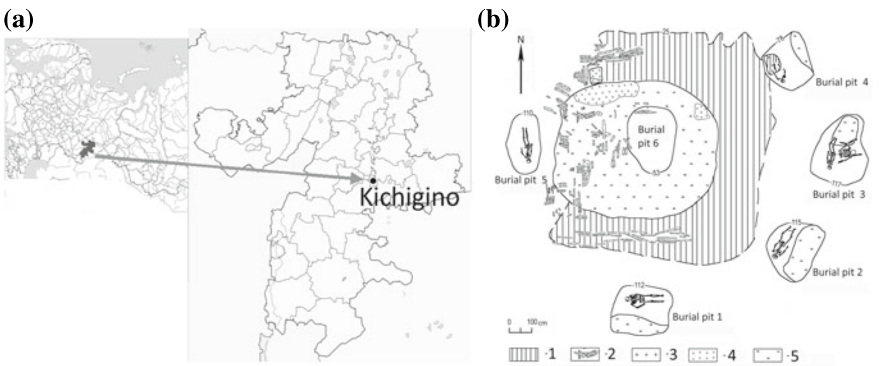

Fig. 1 **a** Location of Kichigino I Burial Ground. **b** Kichigino I Burial Ground, Mound 3, general plan (by A. Tairov). 1—burned soil; 2—wood; 3—charred wood, charcoal; 4—birch bark; 5—bedrock, loam

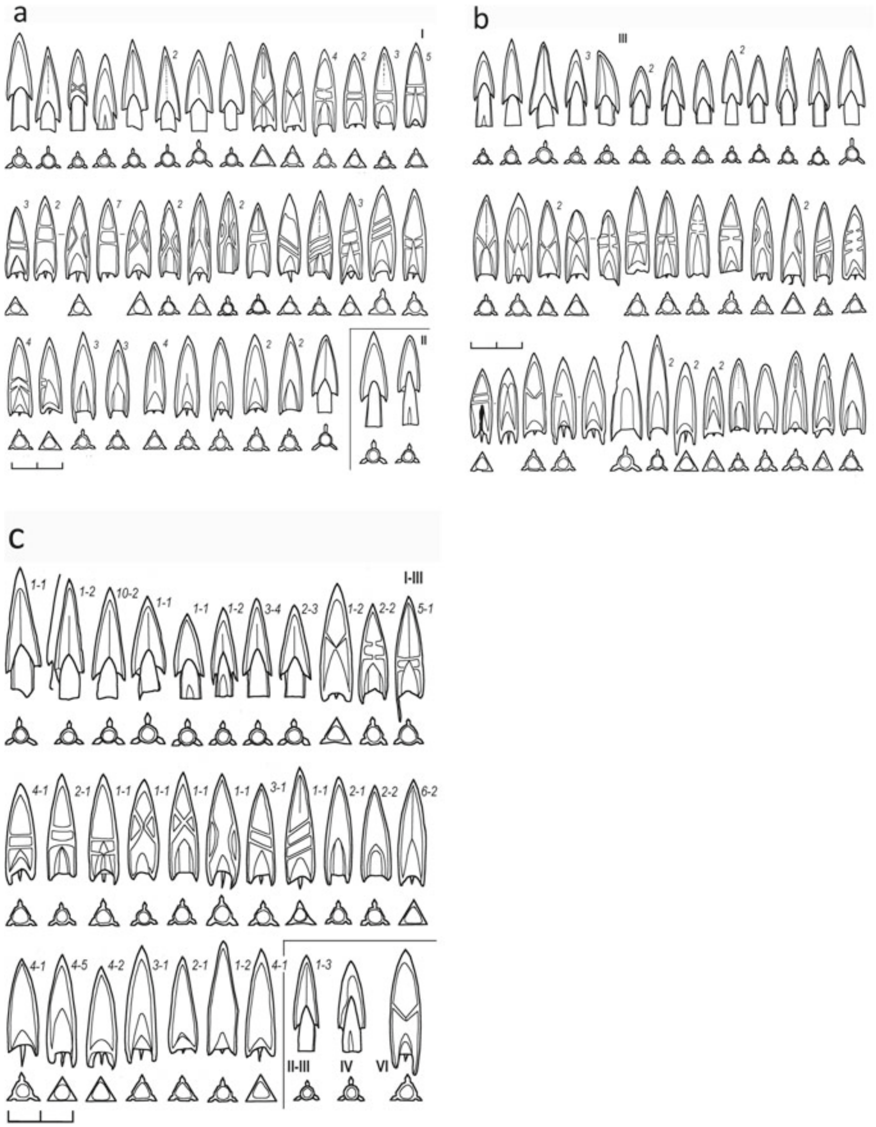

Fig. 2 Arrowhead sketches of Burial pit 1. On figure: I, II, etc.—metal groups; 1, 2, etc.—the number of arrowheads of the same type

One-fifth of the basic arrowheads are represented by the three-bladed/three-edged form: their three-bladed head in its lower part transforms into the three-edged one. Practically, all basic arrowheads are arched, triangular, though tower-shaped ones are rare. A significant number of the arrowheads with the hidden socket (99 items) ornamented with welts shaped in the form of a tick, sidelong cross, two parallel horizontal lines, two or three parallel slanting lines, two vertical arches assembled in the arrowhead central part, etc.

Across the upper part of the quiver, an iron slightly bent plate is laid. Iron quiver hanger fragments are found under the quiver. Besides arrows, in the quiver, there was an iron knife with a broad grip and a slightly curved blade and an iron piercer with a wooden handle.

Immediately next to the quiver, between the quiver and burial wall, there was a long iron-tanged knife with a slightly curved blade. To the East from the quiver, right next to the northern wall, to the north from the knee joint, there was a snaffle with iron bits and cheek-pieces; its hide ropes were decorated with many bronze inserts of various sizes and shapes, half-round tassels.

Burial pit 2 is situated at 4.6 m to NEE from Burial pit 1. In the central part of the burial male's skeleton was found. The individual died at the age of 40–45 years. The deceased was laid supinely with his head towards SSW.

Between the north-western wall of the chamber and the bones to the left of its left hand in parallel to the body, there was a long (93.5 cm) iron sword with an arched crossing, a wide oval grip expanded towards the crossing, and, possibly, with a slightly curved umbrella-shaped pommel. To the left from the sword, next to its crossing and upper part of the blade, there were two conical tassels found.

Upon the middle and lower part of the sword blade, similarly to the burial 1, the quiver's pieces were found, located in 0.2–0.3 m to the West from the left knee joint. The quiver contains 130 bronze socketed arrowheads. There was a well-preserved iron claw-shaped hanger near the upper part of the quiver. Next to the feet bones, there was a very poorly preserved iron socketed spearhead.

The quiver contained arrowheads with raised sockets: there are 106 items, among them, there are 24 items of the basic type (Fig. 3). The length of the arrowheads with the raised socket varies from 2.1 to 3.7 cm, though the size of 2.5 to 3.0 cm

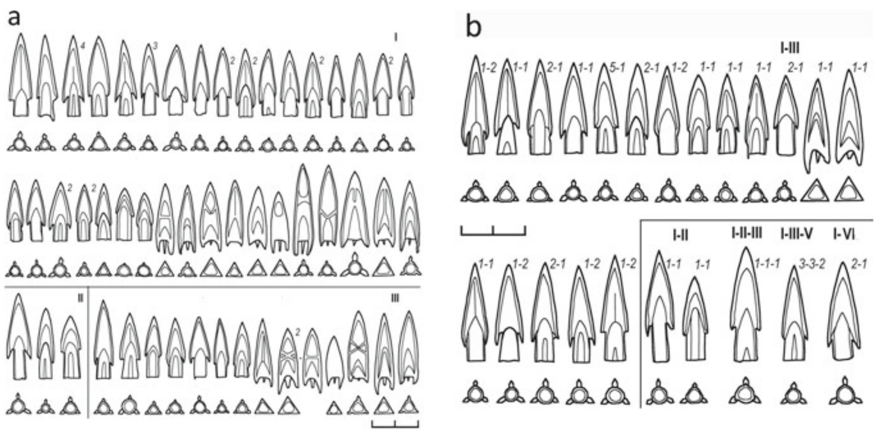

Fig. 3 Arrowhead sketches of Burial pit 2. On figure: I, II, etc.—metal groups; 1, 2, etc.—the number of arrowheads of the same type

prevails. The length of the arrowheads with the hidden socket varies from 2.2 to 3.9 cm. Most of the arrowheads have a narrow-arched head, which in some cases has a triangular shape. The arrowheads with a triangular head are also in the quiver. All the arrowheads with the raised socket are three-bladed. The arrowheads with the hidden socket predominantly have a transitional three-bladed/three-edged form, but one of them is three-edged. Six of the basic arrowheads are ornamented with welts.

2 Methods and Materials

At present, the arrowheads from mound 3 burials 1 and 2 are stored in State South Urals Historical Museum (Chelyabinsk, Russia). Therefore, these items are available only for non-destructive analysis. Among those, X-ray fluorescence analysis is the most accessible method. This method allows defining a wide spectrum of elements (heavier than Ti).

The research has been conducted with XRF- analyzer Innov X Alfa 400 apparatus on Process Analytical Mode, 30 s exposure time, 0.1% sensitivity. The size of the analyzed window is about 1 cm^2.

The specifics of them are that only the surface of an item is being analyzed. Due to that technologic coat (tin-plating), oxidation film or patina obstruct the process of analysis and/or seriously impact its results, distorting metal composition data. All the items studied for the present work are covered by patina layers. Previous works demonstrated that the patina layer can overestimate the analyzed values Sn, As, Sb by 1.5–2 times (Blinov et al. 2017; Blinov and Tairov 2018). The distortion of the analysis is 1.5–2 times, but not by an exponent. The analysis can be considered "semi-quantitative". Correctly determines the qualitative composition and the order of the magnitude of concentrations.

3 Results and Discussion

Among admixtures in the arrowheads, such metals as Ni, As, Sb, Pb, and Bi are detected. On whole, the impurity content is not high and rarely outreaches the 1 wt. %. However, the content of As could be quite high and reach in particular cases 34.2 weight percentage though in the vast majority of cases it does not exceed 0.2 wt%.

Burial pit 1

There are 240 out of 248 bronze socketed arrowheads (71 items have raised sockets and 177 items have hidden sockets) that are subjected to the analysis. They can be further subdivided into several groups (Table 1, Fig. 4). The arrowheads made from pure copper are the most common ones (144 items). The arrowheads with As content up to 0.3% follow the primary group. In some cases, the As concentration reaches 0.7–0.8 wt% (91 items). The other three groups are small in numbers. Thus, the third

Table 1 Summary composition of arrowheads in the burial pit 1

Element	Concentration (wt%)	Average (wt%)	Standard deviation	N
Ni	0.1–0.4	0.2		3
As	<0.1–34.2	0.9	4.4	96
Sb	0.4–2.2	1.2		3
Pb	0.1–0.5	0.2		3
Bi	0.3			1
Cu pure				144

Note Table shows a variety of content of element admixtures that could be several in one item. Therefore, the N sum is bigger than the number of the items analyzed

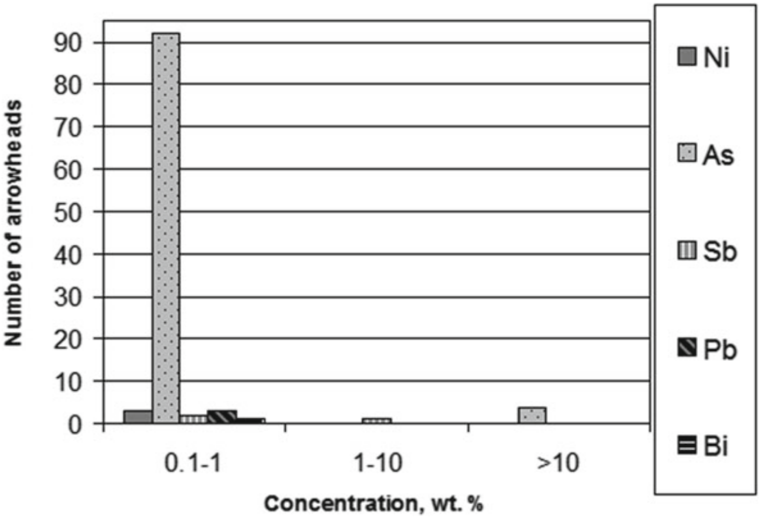

Fig. 4 Histograms of elemental abundances of arrowheads in the burial pit 1

group comprised of the arrowheads containing Sb, Ni, and As in high concentrations (more than 1 wt%), and possible admixtures of Pb and Bi (3 items). One arrowhead has a low content of As and Pb (up to 0.3 and 0.2 wt% accordingly); and another one has a content of As of more than 10%.

Burial pit 2

There are 130 arrowheads sampled for the analysis. The metal of all arrowheads contains impurities of Ni, As, Sn, Sb, Pb, and Bi (Table 2, Fig. 5). The content of impurities usually does not exceed 1%. As an exception, impurities of Sb occur together with elevated concentrations of As (>2%).

The metal artifacts can also be divided into several groups. Here, pure copper prevails as well (82 items), and then the group with the As admixture has up to

Table 2 Summary composition of arrowheads in the Burial pit 2

Element	Concentration (wt%)	Average (wt%)	Standard deviation	N
Ni	0.1	0.1		2
As	<0.1–9.3	0.5	1.6	45
Sn	0.3			1
Sb	0.9–4.6	2.2		6
Pb	0.1–0.5	0.2		3
Bi	0.2–0.4	0.3		3
Cu pure				82

Note Ttable shows a variety of content of element admixtures that could be several in the same item. Therefore, the total number (N) is larger than the number of the items analyzed

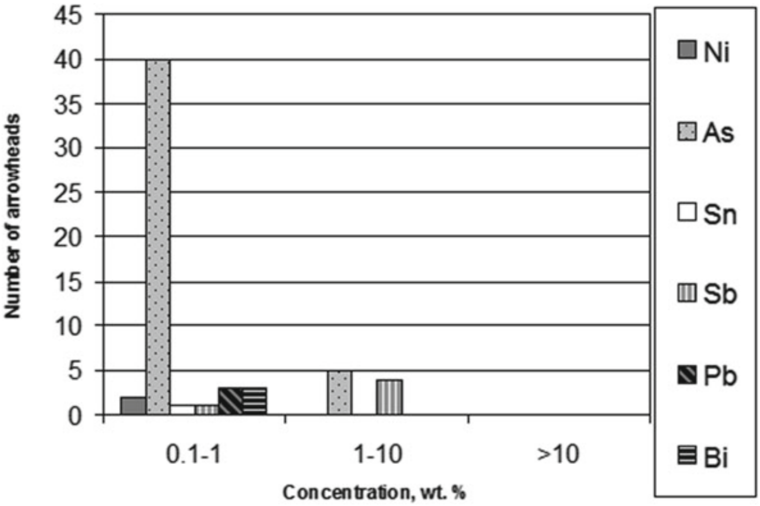

Fig. 5 Histograms of elemental abundances of arrowheads in the burial pit 2

0.1 wt% (39 items) and follows in numbers. The third group is characterized by the combination of high contents of Sb and As (>2%), and possible Ni and Bi admixtures (6 items). Two arrowheads have the admixture of Pb with the content of up to 0.5% and one arrowhead has the Sn admixture up to 0.3% and Pb admixture up to 0.1%.

Morphologically, the arrowheads differ in size, the form of the socket, and the form of the blade. Among them, there are several similar morphologies, but their chemical composition varies. The largest series has 12 arrowheads of the identical form, and 10 of 12 belong to metal group I, while the rest—to metal group III. Besides that, a similar shape occurs among arrowheads in the following combinations of the groups: group II and group III; of group I and group II; of group I, II, and III; of group I, III, and V; of groups I and VI. In such cases, the number of arrowheads in one series does not exceed 8 items.

Some arrowheads are decorated with welts that are shaped in the form of a tick, sidelong cross, two parallel horizontal lines, two or three parallel slanting lines, two vertical arches assembled in the arrowhead central part, etc. Also, the arrowheads differ in the forms of their sockets: there are the arrowheads with the raised socket and the arrowheads with the hidden socket. By the form of the blade, they can be subdivided into the three-bladed, the three-bladed with the triangular base, the three-bladed with a developed triangular base, and the three-edged arrowheads.

In Burial pit 1, the three-bladed arrowheads with the hidden socket (HT) are the most common (Table 3). About two-thirds of them are decorated. The three-bladed arrowheads with the hidden socket and triangular base (HB), and the three-bladed arrowheads with raised socket (RT) are less common. The correlation of the type with the metal also varies. In group I, the HB arrowheads are often presented, though, in group III, there are only the RT arrowheads. The HB arrowheads are ornamented in 50% of cases in group I, and 17% cases in group III. Among the RT arrowheads, only one is decorated.

The hidden socket three-bladed arrowheads with the developed triangular base (HT-B) are very rare. In the case of group I and group III, they have presented only at 3% and 5% cases (4 and 5 items), respectively. However, all of them are decorated.

The arrowheads of group II (3 items), one arrowhead of group IV (1 item) belong to the RT morphological type. The arrowhead of metal group VI (1 item) is of the HT type. No ornament is registered.

In Burial pit 2, arrowheads of the RT type prevail largely (Table 4). The second in numbers is the HB arrowhead type: in metal group I, there are 9% of them, and in metal group III there is 17%. The HT arrowheads are distributed as 6% and 5%, respectively. A significant part of the HB and HT arrowheads are ornamented. The hidden socket three-edged arrowheads (HE) are rare (a single item of each) and they belong to metal groups I and III. These are lacking ornament. The arrowheads of metal types II, IV, and V are rare (6, 1, and 2 items, respectively) and all of them are the RT arrowheads.

4 Results and Discussion

The available metal arrowheads can be divided into 7 groups (Table 5): the pure Cu arrowheads with no admixtures (I); the high Sb and As content (>1%) with the possible admixtures of Pb, Ni, Bi (II) arrowheads; the low As content arrowheads, in which As usually does not exceed 0.2%, but in particular cases As content reaches 0.8% (III); the high As content arrowheads with no other admixtures (IV); the Pb admixture arrowheads, with the content of up to 0.5% (V); the Pb and As admixture arrowheads, with the content of both of up to 0.7% (VI); the Sn admixture and the possible Pb admixture up to 0.2% arrowheads (VII).

The metal groups are uneven in numbers. In both burial pits of Mound 3, the arrowheads have similar compositions. The pure copper arrowheads prevail (group I, 60–63%), the second position belongs to the low As admixture arrowheads (group

Table 3 Morphology of the arrowheads In the Burial pit 1

Metal group	RT (%)	Ornamented RT (%)	HB (%)	Ornamented HB (%)	HT (%)	Ornamented HT (%)	HT-B (%)	Ornamented HT-B (%)	Number of items in the metal group
I	20.6	3.4	25.5	50.0	51.1	63.9	2.8	100.0	141
II	100								3
III	34.8		19.6	16.7	40.2	59.5	5.4	100.0	92
IV	100								1
VI					wt%	100			1

Note RT—raised socket, three-bladed; HB—hidden socket, three-bladed with triangular base; HT—hidden socket, three-bladed; HT-B—hidden socket, three-bladed with a developed triangular base

Table 4 Morphology of the arrowheads in the Burial pit 2

Metal group	RT (%)	HB (%)	Ornamented HB (%)	HT (%)	Ornamented HT (%)	HE (%)	Number of items in the metal group
I	83.8	8.8	28.6	6.3	40.0	1.3	80
II	**100**						6
III	76.2	16.7	28.6	4.8		2.4	42
IV	**100**						1
V	**100**						2

Note RT—raised socket, three-bladed; HB—hidden socket, three-bladed with triangular base; HT—hidden socket, three-bladed; HT-B—hidden socket, three-bladed with a developed triangular base

Table 5 Metal groups of arrowheads from burial1 and 2 Kichigino I burial ground

Metal groups	Characteristics	Quantity in burial pit 1	Quantity in burial pit 2
I	Cu pure	144 (60.0%)	82 (63.1%)
II	Sb + As (high concentrations > 1% or >10%) ± Pb, Ni, Bi	3 (1.3%)	6 (4.6%)
III	As up to 1% (usualy up to 0.2%)	91 (37.9%)	39 (30.0%)
IV	As > 10%	1 (0.4%)	
V	Pb under 0.5%		2 (1.5%)
VI	Pb + As up to 1%	1 (0.4%)	
VII	Sn ± Pb (up to 1%, usualy 0.2%)		1 (0.8%)
	Summ	240 (100%)	130 (100%)

III, 30–36%). The arrowheads of group II with the high concentrations of Sb and As and other admixtures are fairly rare (1.3–4.6%). The other compositions are extremely rare: they are found only in one of the burial pits.

Thus, people conducted burying in burials 1 and 2 of the Kichigino burial ground; mound 3 had stable access to two main sources of metal or the groups of such sources. These sources produced pure copper and copper with the low As admixtures. The additional source was metal compounded with fahlore that contained simultaneously the As and Sb high content. Arrowheads of other metal groups are most likely from other regions and ended up in the Kichigino mound by accident.

Most likely, the metal of groups I and III are of a local origin. In general, it is consistent with the composition of metal artifacts found in the sites of the Itkul archaeological culture. More than 88% of the artifacts are made of pure copper. (Kuzminykh and Degtyaryova 2015, 2017). In the Southern Urals, there is quite a large amount of copper mines exploited in ancient times (Beltikova 2002; Chernykh

1970). Group II metal could be of a non-local origin. This metal is not typical for the Southern Urals.

The metal of the arrowheads with the relatively little Sn content is extremely rare for the Southern Urals. In contrast with the Bronze Age, when Sn-bronze was widely used (Vinogradov 2013), where its distribution is much lower. That could be caused by a breach of connections with regions excavating tin. As well as, expensive metal use for the manufacture of such mass products as arrowheads.

Kichigino is among many Early Iron Age sites in the Central Eurasia steppe zone where bronze arrowheads were found. By the present time, data are published on bronze arrowheads found at the Tegizzhol site, the Philippovsky burial ground, and the Dautov I ancient settlement. However, we can cite the study of the composition of the metal of arrowheads of the Arzhan-Mayemir period from the territory of the Upper Ob and Altai as an example of using X-ray fluorescence analysis from the most distant regions of the Eurasian Steppes (Tishkin et al. 2014; Tishkin 2017). Below, we provide data for comparison.

The Philippovsky burial ground, Mound 1, Grave 2 is situated in the Orenburg region, Russia. The burial site is dated within the IV century BC (Yablonsky 2014). Despite the big quiver, only two arrowheads were analyzed. One of them has the high As (16.9%) and Sb (4.8%) contents, the second arrowhead has the high As and Pb concentration (qualitative measurement) (Blinov et al. 2014).

The Tegizzhol site, Mound 27 is situated 10 km west of Temirtau city in the Karaganda region, Kazakhstan. It is classified as a part of the Tasmolino archaeological culture and dated to the VI–VII centuries B.C. Arrowheads are found in graves 1 and 2 (Varfolomeev 2011). In Burial pit 1 five arrowheads are found. Morphologically all the arrowheads are tanged, i.e., they are shaped differently than ones from the Kichigino mound. Besides that, their metal composition is different: here, the content of the element varies a lot: Pb (0.2–2.3%), As (1.1–10.2%), Sn (0.3–26.0%), and Bi (up to 0.7%) are detected in three of the five arrowheads. In Burial pit 2 only one arrowhead is found. Its composition differs from the composition of metal from Burial pit 1. It also has Pb, As and Bi, but no Sn while Sb admixture is present (Blinov and Varfolomeev 2015).

The Dautov I ancient settlement is situated in the mining works zone of the Chelyabinsk region, Russia, on the shore of the Itkul Lake. Beltikova dated the settlement back to the end of the VII century CE—the beginning of the IV century CE (Beltikova 1986, p. 77). The composition of seven arrowheads was defined. Three of them are of pure copper; two have the As admixture of about 0.1%. There is a Pb admixture of about 0.1% in one of them, and in another one, there is 9.9% of Sn (Tairov and Blinov 2019).

The Borovoe-III settlement is located in the lower part of the Biya River (the Upper Ob region), in Altai Krai, Russia. It is dated from the VIII to the last quarter of the VII century BC. There are 18 arrowheads from the settlement's collection which were analyzed. All of these arrowheads are bilobed. The most common is the shape with the rhombic cross-section and less often is the leaf-shaped morphology. The arrowheads are alloyed. The common formulations are Sn + As + Pb ± Bi, Sb, Ni. Less common are Sb + As + Bi ± Ni, Sn (Tishkin et al. 2014).

The Eleknomar II complex (Mounds 10 and 6) is dated back to the VII-V century BC and is located in Altai (the Republic of Altai, Russia). It contains triangular (2 pieces) and two-bladed (3 pieces) arrowheads. All of them have as well as a constant impurity of Sn, Pb ± As, Zn. One three-bladed tip contains only As and Pb impurities (2.5% and 0.2% in the patinated surface, respectively) (Tishkin 2017).

Among the above-mentioned sites, only Philippovsky and Dautov I are contemporaneous with the Kichigino I burial ground. Tegizzhol appeared one or two centuries earlier.

5 Conclusions

It is difficult to come to any certain conclusions yet as the sample is small. However, it is possible to outline some tendencies. Thus, the composition of the five arrowheads from the Dautov I settlement is close to the metal types I and III of Kichigino. One arrowhead from the Philippovsky burial ground is similar in composition to the type II. The 27 arrowheads from the Mound of Tegizzhol have no conformity with the Kichigino ones. However, two parameters may be significant here: they belong to the different period and they differ in their geographic locations, what could impact the trade connections.

Communities conducted burying in Kichigino Burial pits 1 and 2 of Mound 3 used mainly copper and its alloys of local production. They did not practice copper alloying for arrowheads production. A small amount was supplied from the Orenburg area. There were several metal sources provided by the earlier nomads of the southern Trans-Urals who buried their deceased on the mountain of Tushkan, These sources provided a stable supply.

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The Ancient Bronzes of Bashkiria: Findings on the Composition of Non-ferrous Metal Obtained at the Burial Grounds of the Bronze Age

Ilshat I. Bakhshiev and Elvir V. Kamaleev

Abstract The article presents the results of the elemental analysis of the composition of metal objects obtained at the burials dating back to the Srubnaya Culture of the Southern Urals. The data was received by energy-dispersive analysis of the most common category of jewelry—bronze bracelets. The predominant shapes are open grooved bracelets with rounded ends, as well as bracelets made of rods and twisted wires with semicircular and triangular sections. The primary purpose of this work is to provide a general description of the composition of the ancient metal and compare series of findings from the Urals and the Trans-Urals. The first stage of the work involved the examination of ten samples from the Trans-Ural group of sites, namely objects from Tavlykaevsky burial grounds I and II, and seven ornaments from the Srubnaya culture burials of the Staro-Yabalaklinsky cemetery (Urals). The leading metallurgical group is tin bronze with ternary alloys of copper, tin, and lead or copper, tin, and antimony. In terms of its composition, the series of findings was quite clearly differentiated. In the Trans-Ural assemblages, objects with added lead were mainly found in burials of the Tavlykaevsky I burial ground, while in the Tavlykaevsky II burial ground, there was a predominance of copper-tin alloys with antimony inclusions. In the Staro-Yabalaklinsky necropolis, an object might contain an admixture of antimony and lead. Depending on the elemental composition of copper-based metals in various categories of objects, it is hypothetically possible to reconstruct the sources of metal supply of the South Urals and to characterize the local features of the metallurgy development in this region in the Bronze Age.

Keywords Bronze age · South Ural · Metal production · Composition analysis of bronzes

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1 Introduction

In recent decades, a multidisciplinary approach in studying materials found at excavations of archaeological sites has created an extended information space to help understand cultural genetic processes. The given perspective equipped with a variety of up-to-date archaeometry methods provides us with an opportunity to approach already well-known sites that possess significant features. The key sites to study the South Urals Bronze Age are the Tavlykaevsky complex in the Bashkir Trans-Urals, Staro-Yabalaklinsky cemetery (Gorbunov and Morozov 1991) in the Trans-Urals. Based on these materials, the researchers have formed schemes illustrating cultural dynamics of the region (Rutto 2003; Bakhshiev 2014; Bakhshiev and Bakhshiev 2014; Alaeva 2015; Tkachev 2017). The necessity to continue research of the "old" collections is conditioned by the broad analytic opportunities of the archaeological material itself, as well as a perspective to implement an interdisciplinary program of a complex study of archeology of the Bronze Age in Bashkortostan.

2 Materials and Methods

The research has been carried out with the electronic scanning microscope Vega 3SBH (TESCAN, the Czech Republic), equipped with a reflected electron detector (SE) and an X-ACT energy-dispersive analysis detector (Oxford Instruments)., A section of the sample surface of 2–5 mm was ground to remove the oxide layer to identify the composition of the metal. Then, this area was polished with diamond paste.

In the course of the analysis, at least five spectral samples of each item were obtained, the average value of which was an indicator of the elemental composition of a non-ferrous item. The studies were carried out at the Institute for Metals Superplasticity Problems of the Russian Academy of Sciences (the abbreviated name is the IMSP RAS).

In the course of the research, ten samples from the Trans-Ural group of monuments were analyzed—items that fell under the category of ornaments of the Srubnaya Culture from Tavlykaevsky burial grounds I and II. Most items were grooved bronze bracelets, namely: four items (found at Grave 1, Mound 2) and with one item found at Grave 1, Mound 3 and Grave 14, Mound 2 of the Tavlykaevsky II burial ground, as well as three bracelets from the Tavlykaevsky I burial ground: Grave 1, Mound 5 (1 item) and Grave 10, Mound 5 (2 items). Samples of a fragment of one plate of a braided fillet or ribbon used as an ornament were also taken (burial 1, mound 2).

3 Results and Discussion

The primary and most common category of metal objects found at the sites under study is bronze bracelets. The predominant shapes are open grooved bracelets with pointed and rounded ends (13 items), twisted wire bracelets with semicircular and sub-triangular sections (2 items), as well as one false twist bracelet. Out of 106 burial mounds (kurgans) excavated at the Staro-Yabalaklinsky burial ground, 81 contained 165 burials of the Srubnaya Culture. In 8 burials, there were 20 items of copper-based metals, with bracelets (16 items) found in all these burials. In the Tavlykaevsky II burial ground, in 6 burial mounds, 30 burials of the Srubnaya Culture were excavated, 7 of which contained non-ferrous metals (34 items), with bracelets (8 items) also present in all burials. The situation is similar to the Tavlykaevsky I burial ground, where 41 burials of the Srubnaya Culture were examined in 9 mounds, 2 of which contained non-ferrous metals (4 items) with the obligatory presence of bracelets (3 items).

According to their elemental composition, grooved bracelets from the Trans-Urals group can be further subdivided into two groups. The first group includes bracelets from Group 1, Mound 2 of the Tavlykaevsky burial ground, which have the following composition: copper varies from 84.08 to 90.85, tin varies from 8.39 to 13.62. Two bracelets contain antimony in the amount of 0.31 and 1.62. One bracelet contains 0.39 of iron. The plate fragment of the bib necklace was additionally analyzed to make the obtained quantitative indicators more precise. Its elemental composition turned out to be identical to the primary group of grooved bracelets.

The second group includes the remaining grooved bracelets, which contain from 85.50 to 88.66 copper, from 4.98 to 14.03 tin, and from 0.15 to 0.47 silicon. Apart from the indicated elements, two bracelets contain iron (0.14 and 0.07) and lead (2.68 and 4.30), as well as phosphorus and nickel (Table 1, No. 6, No. 8). Regarding the chemical composition, this group also includes twisted wire bracelets from Grave 7, Mound 10 of the Tavlykaevsky I burial ground, which also consists of copper, tin, silicon, iron, lead, phosphorus, and nickel (Table 1, No. 9–10). Despite a smaller number of composition elements in contrast to the second group, the grooved bracelet from Grave 14, Mound 2 of the Tavlykaevsky II burial ground does not have an aluminum admixture like the other ones.

Thus, the leading metallurgical group is tin bronzes with three-component copper—tin–lead (4 items) and copper–tin-antimony alloys (3 items) (see Table 1).

Regarding its composition, the series under study demonstrates the inner variability. Items with the addition of lead were found mainly in the graves of the Tavlykaevsky I burial ground (except for the bracelet from Grave 1, Mound 3 of the Tavlykaevsky II burial ground). Whereas items from the female burial in Grave 1, Mound 2 of the Tavlykaevsky II burial ground, were made of an alloy of copper (from 84.08 to 90.85), tin (from 8.39 to 13.62), and antimony is1.08 in the plait ornament, and 1.62 and 0.31 in the grooved bracelets. In addition to inclusions of antimony, the group is distinguished by fixed natural admixtures of aluminum (0.22–0.44) that are not found in other analyzed objects.

Table 1 Results of the elemental analysis of the composition of metal objects obtained at the burials dating back to I and II Tavlykaevsky burial grounds (Trans-Urals) and Staro-Yabalaklinsky necropolis (Urals)

No	Sample #	Site	Artifacts	Complex	Fe	Cu	Pb	Al	Si	Sn	Ni	S	Cl	P	Br	Sb	Alloy types
Trans-Urals																	
1	620/1	II Tavlykaevsky burial ground	Plait ornament	Mound 2 burial 1		88.86		0.25	0.3	9.53						1.08	Cu + Sn + Sb
2	620/4	–	Grooved bracelets	Mound 2 burial 1		84.08		0.36	0.69	13.24						1.62	Cu + Sn + Sb
3	620/17	–	Grooved bracelets	Mound 2 burial 1	0.39	85.49		0.22	0.28	13.62							Cu + Sn
4	620/20	–	Grooved bracelets	Mound 2 burial 1		88.43		0.37	0.27	10.93							Cu + Sn
5	620/24	–	Grooved bracelets	Mound 2 burial 1		90.85		0.44		8.39						0.31	Cu + Sn
6	620/25	–	Grooved bracelets	Mound 3 burial 1	0.14	88.66	2.68		0.19	4.98	0.24				3.12		Cu + Sn + Pb
7	620/28	–	Grooved bracelets	Mound 2 burial 14		85.50			0.47	14.03							Cu + Sn
8	631/52	I Tavlykaevsky burial ground	Grooved bracelets	Mound 5 burial 1	0.07	86.39	4.30		0.15	9.03				0.09			Cu + Sn + Pb

(continued)

Table 1 (continued)

No	Sample #	Site	Artifacts	Complex	Fe	Cu	Pb	Al	Si	Sn	Ni	S	Cl	P	Br	Sb	Alloy types
9	631/53	–	Bracelets made of rods	Mound 7 burial 10	0.8	84.26	3.02		0.73	11.15				0.04			Cu + Sn + Pb
10	631/54	–	Bracelets made of rods	Mound 7 burial 10	0.05	84.89	3.09		0.24	11.36				0.37			Cu + Sn + Pb
Urals																	
11	622/3	Staro-Yabalaklinsky burial ground	False twisted bracelet	Mound 23 burial 1		82.9	2.7	0.26	0.27	13.6						0.19	Cu + Sn + Pb
12	622/18	–	Grooved bracelets	Mound 48 burial 3		70.32			1.24	20.25		0.55	6.86	0.78			
13	622/19	–	Grooved bracelets	Mound 48 burial 3		65.01		0.24	0.51	31.08		0.44	2.51	0.21			
14	682/21		Grooved bracelets	Mound 101 burial 1	0.21	83.99	1.17		0.09	13.57						0.27	Cu + Sn + Pb
15	682/22	–	Grooved bracelets	Mound 101 burial 1	0.19	88.63		0.16	0.16	10.68		0.09	0.07				Cu + Sn
16	683/44	–	Grooved bracelets	Mound 106 burial 8	0.07	90.26		0.43	0.04	8.28					0.66	0.25	Cu + Sn

(continued)

Table 1 (continued)

No	Sample #	Site	Artifacts	Complex	Fe	Cu	Pb	Al	Si	Sn	Ni	S	Cl	P	Br	Sb	Alloy types
17	683/45	–	Grooved bracelets	Mound 106 burial 8	0.23	89.51		0.37	0.71	9.18							Cu + Sn

According to Yu. A. Morozov, the materials of the Tavlykaevsky I burial ground may date back to earlier burial mounds than the complexes of the Tavlykaevsky II burial ground, and correlate with the early Srubnaya Culture antiquities (Morozov 1984, p. 134).

E. N. Chernykh points out the morphological and chemical-metallurgical closeness of the metal of the Srubnaya culture to the metal of the Andronovo culture community (Chernykh 1970, p. 112), which is also confirmed by the materials of the Tavlykaevsky burial grounds I and II located in the Srubno-Alakul contact zone of the eastern foothills of the South Urals.

The Ural group of the Srubnaya culture objects is represented by grooved bracelets (6 items) and a false twisted bracelet, rare for the South Urals (1 item).

The leading metallurgical group is tin bronzes with two-component copper-tin alloys (3 items) and copper-tin–lead alloys (2 items) (Table 1, No. 11–17).

Three grooved bracelets have almost identical elemental composition, where copper ranges from 88.63 to 90.26, tin from 8.28 to 10.68, aluminum from 0.16 to 0.43, silicon from 0.04 to 0.71, and iron from 0.07 to 0.23, as well as individual admixtures of either sulfur and chlorine, or bromine and antimony (Table 1, No. 15–17). In the Urals' group, a grooved bracelet from Grave 1, Mound 101 stands out as it does not contain aluminum admixtures, but it contains lead, which makes it close to the bracelets of the Trans-Ural group. The twisted wire bracelet of the Staro-Yabalaklinsky burial ground has a copper-tin–lead alloy with an admixture of aluminum (Table 1, No 11).

In the presence of the objects mentioned above, two grooved bracelets from Grave 3, Mound 48 are prominent with such composition elements as sulfur, chlorine, and phosphorus. These bracelets are also distinguished by the abnormally high tin content (20.25–30.08) within the analyzed series.

4 Conclusions

The use of a tin ligature additive is explained, on the one hand, by the traditions of Andronovo metallurgy and, on the other hand, by a possible correlation between the choice of complex alloys and the typology of the analyzed products—jewelry (Tigeeva 2013). The point is that there are no significant ore occurrences of tin in the South Urals; therefore, the literature considers several regions from where tin could be imported in the Late Bronze Age—Altay, North and South Kazakhstan, as well as Central Asia (Zaravshan) (Tkachev 2020).

Depending on the element composition of non-ferrous metal in different categories of objects, it is hypothetically possible to reconstruct the paths of transporting metal to the South Urals and characterize local features of regional metallurgy development at the Bronze Age.

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The Mineral Composition of Ground Material from the Stone Pestles of the Gonur-Depe Administrative and Religious Center (South-Eastern Karakum)

Anatoly M. Yuminov, Ivan A. Blinov, and Natalia Ankusheva

Abstract In this paper, we analyzed grounded materials on working surfaces of stone tools from the Gonur-Depe archaeological site (Turkmenistan). There are groups of minerals used for paint manufacturing (gypsum, antimonite, bismuthine, hematite, red lead) and bronze-casting (cassiterite, fluorite). In addition, we detected the chemical composition of stone products treated with microinclusions of ground material.

Keywords Stone tools · Mineral microinclusions · Chemical and mineral composition · Gonur-Depe · Late bronze age · Bactrian-Margian archaeological culture

1 Introduction

Gonur-Depe is one of the most famous Late Bronze Age archaeological sites in Central Asia. It is located in the south-eastern part of the Karakum desert, 85 km north of the city of Bayramali (Mary Velayat, the Republic of Turkmenistan). The site belongs to the Bactrian-Margian archaeological complex and in ancient times was the largest administrative and religious center of the surrounding area (Sarianidi 2010). Gonur-Depe was founded at the end of the third millennium BC of the Murghab River delta and lasted until the middle of the second millennium BC (Zaitceva et al. 2008).

The monument was discovered in 1972 and studied by V. I. Sarianidi for the rest of his life. During the years of work, the research team has collected ceramics, copper, bronze, and precious metals, as well as many stone-made objects (Sarianidi et al. 2020). However, despite the long study period, a systematic study of it has been started recently. The stone tools on Gonur-Depe are common artifacts. They were

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detected on almost every burial grave as well as in residential, administrative, and religious contexts.

In the process of work with the lithic collection, we examined 294 different types of stone tools, mainly (about 80%) represented by abrasives: pestles, mortars, sharpeners, grating plates, hollows, etc. The microscopic study has revealed linear traces on the working surface in the form of multidirectional shallow thin lines with soft, blurred edges, scuffing, and spotty polishing (Yuminov 2012; Yuminov and Manbetova 2016; Yuminov and Tyutev 2016). A detailed study of the working surface of 12 tool samples has revealed the presence of grounded materials, namely, microinclusions of minerals that were rubbed (pressed) into the intergranular space during the work with stone tools. В 12 обнаружены следы растертого материала.

The work aims to diagnose the composition of the material that was rubbed onto stone tools.

2 Materials and Methods

The size of the identified microinclusions varies from the first to tens of microns. Their detection is possible with an electron microscope, and the diagnosis of the substance can be determined by the mean of microprobe analysis. Electron microscopy provides data about the shape, size, and position of inclusions (Vlasov et al. 2011). Using the analysis of microprobes, we are conducting a high-quality local chemical analysis of mineral grains.

In total, twelve stone pestles-chimes of various shapes and sizes were analyzed. The working surface of the abrasive tools was visually examined for the detection of strips, thin crusts, spots, or small inclusions of foreign matter on them. Then the samples were examined in detail using a binocular microscope, sketched, and photographed. After a macroscopic study of the tools, the part of the tool surface with the microinclusion of minerals was cut off with a diamond saw. The resulting material (1–2 cm across) was glued to an aluminum substrate using conductive adhesive tape. Then, the samples were sprayed with graphite or gold in a vacuum and submitted for analysis. The analysis was conducted using a Tescan Vega 3 sbu scanning electron microscope with an Oxford Instruments X-act EDA; accelerating voltage is 5–30 kV, a spatial resolution of the electron-optical system is up to 3 nm, the spectral resolution of the detector on the line is Mn 114 eV. However, while interpreting the results of the analysis, it is important to pay attention to the fact that some artifacts sometimes contain scratches left by modern steel tools (shovels, picks, knives, trowels, etc.). Usually, such modern tools are made of steel with special ligatures. Therefore, the presence of Cr, Ni, and Mn in EDS makes it possible to cull off fragments left by modern tools.

3 Results and Discussion

Three technological groups of the material have been identified during the analysis (Table 1). They could be used in crushed and ground forms for the following processes:

(1) Paint producing;
(2) The processing of mineral raw materials in the bronze foundry;
(3) The subsequent processing of metal products.

The leftovers of coloring pigments are most often recorded on surfaces of stone pestles and pestles-chimes (Fig. 1a). This is because the colors were used to paint buildings in Gonur Depe with white, red, green, blue, black, and other colors (Veresotskaya 2012).

White and light gray pigments are the most widespread. They covered the walls of administrative and religious buildings, i.e. altars of Fire, the "White" Room,

Table 1 Brief description of the rubbed material on the working surface of Gonur-Depe abrasives

Technological groups	Function	Mineral (formula)	No sample
1. Paints	White pigment	Gypsum ($Ca[SO]_4$ * $2H_2O$)	GD 137-133c GD 143-6
	Black pigment	Soot, coal (C)	GD 137-117a
	Dark-grey pigment	Antimonite (Sb_2S_3) Bismuthine (Bi_2S_3)	GD 142-9ad GD 4c
	Red-brownish pigment	Hematite (Fe_2O_3)	GD 4e GD 137-133 g
	Yellow–red pigment	Lead litharge (PbO) or red lead (Pb_3O_4)	GD 137-98c
	Paint stabilizer (?), poison (?)	Anglesite ($Pb[SO]_4$)	GD 137-133a
2. Bronze foundry	alloying elements for Sn bronzes manufacture	Cassiterite (SnO_2)	GD 137-113a
	Flux (?)	Fluorite (CaF_2)	GD 137-113b GD 137-133c
3. Metal items processing	Jewelry abrasion	Cupronickel (Cu, Ni, Fe)	GD 4 d
	Cu tools sharpening	Metal copper (Cu, Fe)	GD 142-115ba GD 142-115bb
Contamination of artifacts during excavation and sample making for analysis	'Soil' ground	Carbonates; Fe sulfates; halite, sylvite; clayey minerals	GD 137-133d
	Contact with modern Fe tool	(Fe, Ti, Cr, V, Mn)	
	Cutting through the samples in the workshop	Bronze (Cu, Sn)	GD 137-133g
	Scratch of pen and ink	Ni	GD 137-107a

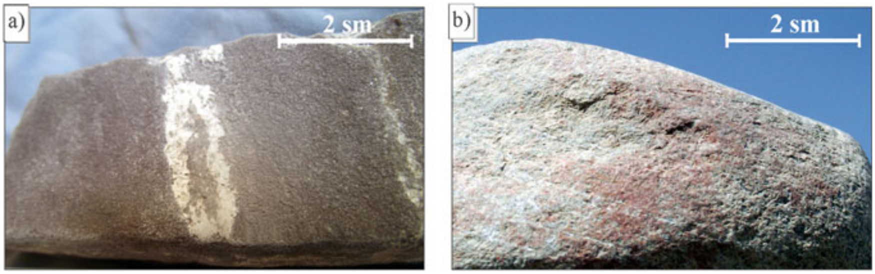

Fig. 1 Fragments of ground material on the working surface of a pestle: **a** gypsum grains (sample GD 137-98); **b** a thin crust of hematite (sample GD 143-6)

etc. Gypsum was used for the manufacture of white paint. This material is in large quantities on the abrasive bar (mod. GD-143-6) and composes numerous crusts with various shapes and sizes, usually pressed into numerous cracks (Fig. 1b). The mineral composition of the raw material is determined not only by microprobe studies but also confirmed by the RFA. In addition to gypsum, a small amount of calcite and cerussite is in the mixture. At Gonur-Depe, in addition to whitewashing the walls, gypsum was used to coat the inner walls of large ceramic vessels intended for the production and storage of various fluids (Yuminov and Manbetova 2016).

Black and dark gray pigments. There are papers on the use of charred organic matter as a paint on the texture that was published in 2012 (Veresotskaya 2012; Kovaleva 2012; Pisareva 2012). They describe the black carbonaceous pigment. Indeed, coal or soot material rubbing, due to its availability, was widely developed at this facility. This is evidenced by numerous finds of tools with fragments of thin crusts of black matter composed of carbon (Fig. 2a).

Stibnite (antimonite-Sb_2S_3) was discovered on the working surface of the pestle GD 142-9. The mineral formed lamellar fragments, angular in shape, with a size of about 5 μm (Fig. 2b). The chemical composition is dominated by antimony and sulfur. Bismuth and lead are presented as trace impurities. When mashed, they have a dark gray to black color. Probably, the mineral has been used for cosmetic purposes as eyeliner. In nature, it is found in quartz veins of the antimony-mercury deposits.

Bismuthine (Bi_2S_3) was found on the working surface in the brick-red grout of the pestle-courant GD 4. The mineral is presented by a thin plate-shaped fragment of 3–5 μm in diameter. In addition to the main elements (Bi and S), it contains small amounts of Sb, Pb, and Cu. It is a rare mineral and it is never found in large masses. It has bactericidal properties. As well as stibnite, it could be used for cosmetic manufacture.

The red pigments are presented by grains of two minerals of Pb-oxides: lead litharge (PbO) and red lead (Pb_3O_4). They were found on the working surface of a pestle-chime of a washer-shaped shape (mod. GD 137-98) and presented by fragments of flattened grains with diameters of about 15–20 μm (Fig. 2c). Their chemical composition was also diagnosed. Red lead is a stable paint of a reddish-orange color. This mineral is formed in the zones of oxidation of sulfide deposits. In addition, red

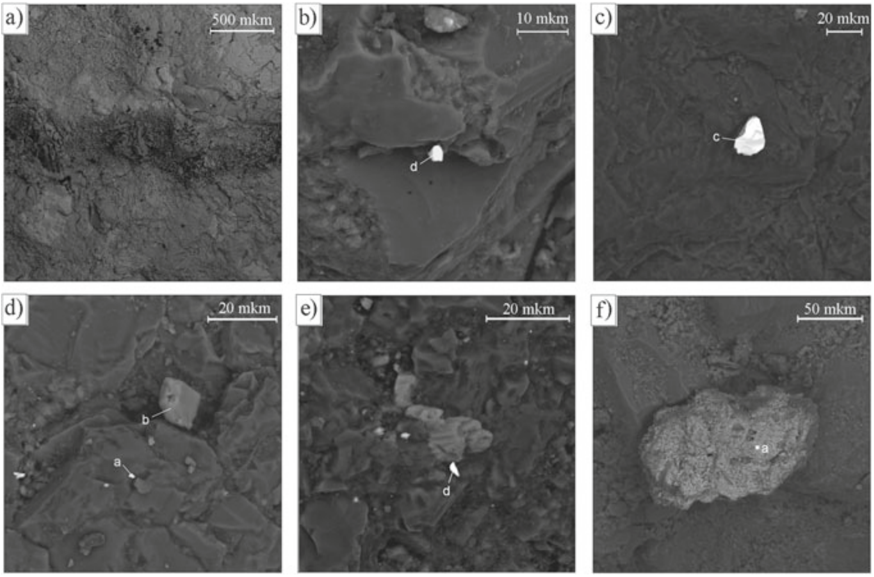

Fig. 2 Micrographs of the ground material on the working surface of the Gonur-Depe stone tools: **a** fragments of carbonaceous matter (sample GD 137-117a); **b** antimonite (**d**) in the recess between quartz grains (gray) (sample GD 142-9); **c** lead oxide on the limonite crust (dark gray) (sample GD 137-98); **d** small fragments of cassiterite (**a** light gray) and fluorite grains (**b** gray) in the intergranular area of the stone pestle (sample GD 137-113); **e** nickel silver chips (sample GD 4d); **f** metallic copper (**a**) pressed between the grains of plagioclase (sample GD 142-115a)

lead can be obtained by oxidation of metallic lead and re-forged a lead whitewash (Popular … 1983).

Hematite (Fe_2O_3) is found in the vast majority of samples as thin accretions with limonite. Hematite, when rubbed, has a stable reddish-brown color and can be used for making paints. It is widespread and has been used as red ochre.

The discovery of lamellar angular grains of anglesite or lead vitriol ($Pb[SO]_4$) on the surface of one of the pestles (mod. GD 137-133) is not entirely clear. Anglesite is found in the oxidation zone of lead deposits but does not form large accumulations. It can be used as a paint stabilizer. At the same time, lead vitriol is a very toxic substance that causes kidney damage, visual impairment, and damage to the central nervous system. Therefore, this substance could be used as a poison or for medicinal purposes.

The second technological group includes minerals that could be used in metallurgical or bronze-casting production. In the production premises of Gonur-Depe, in the so-called "metalworker's workshops", there are finds of crucibles, ice cubes, foundries, as well as fragments of drains and metal drops (Sarianidi and Dubova 2006; Papachristou 2016). This indicates the possibility of metalworking on Gonur-Depe. An important and necessary material for the production of tin bronzes is cassiterite (SnO_2). Cassiterite grains were found on the working surface of the pestle GD 137-113 (Fig. 2d).

The nearest tin deposits are known in Central Asia. They are located in the territory of modern Uzbekistan (Karnak), Tajikistan (Mushiston), Kazakhstan (Syrymbet), Iran (Deh Hosain), and Afghanistan (Helmand) (Cleuziou and Berthoud 1982; Weisgerber and Cierny 2002; Ciernyand and Weisgerber 2003; Boroffka and Parzinger 2003; Stöllner et al. 2011, 2013; Pigott 2011: 284–285).

Radiocarbon studies of eco- and artifacts, as well as finds in mine workings and accompanying settlements of Andronovo-Fedorovo and Batria ceramics prove the active contacts of ancient miners with the population of the Bactrian-Margiana archaeological complex (Lyonnet 2005; Avilova 2008).

In addition, fragments of ***fluorite*** $\boldsymbol{(CaF_2)}$ were used in ancient times as a special additive to reduce the melting point and facilitate the dissolution of the added substance in the total volume of the alloy. The presence of these minerals on the working surface of the stone tools left in the process of their operation, suggests the presence of the bronze-casting production in ancient Gonur-Depe.

Thus, the study of separate stone tools revealed traces of the processing of metal products. Between the grains, sometimes there were fine particles of nickel silver (a copper-nickel alloy with small iron content) and metallic copper (Fig. 2e, f). The analysis of the metallic copper composition revealed a slight admixture of iron. The presence of iron in the range of 1.5–0.5% in ancient copper products is a typical feature of metallurgical copper.

4 Conclusions

Thus, the current study has shown that the preparation of mineral paints obtained by fine grinding of gypsum, calcite, red lead, hematite, stibnite (antimonite), and bismuthine took place directly at Gonur-Depe. As a tool for grinding, small pestleschimes were used, usually made of fine-grained arkose or polymictic sandstone. All the dye raw materials were imported from other regions.

In addition, fragments of grains of cassiterite or tinstone (SnO_2)—the main mineral used for the production of bronze since ancient times,—was found in the intergranular space of individual stone tools, as well as, grains of fluorite (CaF_2)—a mineral used as a flux to reduce the melting point and viscosity of metallurgical slag. These findings raise questions about the presence of metalworking skills among the ancient artisans of Gonur-Depe (previously, the ruins of bronze-casting furnaces with the remains of inventory and drops of tin bronze were found on the monument) and also the possibility for the production of bronze.

Our approach has made it possible to specify the technological groups of minerals. Its further development allows to identify of new types of mineral raw materials used on the site and also to describe in detail the technology of their application.

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Comparison of the Results of Studying the Composition of the Alloy of Coins of Chersonesus Minting of the Roman and Byzantine Times

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Abstract This work presents a comparative analysis of the elemental composition of two groups of coins minted in Chersonesos/Cherson of the Roman period from the collection of the Chersonesean Museum Preserve and coins of the Byzantine time from excavations of the hillfort of Mangup-Kale in South-Western Crimea. The analysis of the elemental composition of coins was carried out using energy-dispersion X-Ray fluorescent desktop spectrometers. Totally 55 coins of late Roman and Byzantine times were investigated dated from the second to the sixth centuries A.D. It was found out that lead–tin bronze was used as the material for making coins of both periods. Comparing the elemental composition of coins minted in Chersonesos/Cherson indicates that the practice of "spoiling" a coin alloy with an unnecessarily large amount of lead, which appeared in Roman times, was widely used throughout the Byzantine period.

Keywords Crimea · Mangup · Chersonesos/Cherson · Roman Empire · Byzantine Empire · Coin copper-based alloys

1 Introduction

One of the most essential sources for studying the history of Tauric Chersonesos is coins, minting of which continued with some interruptions for 1500 years. In 2019–2020, we began studying the alloy composition of coins from ancient Chersonesos belonging to the collection of the Chersonesean Museum Preserve and Byzantine Cherson, from excavations of the hillfort of Mangup in South-Western Crimea.

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Previously, the alloy composition of the coins of this center was investigated on the materials from the State Hermitage Museum (Smekalova 2001).

In 144 AD, Tauric Chersonesos gained from the Roman emperor Antoninus Pius (138–161 AD) the status of a free town. This period, which continued until the AD 260s and was called the 'second eleutheria' in the literature, was a special one in the history of Chersonesos because during two and a half centuries, although under a strong influence of Bosporos, it enjoyed the rights of a free town. This lead to the further economic development of the chora of Chersonesos, which started already in the third century BC when equal civil plots were replaced by large vineyards (Smekalova and Terekhin 2018, pp. 91–93; Smekalova et al. 2018, p. 72). With the beginning of a new period, also the coinage of Chersonesos changed. Now coins were minted, although varied stylistically, extremely weighted with diverse additional signs, monograms, etc. Only four denominations were issued: tetrassarion (head of a deity Chersonas/Maiden and a hind), tressis (Asklepios/Hygieia), dupondius (Maiden and hind/butting bull), and assarion of two types: Chersonas/Maiden or Chersonas/Nike).

2 Methods and Materials

The analysis of the elemental composition of coins from the Chersonesean Museum-Preserve collection was carried out using an energy-dispersion X-Ray fluorescent spectrometer M1 Mistral (Bruker) with a semiconductor silicon drift detector of high resolution (50 keV, 50 W), PO—XSpectPro. Registration of the fluorescent emission was conducted 'in the air' enabling us to detect elements with an atomic number over 17 (Cl). Identification of the elemental composition was conducted in several points on the obverse and reverse of the coins. The investigated area in each measurement was 1.5 × 1.5 mm. The time of measurement was 20 s. For the comparative analysis, averaged data for a particular studied coin were selected. The elemental composition was measured in the concentration range up to 0.01%. The identification of the main components in the alloy (Cu, Sn, Pb, Ag, Ni, Zn, Fe, As, Sb) is presented in Table 1 and introduced into a general database.

The investigation of the elemental composition of the alloy of the surface of 17 coins found during archaeological excavations of the medieval hillfort of Mangup (see Table 1) was conducted by the method of X-ray fluorescent analysis using a desktop sequential wave dispersion spectrometer Supermini 200 (Rigaku, Japan). This instrument makes it possible to analyze elements from oxygen (O) to uranium (U). The equipment Supermini 200 (X-ray tube: 50 kV, 200 W, Pd-anode; spectral resolution—5 to 10 eV; the limit of the detected concentration <0.01%) provides for the possibility to identify the contents both of the heavy and light elements in the composition of the alloys of the coins under investigation. The measurement is conducted on examples in the vacuum in a non-destructive way. The cell diameter for a solid sample is 44 mm, with the diameter of the measurement window of 32 mm.

Table 1 Descriptions of the analyzed coins mentioned also in Table 3

Nr	Place of find, Nr. in the collection list	Wt, g	Obverse	Reverse	Emperor, date, mint	References
1	Tauric Cape, 22	4.19	DN LEOP[E] PRETAC. Diademed, draped and cuirassed bust, right	SALVS RPVRLICA. Emperor standing to right, holding standard and globe, spurning captive; in exergue: CON	Later Roman Empire, Leo I (457–474). Mint of Constantinople	Grierson and Mays (1992), pl. 22: Leo I (3), nr. 561 (Class 2)
2	Palace, 45	2.86	[DN IVSTINIANVS]. Profile bust r. with diadem and cuirass	Emperor standing holding long cross and globe, around VIC [TOR]	Byzantine Empire. Justinianus I (527–565) Pentanummium. Mint of Cherson. V.A. Anokhin considers this type of coin issued in Constantinople	Hahn (2000), p. 157, nr. 252a, pl. 29,252a; Anokhin (1977), nr. 310–311; Anokhin (2016), pp. 245, 246
3	Palace, 121	1.33	as nr. 2	–	–	–
4	Palace, 186	1.68	[DN IVSTINIANVS PP AVC]. Profile bust r. with diadem and cuirass	Monogram combining the name of the city of Cherson	Byzantine Empire. Justinianus I (527–565) Pentanummium. Mint of Cherson	Hahn (2000), p. 158, nr. 253, pl. 29,253; Anokhin (1977), nr. 314
5	Palace, 222	3.82	as nr. 2	–	–	–
6	Palace, 427	1.74	as nr. 4	–	–	–
7	Palace, 428	2.31	as nr. 2	–	–	
8	Palace, 385	3.71	Large B. Linear border	Cross crosslet on base and two steps. To left and right, pellet. Linear border	Byzantine Empire. Basile I (867–886). AE. The cast of Cherson 879–886	Bellinger and Grierson (1993), p. 505, nr. 20a, pl. XXXIII, 20a; Anokhin 1977, nr. 371

(continued)

Table 1 (continued)

Nr	Place of find, Nr. in the collection list	Wt, g	Obverse	Reverse	Emperor, date, mint	References
9	"Garrison Church", 311	2.61	Patriarchal cross on base and two steps. To left – Λ. To right – A	Cross on base and two steps with crosslets at extremities. To the left and right pellet	Byzantine Empire. Leo VI and Alexander (886–912). AE. The cast of Cherson	Bellinger and Grierson (1993), p. 522, nr. 12.1–3, pl. XXXV, 12.1–3; Anokhin 1977, nr. 390
10	"Garrison Church", 312	3.8	Monogram of the name of Romanus	Cross on base and two steps with crosslets at extremities. To the left and right pellet	Byzantine Empire. Constantin VII (913–959). AE. The cast of Cherson under Romanus I (920–944)	Bellinger and Grierson (1993), p. 577, nr. 3a.1–5, pl. XL, 3a.3–4 (Romanus II); Anokhin (1977), nr. 408–413
11	Palace, 408	2.52	as nr. 10	–	–	–
12	Palace, 425	0.58	as nr. 10	–	–	–
13	Palace, 180	9.23	Monogram of the name of Romanus	Cross on base and two steps with crosslets at extremities of arms. To the left and right pellet	Byzantine Empire. AE. The cast of Cherson of the End of 11th – early 12th c	Bellinger and Grierson (1993), p. 571, nr. 32a-b, pl. XL,32a-b (Romanus I alone)
14	Palace, 41	1.43	[DN IVSTINIANVS PP AVC]. Profile bust r. with diadem and cuirass	Large I, above the cross. To left—A|N|N|O, to right—year (?), in exergue: [CON ?]	Byzantine Empire. Justinianus I (527–565) Decanummium. Mint of Constantinople (?) 538–565	Hahn 2000, p. 133, nr. 99–100, pl. 21, 99–100
15	Palace, 54	3.57	as nr. 14	–	–	–
16	Palace, 119	1.75	[DN IVSTINIANVS PP AVC]. Profile bust r. with diadem and cuirass	Large I, above the star. To left—A|N|N|O, to right—year (X|XX|ЧI = 36), in exergue: NIK	Byzantine Empire. Justinianus I (527–565) Decanummium. Mint of Nicomedia 560–565	Hahn (2000), p. 138, nr. 118b, pl. 22, 118b

(continued)

Table 1 (continued)

Nr	Place of find, Nr. in the collection list	Wt, g	Obverse	Reverse	Emperor, date, mint	References
17	Palace, 225	2.88	[DN IVSTINIANVS PP AVC]. Profile bust r. with diadem and cuirass	Large I, above the star. To left—[A|N|N|O], to right—year (?), in exergue: NI[K]	Byzantine Empire. Justinianus I (527–565) Decanummium. Mint of Nicomedia 553–565	Hahn (2000), p. 138, nr. 118f-b, pl. 22,118b

Measurements were carried out on a single side of the samples. Results of chemical analyses should be presented and referred to in Results and discussion.

3 Results and Discussion

The results of the measurements of coins alloy composition are presented in Tables 2 and 3.

By AD 222, the composition of the alloy of coins of the 'second eleutheria' significantly changed. Previously the coins were predominantly made from lead–tin bronze with a high lead content, sometimes up to the third or even half of the composition (Smekalova 2001). Now coins of a large denomination are struck from a multi-component alloy identical to that of Roman asses, which contains almost no lead and includes a moderate concentration (a few percent) of tin. For coins of small denominations (dupondii and extremely rare assarii), leaded tin bronze is employed with high, occasionally superfluous, the content of lead (more than half of the composition) (Table 2, *2, 7–9*). This feature has been already noted during the examination of similar coins from the collection of the State Hermitage Museum (inventory nr. 26245/290, 26241/286, 26248/292–293) (Smekalova 2001).

The next series of AD 222–235 coins (Anokhin 1977, nr 296–303) differs in the alloy from the previous issues. Now the coins repeat only the types of tetrassaria and are struck from bronze with large lead contents (Table 2, *37*). The last issue of coins of Chersonesos of 253–268 AD (Anokhin 1977, nr. 304–308) turned to be the most numerous one. There is a degradation of the style of images on the coins and their weight and a deterioration of the quality of the coin alloy so that now all the coins are minted from an alloy containing still more lead (Table 2, *38*). This phenomenon probably is connected with the social and political changes occurring both in the Roman Empire and in Olbia and Bosporos. The 'Gothian' and 'Scythian'

Table 2 Alloy composition (Wt%) of the coins of ancient Chersonesos from second and third centuries A.D. from the collection of the Chersonesean Museum Preserve

No	Inv. No	(Anokhin 1977)	Date	Wt, gr	Alloy composition, Wt%							
					Cu	Pb	Sn	Zn	Fe	Ag	As	Sb
1	17757	251	138–161	11.9	96.84	0.88	1.85	0.00	0.09	0.22	0.00	0.12
2	20829	261		2.55	53.70	44.25	1.02	0.33	0.28	0.24	0.00	0.19
3	14107	262		5.00	98.71	0.30	0.15	0.00	0.00	0.06	0.00	0.01
4	13427	270	161–180	4.95	90.37	2.12	6.95	0.13	0.19	0.09	0.00	0.14
5	17107	270		1.85	92.14	0.98	5.95	0.21	0.00	0.42	0.00	0.23
6	18026	271		2.80	85.54	2.60	8.88	0.43	0.07	0.05	0.00	0.12
7	21416	271–272		2.85	18.01	66.35	14.56	0.00	0.00	0.24	0.00	0.83
8	21426	271		3.20	44.15	45.29	6.64	2.87	0.55	0.10	0.00	0.40
9	21496	271		3.55	60.68	37.38	1.19	0.40	0.00	0.10	0.00	0.24
10	17770	273	180–192	4.26	99.34	0.24	0.23	0.00	0.00	0.08	0.00	0.12
11	17771	273		3.67	96.07	1.12	1.88	0.59	0.1	0.09	0.00	0.13
12	14191	273		1.50	96.98	0.08	0.16	0.00	0.12	0.31	0.00	0.06
13	13544	275		7.30	85.84	2.67	11.09	0.20	0.08	0.04	0.00	0.09
14	13434	276		6.30	92.95	1.03	4.37	1.12	0.30	0.09	0.00	0.13
15	17773	278		3.76	99.07	0.73	0.00	0.00	0.13	0.00	0.00	0.07
16	13951	278		3.85	99.37	0.32	0.21	0.00	0.00	0.06	0.00	0.04
17	80	280		3.45	97.69	0.672	0.522	0.464	0.085	0.17	0.25	0.14
18	13362	280		3.45	95.57	0.44	3.89	0.05	0.00	0.00	0.00	0.04
19	13436	280		3.30	93.36	0.89	5.62	0.00	0.09	0.00	0.00	0.04
20	16721	283		1.15	82.68	5.56	11.23	0.00	0.10	0.05	0.00	0.12

(continued)

Table 2 (continued)

No	Inv. No	(Anokhin 1977)	Date	Wt, gr	Alloy composition, Wt%							
					Cu	Pb	Sn	Zn	Fe	Ag	As	Sb
21	17776	284	192–211	4.00	93.27	5.46	1.16	0.00	0.00	0.05	0.00	0.06
22	13505	284		2.95	94.81	3.97	0.81	0.14	0.05	0.00	0.00	0.09
23	17777	285		2.29	97.71	0.88	1.4	0.00	0.00	0.00	0.00	0.00
24	17778	286	212–217	4.35	98	1.18	0.52	0.00	0.14	0.08	0.00	0.07
25	17779	286–287		5.01	98.09	1.02	0.04	0.00	0.23	0.12	0.45	0.05
26	13555	286		4.20	98.04	1.02	0.62	0.12	0.00	0.08	0.00	0.11
27	13559	287		4.15	99.02	0.53	0.25	0.11	0.00	0.04	0.00	0.06
28	13425	289	218–222	5.90	99.22	0.51	0.10	0.00	0.08	0.05	0.00	0.04
29	13433	289		3.65	98.74	0.79	0.08	0.00	0.19	0.10	0.00	0.10
30	17780	291	212–222	3.23	99.03	0.65	0.1	0.08	0.00	0.08	0.00	0.06
31	5822	291		5.05	98.83	0.71	0.11	0.10	0.12	0.07	0.00	0.07
32	17781	292		3.05	97.58	1.55	0.56	0.00	0.15	0.08	0.00	0.09
33	17782	293		3.42	96.39	2.8	0.51	0.00	0.16	0.08	0.00	0.07
34	19604	294		3.20	96.53	2.32	0.61	0.00	0.24	0.14	0.00	0.16
35	13966	300	222–235	3.95	94.70	0.53	2.43	0.34	0.11	0.11	0.00	0.08
36	13557	301		4.70	81.34	3.10	13.9	0.29	0.94	0.22	0.00	0.11
37	2046	296–303		7.45	76.58	11.24	9.05	2.05	0.77	0.10	0.00	0.21
38	17667	306–307	253–268	3.10	56.62	36.66	5.69	0.38	0.24	0.14	0.00	0.27

Table 3 Elemental composition (Wt %) of the numismatic finds from excavations at the hillfort of Mangup

Nr	Place of find, Nr. in the collection list	Wt, g	Alloy composition, mass Wt %									
			Cu	Pb	Sn	Zn	Fe	Ag	As	Sb	Ni	In	Other elements
1	Tauric Cape, 22	4.19	56.56	28.86	9.45	1.99	1.63	–	0.77	–	0.07	0.67	–
2	Palace, 45	2.86	56.34	34.15	5.67	–	1.44	1.01	0.67	–	0.07	0.67	–
3	Palace, 121	1.33	62.76	30.4	4.91	0.13	0.81	–	0.91	–	0.1	–	–
4	Palace, 186	1.68	30.97	59.24	7.41	0.18	0.85	–	0.8	–	0.12	0.44	0.02 (Co)
5	Palace, 222	3.82	58.6	31.08	6.62	0.21	1.63	–	1.05	–	0.1	0.71	–
6	Palace, 427	1.74	14.59	68.18	14.26	0.13	0.92	–	0.65	–	0.12	1.15	–
7	Palace, 428	2.31	37.07	50.91	8.70	0.22	1.99	–	1	–	0.12	–	–
8	Palace, 385	3.71	35.72	58.7	3.81	0.34	1.43	–	–	–	–	–	–
9	“Garrison Church”, 311	2.61	10.46	73.93	7.83	0.52	0.57	1.92	0.59	2.91	–	1.11	0.19 (Ru)
10	“Garrison Church”, 312	3.8	22.58	69.52	6.19	0.31	0.22	–	0.54	0.63	–	–	0.34 (Bi)
11	Palace, 408	2.52	36.39	61.9	1.52	–	0.19	–	–	–	–	–	–
12	Palace, 425	0.58	44.73	52.7	2.32	–	0.15	–	–	–	–	–	0.1 (Cr)
13	Palace, 180	9.23	23.04	69.75	3.77	0.09	2.37	0.49				0.49	–
14	Palace, 41	1.43	17.01	61.22	13.85	1.16	5.15	–	1.29	–	0.15	–	0.17 (Mn)
15	Palace, 54	3.57	23.37	73.46	–	0.15	0.97	–	–	2.05	–	–	–
16	Palace, 119	1.75	35.75	53.81	7.08	0.35	0.79	–	0.82	–	0.14	0.56	–
17	Palace, 225	2.88	20.21	72.93	3.92	0.47	1.22	–	0.56	–	–	–	–

wars violated the traditional routes of delivery of coin metals, while under the emperor Gallienus (253–268), Chersonesos ceases its minting completely.

The researchers link the resumption of the activities of the mint of Cherson with the time of the rule of the emperor Zenon (474–491) (Anokhin 1977, 97). Possibly, already under his predecessor Leo I (457–474), the needs of the monetary circulation of the city demanded issuing of a new 'copper' coin. This supposition is suggested by several signs characteristic of the Chersonesean mint's issues in the time of that ruler: a high percentage of tin or lead in the composition of the coins and the flaky edge (Korshenko 2000). Several researchers believe that these coins could have been minted in Cherson or for it (Grierson and Mays 1992, pp. 148, 149; Kent 1994, p. 92; Hahn and Wojtek 1996, p. 388; Korshenko 2000, 34–36; Anokhin 2016, 242; Sidorenko 2018, 130, 131).

Table 3 represents the results of the analysis of the elemental composition of the numismatic finds from excavations at the hillfort of Mangup in South-Western Crimea. The coins examined in this work were found in the archaeological investigations of 2019 at two sites of the Mangup hillfort—the palace complex of 1425–1475 in the central area of the Mangup plateau the so-called 'garrison church' on the Teshkli-Burun promontory. The collection of the coins under study includes samples characteristic of the coinage of Byzantine Cherson from the mid-5th—early twelfth century. For comparison, the data on the composition of the alloy of coins minted in other Byzantine Empire centers are represented. The most numerous examples are petty 'copper' coins of lower denominations dated to the time of the rule of Justinian I (527–565) (Table 3, *2–7*) and Constantine VII Porphyrogenitus (913–959) (Table 3, *10–12*).

4 Conclusions

It is of note that in all these cases, lead–tin bronze was used as the material for making coins of Byzantine Cherson. The concentration of lead in the composition of the alloy is considerably higher than that of tin. In particular samples, the content of lead exceeds half of the composition. In coins of the 5th–sixth century AD, arsenic is found in quantities bordering the doping threshold (1%) and micro-additions of nickel are detected. The alloy also contains zinc in trace concentrations, but in a coin struck during the rule of Leo I (457–474) its content reaches almost 2%. In two cases, silver content over 1% was detected (Table 3, *2*, *9*), and in another case, below 1% (Table 3, *13*).

Comparison of the results of elemental analysis of the composition of coins issued at Chersonesos and other mints, both metropolitan and provincial ones (Table 3, *14–17*) demonstrates that 'spoiling' of coin metal with lead started in the Roman period was a widespread practice in the medieval Byzantine Empire. The Chersonesean mint was not exclusion. It is worth noting, however, that also the active use of lead ligature was characteristic not only of the Chersonesean mint.

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"A Crucible with Solidified Substance" or an Ore Sample: Experience of the Complex Analysis of a Unique Find of the Chepetskaya Archaeological Culture

Elena L. Russkikh, Vasiliy A. Volkov, and Faat Z. Gilmutdinov

Abstract In this paper, we present the results of the complex analysis of "a crucible with the solidified substance". This "crucible" was found during the archaeological research of the Kachkashursky I burial ground—one of the 9–13th centuries CE funeral sites of the basin of the Cheptsa RiverA unique find was revealed during a study of the 1971 collection. A primary interpretation of the find as a crucible and a search for analogies requested a further archaeometry study. The results of the chemical and phase composition analysis are presented in the work. The chemical analysis has revealed that "solidified substance" from the artifact is oxidized iron. The phase analysis revealed that the basis of the material of the contents of the "crucible" and the "crucible" itself is iron metahydroxide FeO(OH) (goethite) with quartz impurities. This composition is typical for bog ore. We examined that the find is a large nodule—a type of bog ore, which was the main source of iron ore during the Middle Ages.

Keywords Middle ages · Chepetskaya culture · Kachkashursky I burial ground · Crucible · Chemical analysis · Phase analysis · Marsh ore · Concretion

1 Introduction

Among the finds from ancient burial grounds, various tools are especially interesting. Tools located in a grave may indicate that a "craftsman" was buried in it. By studying such burials, researches may obtain knowledge to reconstruct ideas about the social structure of the ancient society and new pieces of information about the prehistoric production.

We aim to study the non-ferrous metalworking of the population of the Cheptsa River basin during the 9–13th centuries CE. There are many metalworking-related

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finds including casting tools, metal ingots, metal plates, and wire in the materials from the settlements of the Chepetsky archaeological culture of the 9–13th centuries CE. This fact indicates that non-ferrous metals were processed on these settlements. To date, we have investigated certain aspects of medieval non-ferrous metalworking of the Cheptsa River basin. The markers of jewelry production were identified and analyzed in the materials of the fortified settlements and burial sites of the Chepetsky culture. The data was received on the composition of non-ferrous metal alloys used by the local goldsmith's foundry (Russkikh and Sabirova 2017, 2018, 2019). In this paper, we analyze a crucible from the materials from the Kachkashursky I burial ground. This finding gathered our particular interest during the processing of the archaeological collection of this site (Fig. 1, *1*).

The Kachkashursky I (Ludoshurskiy) burial ground of the 9–13th centuries is located 3 km south of the village of Kachkashur, 1.5 km east of the villages of Maly and Bolshoy Ludoshur of the Glazovsky region of the Udmurt Republic, Russia. It occupies a promontory and a steep slope of the high right bank of the Sepich River (a left tributary of the Cheptsa River) (Fig. 2, *9*).

Currently, the burial ground is completely covered with the forest. Its surface has been damaged by illegal excavations. The monument has been known since

Fig. 1 The fragments of crucibles from the Chepetskaya culture sites: 1—"a crucible with solidified substance", the Kachkashursky I burial ground, 1971; 2—the Kushmansky settlement Uchkakar, 2016; 3, 4—the Kachkashursky settlement, 1971; 5—the Soldyrsky III burial ground, 2000–03; 6—the Adamsky II burial ground, 1957

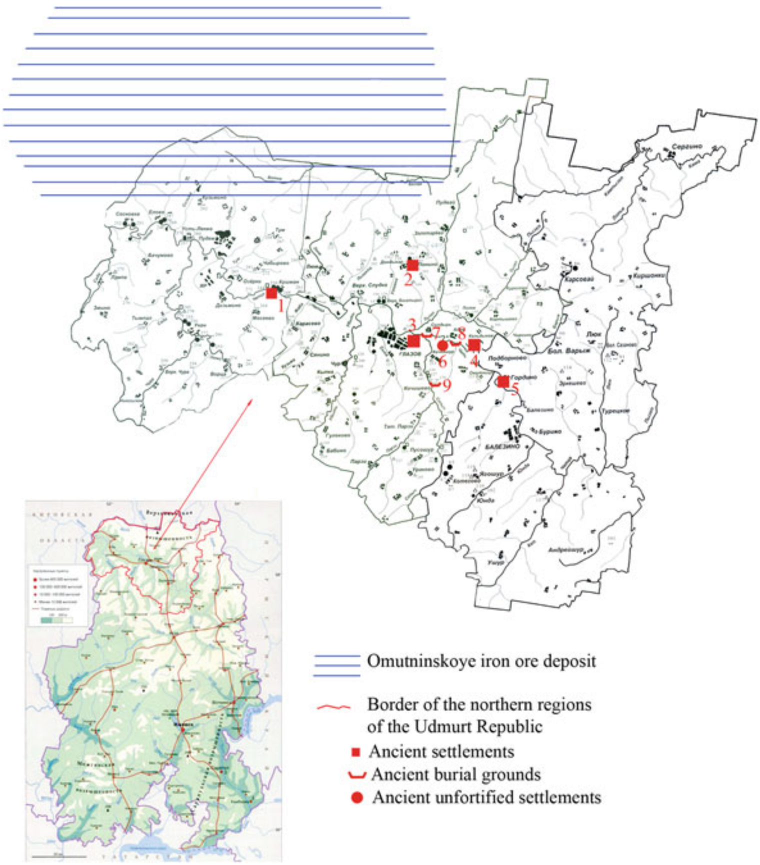

Fig. 2 The sites of the Chepetskaya culture (the 9–13th centuries): 1—the Kushmansky settlement Uchkakar; 2—the Dondykarsky settlement Dondykar; 3—the Soldyrsky I settlement Idnakar; 4—the Vesyakarsky settlement Vesyakar; 5—the Gordinsky I settlement of Guryakar; 6—the Kachkashursky settlement; 7—the Soldyrsky III (Idnakarsky I) burial ground; 8—the Adamsky II burial ground; 9—the Kachkashursky I burial ground

the end of the 19th century under the name of Ludoshursky "Bigershai". In 1894, small excavations were carried out by Smirnov. In 1967–1968, the burial ground was investigated by Kondratyeva (the number of excavated burials remains unknown, as the report is missing, and a part of the collection was also lost). In 1971, Korepanov investigated a crumbling grave (Ivanov 2004). In 1987–1988, Ivanov studied 78 burials on the area of 362 m^2. In 1999, the burial ground was examined in the process of an inventory of the archaeological sites in the Glazovsky district of the Udmurt Republic. In 2004, Ivanova carried out emergency excavations at the burial ground. On an area of 110 m^2, she investigated 34 burials of the 11–12th centuries CE (Ivanova 2004; Kirillov 1999).

The research on the burial ground revealed the following. Burials were made in the sub-rectangular pits. Human remains inside the burial pit were usually located stretched out on the back, heading to the North-West and North. The usual funeral inventory consists of ceramic vessels, metal cauldrons, beads, bronze jewelry, iron tools, weapons, bone products, household items made of metal and bone (Ivanov 1989, 1991; Alekseeva and Ivanov 1999).

The archaeological collections of the Kachkashursky I burial ground (from excavations in 1971, 1987–1988, 2004) are currently kept in the Historical and Cultural Museum-Reserve of the Udmurt Republic "Idnakar" (the City of Glazov). While working with these collections, the author's attention was drawn to an interesting find of a production nature. An archaeologist named Kranit I. Korepanov interpreted it as "a fragment of a crucible containing a solidified piece of a yellowish-brown mass of unknown composition (but not iron)" (Semenov and Korepanov 1971a, b).

At first glance, the find really resembles a fragment of the bottom part of a cylindrical ceramic crucible. The "crucible" contains compact contents of an indefinite shape and composition, similar in color to iron oxides (Fig. 1, *1*). The interpretation of the artifact by Korepanov was not in doubt. First of all, finds of crucibles from other burial sites of the Chepetsky culture, despite their rarity, have been previously identified (Fig. 1, *6, 7*). Secondly, samples of crucibles, similar in appearance to the investigated one, have been also gathered from the collections of foundry tools of the Chepetsky culture medieval settlements. In particular, similar fragments of crucibles were found at the nearby Kachkashursky unfortified settlement, which forms an archaeological microdistrict with the Kachkashursky I burial ground (Fig. 1, *3, 4*). However, such finds of crucibles with a "hardened" remnant of metal have never been found before in the medieval settlements of the Chepetskaya archaeological culture. This is the uniqueness of the investigated find. It is generally accepted that crucibles are small vessels designed to melt alloys of non-ferrous metals, but not iron. In addition, the finds of foundry equipment in the burial accompanying inventory are interesting from the point of view of studying the "phenomenon of craftsmen burials." In this regard, we have decided to conduct a comprehensive analysis of the artifact.

2 Materials and Methods

2.1 Historical Method: A Search for Similar Finds of Crucibles in Medieval Burial Grounds in the Cheptsa River Basin

Burials containing tools for metal processing are found, although quite rarely, among the medieval burial grounds of the Cheptsa River basin. Thus, Ivanov revealed the following (Ivanov 2001). There are only 9 or 10 burials of the Chepetsky burials of the fifth-fourteenth centuries CE that can be attributed as the "craftsmen" burials

(0.5% of the total number of excavated burials). There are 2 burials out of 10 which is associated with metal processing (burials containing small hammers), 5 burials (0.25%) with blacksmithing-related inventory (burials containing finds of ticks and hammers), and 1 burial (0.05%) containing woodcarving tools.

The burials with the tools for the processing of non-ferrous metals are of the greatest interest. According to Ivanov (2001), they are extremely rare sharing only 0.1%. These include two female and one children's burial. The first of them was found in Grave 7 of the Polomsky I burial ground (a second half of the 7th century). Along with a rich complex of femalejewelry, two fragments of casting molds were discovered. In the Adamskiy II Mydlanshai burial ground, a crucible was found in Grave 7, among female jewelry and household items (Ivanov 2001). Another crucible was found in Grave 37 of thr Soldyrskii III (Idnakar I) burial ground of the 11–12th centuries. A cone-shaped crucible with a pointed bottom (Fig. 1, *5*) was found in a child's burial right to the child's skull (Soldyrsky 3 cemetery… 2019).

Thus, in the basin of the Cheptsa River, three medieval graves containing finds of crucibles among the grave goods have been identified. There are two synchronous burial grounds—Kachkashursky I (IX–XIII centuries) and Soldyrsky III (dated to the 9–12th centuries CE), and—Adamsky II burial grounds is earlier, dated to the (8–9th centuries CE). Geographically, these burial grounds there are located closely one to another (Fig. 2, *7, 9*). Gazimzyanov's studies of anthropological materials from the Soldyrsky III burial ground revealed the proximity of some anthropological indicators to the population of the Soldyrsky III, Kachkashur I burial grounds, as well as their connection with the earlier Adamsky II and Varninsky burial grounds (Soldyrsky 3 cemetery… 2019). This fact suggests that these burial grounds were left by the same group, who lived in the territory of the Cheptsa River basin in the Middle Ages.

The crucibles found in the Soldyrsky III and Adamsky II burial grounds (Fig. 1, *5, 6*) are similar in shape (cone-shaped with a pointed bottom), but slightly different in dating. It is also noteworthy that in each grave only a single crucible was found. The "crucible" from the Kachkashursky I burial ground differs from its counterparts in its shape and some characteristics (Fig. 1, *1*). In the process of working with the Korepanov's field materials (1971), it has become clear that this "crucible" was found in the destroyed layer of excavations of previous years and not inside the grave. Nevertheless, the authenticity of the find is beyond doubt. Since the search for analogies did not explained the nature of the substance in the "crucible", we have decided to perform a complete archaeometry analysis of the find.

2.2 The Archaeometry Study of the Chemical and Phase Composition of the "Crucible"

The study of the chemical and phase composition of the "crucible" were carried out in the Physical-Technical Institute of the Udmurt Federal Research Center of the UB

RAS by Faat Z. Gilmutdinov and Vasily A. Volkov. The obtained data has helped to clarify the nature of the artifact.

The analysis of the chemical composition of the "crucible" was performed by X-ray photoelectron spectroscopy on a SPECS spectrometer using MgKα excitation (operated by Faat Z. Gilmutdinov). Initially, we aimed to prepare a sample by cutting off the upper part of the "crucible" and then examine a flat part of the cutout. However, the substance turned to be extremely hard and it could not be cut with a conventional sheet metal. Therefore, a sample for analysis in a form of powder was prepared using emery. Before preparing the powder for analysis, the surface area was cleaned. Further, while grinding the powder, it was found that the investigated object is hollow and forms a capsule.

The data of chemical analysis were significantly supplemented by the study of the phase composition of the sample, which was carried out by the method of X-ray phase analysis (operated by Vasily A. Volkov). In hole area formed during the sampling for photoelectron spectroscopy, an annular piece of the capsule with a width of about 1.5 mm was sawed off with a diamond wheel. Sections of the outer "clay" layer were separated from the metal-like layer. It was not possible to separate loose formations from the inner surface of the capsule from the metal-like layer because the hard and brittle material collapsed and pieces were mixed. A piece of the crucible material was separated from the object. The samples taken for the analysis were ground into powder in an agate mortar and glued onto a plexiglass substrate of 20×20 mm with a layer of about 0.5 mm thick.

3 Results and Discussion

3.1 Results of the Chemical Analysis of the Contents of the "Crucible"

On the cut, the capsule wall consists of a layer of a metal-like substance of black-gray color with a thickness of 1–2 mm. Outside, there is a thin layer similar to the material of the "crucible". The inner surface of the capsule is covered with uneven, looser formations, which are up to 2–3 mm in height, similar to rust on iron (Fig. 1, *1*).

Figure 3 shows an overview spectrum obtained by analyzing the powder; Fig. 4 shows a section of the survey spectrum with low intensity which is shown on an enlarged scale.

The analysis of the spectrum showed that the substance of the investigated powder consists of iron, oxygen, as well as silicon and aluminum with small impurities of calcium, sodium, and potassium. The average elemental composition of the powder was calculated from the X-ray electron spectra, wt.%. The total content of calcium, sodium and potassium is less than 1% (Table 1).

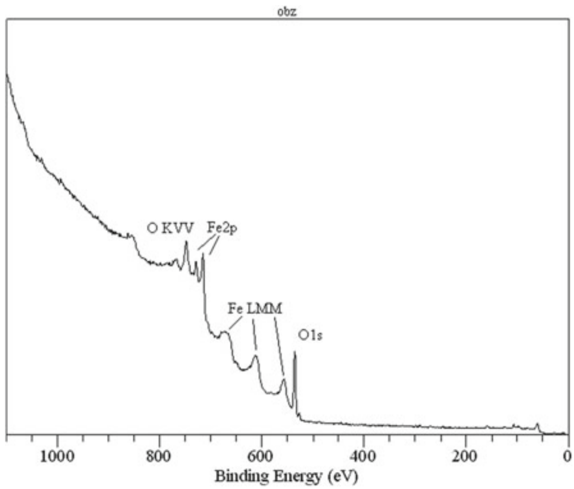

Fig. 3 Overview spectrum of the substance of the contents of the “crucible”

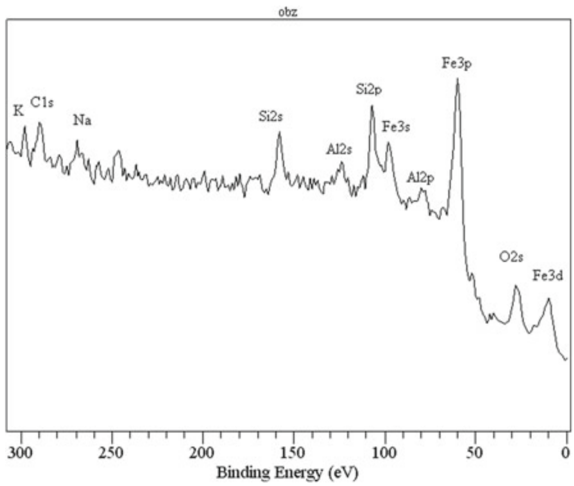

Fig. 4 An enlarged fragment of the survey spectrum in the region of low binding energies

Table 1 Elemental composition of the substance of the “crucible” content

C	O	Fe	Si	Al
3	25	52	12	8

An analysis of the Fe2p and O1s spectra suggests that the substance of the metal-like layer of the capsule wall is oxidized iron. The parameters of the Fe2p spectrum (Fig. 3) correspond to the data of Mansour and Brizzolara (1996), and can be attributed to the goethite substance (a-FeOOH). No signs of iron carbides were found. Silicon and aluminum are oxidized to the 4+ and 3+ states, respectively, which can be attributed to the presence of SiO_2 and aluminosilicates. It is assumed that silicon, aluminum and part of the oxygen are parts of the material of the strong clay-like “crucible” covering the capsule.

3.2 *Results of the Phase Analysis of the Contents and Shell of the “Crucible”*

Figure 5 shows the diffractgram of the sample obtained from the material of the contents of the “crucible” with superimposed standard bar-diagrams of the detected phases. The phase composition of the sample is represented by two main phases—FeO (OH) (goethite, about 95 vol. %) and SiO_2–α (quartz) with a content of 3–5 vol. %. There are small impurities of other phases.

Figure 6 shows an X-ray diffractogram of a sample obtained from a “crucible”

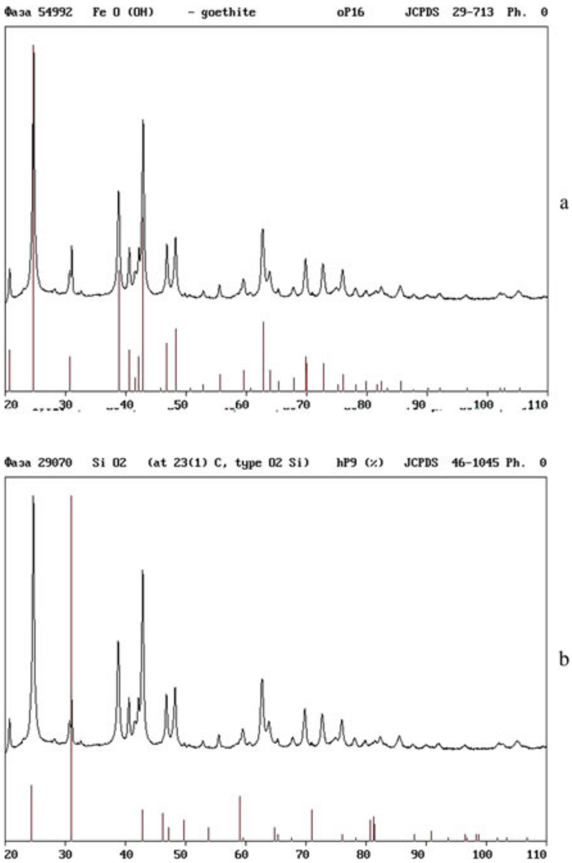

Fig. 5 An X-ray diffraction pattern from the material of the contents of the “crucible” with superimposed reference bar-diagrams of the FeO(OH) (goethite) (**a**) and SiO_2–α (quartz) (**b**) phases

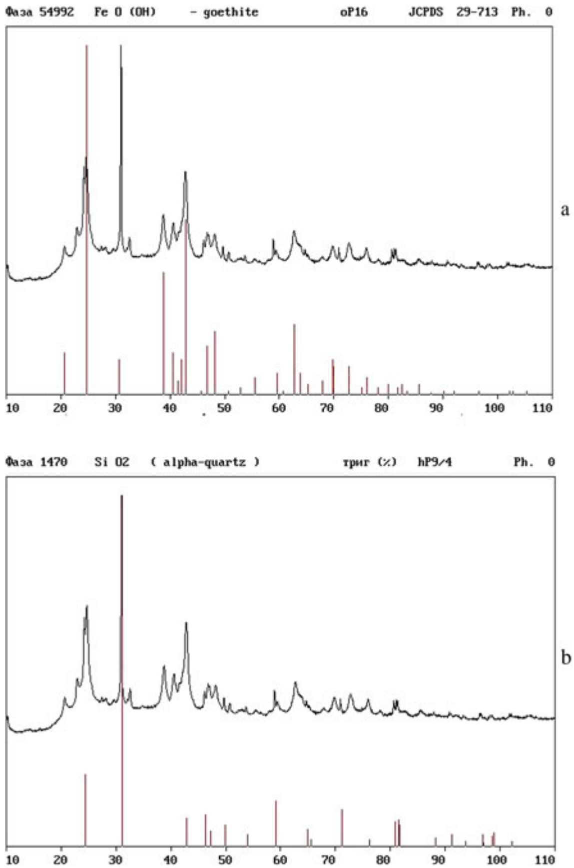

Fig. 6 An X-ray diffraction pattern from the "crucible" material with superimposed standard bar diagrams of the FeO(OH) (goethite) (**a**) and SiO_2–α(quartz) (**b**) phases

material with superimposed reference bar-diagrams of the detected phases.

This sample is also represented mainly by the FeO(OH) (goethite) (a) and SiO_2–α (quartz) (b) phases. However, in this case, the phase ratio is different. The sample is also based on the FeO(OH) phase (about 80 vol.%). At the same time, a significant part of the sample is represented by the Si O2 phase (about 10%). In addition, the diffractogram contains additional lines that cannot be deciphered. Their contribution to the intensity of the diffractogram can be estimated at about 10–15%. According to the results of X-ray electron spectroscopy, which revealed the presence in the sample of aluminum, calcium, potassium and sodium in addition to iron and silicon, these lines may belong to clay particles.

Despite the outward similarity of the "crucible" material with clay materials, the phase composition of the sample differs from that of clays. Clays are usually represented by aqueous aluminosilicates such as kaolinite ($Al_2O_3 \times 2SiO_2 \times 2H_2O$), andalusite, disthene and sillimanite ($Al_2O_3 \times SiO_2$), halloysite ($Al_2O_3 \times SiO_2 \times H_2O$), monothermite ($0.2[K_2MgCa]^0 \times Al_2O_3 \times 2SiO_2 \times 1.5H_2O$), montmorillonite ($MgO \times Al_2O_3 \times 3SiO_2 \times 1.5H_2O$), muscovite ($K_2O \times Al_2O_3 \times 6SiO_2 \times 2H_2O$), narcite ($Al_2O_3 \times SiO_2 \times 2H_2O$), pyrophyllite ($Al_2O_3 \times 4SiO_2 \times H_2O$) and other compounds. The basis of the material for the contents of the "crucible" and the "crucible" itself is iron metahydroxide FeO(OH) (goethite) with quartz impurities. This phase composition is typical for bog ores (ссылка).

Swamp ore is a kind of brown iron ore naturally deposited on the rhizomes of bog plants in stagnant water bodies. Main components of ore are iron oxides and silica (SiO_2). Silica, constituting the basis of the waste rock of ore, is an easily separable impurity. Other impurities such as lime, phosphorus and sulfur oxide are found in smaller quantities. These properties make brown iron ores and marsh ores most suitable for ancient metallurgical production. This is a common method during the Early Iron and the late Middle Ages. The iron processing and related processes in the Cheptsa River basin in the 5–13th centuries CE Zavyalov (2005), Perevoshchikov (2002), Ivanova (1976, 1979), Semenov (1985). These authors described the main types of raw materials, methods of making iron products and types of production facilities; recorded on the ancient settlements of the Cheptsa River basin, namelt the settlements of Idnakar, Uchkakar, Vesyakar, Dondykar (see Fig. 2, *1–5*). Acording to these authors, the primary raw material during the time of the Chepets culture was precisely bog ores, among the deposits of which the Omutnitskoe bog ore deposit is the closest to the Cheptsa River (see Fig. 2).

The shape of the sample can be explained by its origin from bog ore. It can be assumed that this sample was formed as a concretion (spherical mineral aggregate) on a piece of organic matter. Over time, organic materials decomposed and formed a hollow space within the clay-covered metal object.

4 Conclusions

Thus, comprehensive analysis of a non-typical archaeological find allowed us to obtain reliable results. The interpretation of this unusual artifact, found during archaeological research of the Kachkashur I burial ground of the 9–13th centuries CE have been formulated. The artifact, originally attributed as a "crucible with solidified matter," turned out to be a natural specimen, namely, a fragment of bog ore that was common in the area and served as the main source of iron. The ore fragment is a nodule (a spherical mineral body containing a fairly "pure" iron, hollow inside, and an outer "clay-like" shell), most likely attracted the attention due to its unusual shape. The fact is that nodules of bog ores formed by ferrophilic bacteria, as a rule, are clusters of small balls, much smaller in size, in contrast to the one under study. It can be assumed that a specimen which was found during the mining of bog ore, or by accident, attracted the attention of "miners" as an unusual natural phenomenon. It is possible that such an object was endowed with some supernatural properties, and for this reason it accompanied its owner after death as a burial inventory.

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Kazburun Archaeological Micro-district of the Late Bronze Age and Copper Ore Mines in the Southern Trans-Urals

Nikolai B. Shcherbakov, Iia A. Shuteleva, and Alexandra A. Golyeva

Abstract The Late Bronze Age in the Southern Trans-Urals is represented by a large number of archaeological cultures and population groups, including Srubnaya and Andronovo (Alakul). New analyses currently applied to bronze wares of the Late Bronze Age, once again raise the matter of copper-ore sources of bronze metallurgy of the Late Bronze Age in the Southern (Bashkir) Trans-Urals. The analysis to bronze materials in the Southern (Bashkir) Trans-Urals and northern part of the Kargaly mines (the Saygachy mines), such as light microscopy techniques, sample examination by scanning electron microscope, X-ray electron probe method of elemental analysis, neutron activation analysis, and isotopic analysis of lead, puts forward a topic of materials gathering in copper-ore sources. Another matter is studying of the bronze production technology at the settlements of the Kazburun archaeological micro-district of the Southern (Bashkir) Trans-Urals. The Kazburun archaeological micro-district dates to the Late Bronze Age (1770–1630 Cal BCE).

Keywords Mines · Copper · Tin · Bronze · Metallurgy · Late bronze age · Srubnaya and Andronovskaya cultures

1 Introduction

The Late Bronze Age of the Southern Trans-Urals is studied quite properly (Gorbunov 1989; Obydennov and Obydennova 1992; Rutto 2003). The same refers to the Dyoma-Urshak interfluve area. At present moment, there are 41 settlements of the Late Bronze Age known on this territory; archaeological excavations were conducted at 14 of them. Despite extensive archeological studies, the subject of archaeometallurgy of bronze and ore resources for metal production is still open.

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The complex under study is the settlement and burial complex in the Kazburun archaeological micro-district of the Southern (Bashkir) Trans-Urals. The Kazburun archaeological micro-district comprise a part of the area of Srubnaya and the Andronovo (Alakul) cultural interaction area of the Late Bronze Age. The archaeological micro-district consists of three burial mounds and seven settlements in the Urshak and Bely Kluch rivers interfluve.

The results of radiocarbon dating of materials from the Kazburun archaeological micro-district, conducted from 2007 to 2017 (Shuteleva et al. 2017; Shcherbakov et al. 2014; Krzewińska et al. 2018), produced a quite wide range of measurements. At the Usmanovo-3 settlement, a piece of ceramic resulted in 4040 ± 30 BP (Beta—352,489), cal. BC 2830-2820. A sample of soil was also dated, and results of the dating cover the span from 3440 ± 30 BP (Beta—395,800) cal. BC 1875-1840 to 3380 ± 30 BP (Beta—347,343) cal. BC 1890-1740. Obtained series of only 14 dates (2–3 dates from each buried in the mound complex) allowed characterizing chronology of archaeological micro-district during 1765-1690 cal. BC (2 sigma): 3420 ± 30 BP (Beta—347,344) cal. BC 1930—1750; 3520 ± 30 BP (Beta—439,417) cal. BC 1780-1630; 3360 ± 30 BP (Beta—451,578) cal. BC 1735-1565; 3440 ± 30 BP (Beta—451,579) cal. BC 1875-1665; 3410 ± 30 BP (Beta—451,577) cal. BC 1765-1630; 3415 ± 31 BP (Ua—56,444) cal. BC 1750-1620; 3459 ± 30 BP (Ua—56,445) cal. BC 1880-1690; 3407 ± 30 BP (Ua—54,446) cal. BC 1745-1620; 3422 ± 30 BP (Ua—54,447) cal. BC 1755-1630; 3479 ± 30 BP (Ua—56,448) cal. BC 1880-1690; 3401 ± 29 BP (Ua—56,449) cal. BC 1745-1620. This allowed pushing back the dating of the artifacts of the Late Bronze Age from the Urshak River basin for 300–400 radiocarbon years. Also, one can acknowledge the synchronism of the Kazburun I burial mounds and the Usmanovo I/III settlements. Thus, chronologically wise, the bronze artifacts from the Kazburun archaeological micro-district are probably the earliest in the Urshak River basin, which makes their production a topic of particular interest. Almost all examined settlements and mounds of the Kazburun archaeological micro-district provided evidence for metallurgy of bronze.

The primary problem in studying of metallurgy of bronze is the exploration of copper ore mines. It is a well-known fact that the copper ore mines of the Late Bronze Age in the southern Urals were re-used during the development of copper-smelting production in the 1700–1800 CE. This justifies a study of the ancient copper ore mines in the Kazburun archaeological micro-district.

The territory of the Southern (Bashkir) Trans-Urals represents an area of multiple and quite various copper deposits in terms of their density. These deposits were utilized in the 1700–1800 CE. Their commercial development ends in the 19th c. CE as opposed to deposits of the Cis-Urals (area behind the Ural Mountains).

Deposits of the Cis-Urals, abundant in copper pyrite, constitute the focal point for the studies in the beginning of the 20th c. CE (Krasnopolsky 1901; Zavarytzky 1920), as well as the most recent studies (Kuzin 2013).

On the contrary, the mines of the Southern (Bashkir) Trans-Urals, which development relates to the production of cupriferous sandstones, are studied to the lesser degree. The exception is the Kargaly ore-mining and smelting center (Chernykh 1997; Bogdanov and Ryabukha 2005). The copper ore mines in the Southern (Bashkir)

Trans-Urals became an object of study in works by Nechyaev (1902), Efremov (1954); Chernykh (1997); Dolotov and Grek (2001).

There was a similar issue while analyzing archival sources: a study by Gudkov and Gudkova (1993) states archival data (about copper-mining sources) characterizing the number of copper mines belonging to one copper mine works in the 1700s CE named Arkhangelsky (Sharansky)—122 copper mines in the Middle Urals.

There was a similar issue with identifying copper mines and their number has arisen earlier. In the investigate of Gudkov and Gudkova (1993) provides archival data that describe the number of copper mines included in one common copper mine in the 1700s AD called Arkhangelsk (Sharansky). There were 122 such mines in the Middle Urals.

The copper ore mines of the Voskresensky and Verkhnetorsky copper-smelting plants connected with the production of cupriferous sandstone, apart from the Kargaly mines, are almost not mentioned in the current archaeological literature.

The copper ore mines of the Southern Trans-Urals and systematic archaeological researches of this territory have been performed by Chernykh (1970). In this area, he outlines the West-Asian metallurgical province which was connected with the Eurasian steppe. On the territory of the Southern (Bashkir) Trans-Urals, systematic archaeological works in the area of copper ore mines have not been yet conducted. Chernykh (1970) developed a study program but this still has not been implemented.

The known copper ore mines have not been always included in the register of archaeological sites, and most of them are not mapped, hence, they are not covered by monitoring of archaeological sites, they are being destroyed and are used for industrial purposes without any initial archaeological examination (one example are the destroyed workings of the Bashkir Cis-Urals and the Bakr-Uzyak ore mine).

Currently, the Late Bronze Age metal artifacts and metal wares from the Southern (Bashkir) Trans-Urals are being studied through the prism of new analytical approaches. All this became a stimulus to continue the copper-ore sources studies, first of all, on the territory of the Southern Trans-Urals. The copper-ore sources of the Southern Trans-Urals in relation to the production of bronze items in the region are within the scope of the current study.

2 Methods and Materials

The analyses were conducted by the RAN, the UCL Institute of Archaeology, and the Centre for Archaeometry in Mannheim. In 2013, the primary analysis of copper-ore sources of the region an example of a small northern part of the Kargaly mines (the Saygachy mines) was conducted. A series of complex analyses were applied to obtained materials: optical microscopy, scanning electron microscopy equipped with SEM–EDS, electron probe X-ray microanalysis (EPMA), neutron activation analysis (NAA), and lead isotope analysis (LIA).

We generated a database of the copper ore mines of the Southern (Bashkir) Trans-Urals as the potential sources of metal ore for the Late Bronze Age sites and to apply the whole range of possible analyses (OM, SEM / EDS, EPMA, NAA, LIA).

Our project aims to study the copper-ore sources of the Kazburun archaeological micro-district of the Late Bronze Age within the methodological framework proposed by Chernykh (1970).

The copper ore mines associated with the Myakinsky-Sterlibashevsky and Fedorovsky-Kuzminovsky minefields were explored (Rakhimov 2013); in the Orenburg Region of Russia, the Saygachy mines were examined. The territory of the copper ore mine is stretched out considerably. The Saigachiy Mine (the Leninsky district of Orenburg) is located on the swinging hill, at a distance of 20.8 km SE of Orenburg, and a distance of 3.52 km NE of the Berdyanka village, on the elevated terrace of the left bank of the Berdyanka River. The visible part of the mine covers the area of 9.75 ha. The mining remains are recorded on the surface of the mine; today, they look like shallow caves in sandy soil. Also, fragments of ceramic vessels from various periods, as well as individual fragments of copper oxides, were found on the surface. The mine itself is the old working of copper sandstones of the Tatar stage of the Permian geological period. Sandstones with malachite and azurite in cement, chalcedony pseudomorphs on fossilized wood with deposits of azurite and malachite are found in the dumps. The mouth part of the adit that passed through the sandstones has been located. In 1769, the mine was examined by the Pallas of who reported on the finds of clay smelting ceramic, crucible, and smelted copper in the form of a flat round cake. Based on this, it can be assumed that the extraction of copper ore at the mine began in the Late Bronze Age.

In the Fedorovsky district of the Republic of Bashkortostan, copper ore mine of Novoye Dedovo was examined, which is located near the village of the same name. The site of the copper ore mine was destroyed earlier. The Novoye Dedovo mine is located on a hill, almost on the top of a small ridge, at the distance of 2.89 km southeast of the Dedovo village, at the distance of 2.14 km to the east of the Yurkovka village, and the distance of 2.05 km to the west of the Karmalka River. The mine covers the area of 8.51 ha. Based on the current state of the mine, it can be concluded that ore was mined in the 1700s–early 1900 CE with the open-pit method. Such a method of development could destroy workings traces belonging to the earlier periods of the mine operation. Isolated fragments of copper oxides are found on the surface.

Also, the road construction ruined the territory of the copper ore mine near the Sukhorechka village in Bizhbulyak district of the Republic of Bashkortostan. The Sukhorechka mine is located on a rocky hill, at a distance of 2.0 km southeast of the Sukhorechka village, on a cliff on the right bank of the Sukhoi stream. The surviving part of the mine covers the area of 0.45 ha.

The majority of the copper ore mines were examined in the central part of the Republic of Bashkortostan, the Alsheevsky district. The distance from them to Kazburun archaeological micro-district does not exceed 30 km. In 2009, while monitoring the archaeological sites, Akbulatov (2009) examined two copper ore mines, near Verkhnee Avruzovo. In 2015, the topographic characteristics of the copper ore mines were observed. It was noted that they had a good state of preservation. The Verkhnee Avruzovo mine 1 is located in the forested area, 3.4 km northeast of the village of the same name and 2.23 km south-southeast of the Mikhailovka village. The mine covers an area of 120.78 ha and is located between the Avryuz and Ishma rivers. Inside the forest area, there are traces of works represented by small dumps of soil and waste rock. Between the dumps, there are traces of the road that previously led to the mine. Isolated fragments of copper oxides are found on the surface.

The Verkhnee Avruzovo mine 22, is located in the forested part, at a distance of 4.12 km west-northeast of the village, 3.49 km southeast of the Mikhailovka village, 3.43 km west-northwest of the Avryuztamak village, and 1.23 km southeast of the mine 1. The mine covers an area of 26.78 ha and is forest-covered. In its appearance, it is similar to the mine 1.

Also, in the Alsheevsky the district of the Republic of Bashkortostan copper ore mines, Nizhnee Avruzovo (being damaged by waste deposit) and the Kunkas copper ore mine (good condition of the site) were examined. The Nizhnee Avryuzovo mine is located at an elevated position relative to the village and the river, partially wooded, at the distance of 0.82 km to the WNW from the village of same name and 0.41 km southeast of the Avruz River. The mine covers the area of 0.84 ha. Inside the forest, there are traces of work, represented by small dumps of soil and waste rock. Soil is completely taken to the depth of 2.5–3 m to the NNE of the mine, thus it is likely that this area could also belong to the mine.

The Kunkas mine is located on a high cliff of the left bank of the Dyoma River, at the distance of 1.67 km WNW of the village of the same name, at the distance of 2.23 km to the NNE of the Kul-Kunkas village and 2.83 km ENE of the Abishevo village. The mine covers the area of 1.82 hectares. On the surface, there are traces of open work going into the cliff of the river.

3 Results and Discussion

The extensive studies of typology, composition, and distribution of metal implements found throughout the Eurasian steppes laid the building blocks of narratives explaining cultural dynamics of Late Bronze Age societies in this region (Shcherbakov et al. 2016a, b). The widely accepted model of metallurgical provinces, established by Chernykh, differentiates multiple core areas of metal production and, hence, innovative centers of the copper and bronze making industry across the Eurasian steppes. The territory of the Republic of Bashkortostan did not turn to be not covered by integrated studies of such type and currently have neither comparative analysis of metallographic samples of the bronze foundry, nor radiocarbon dates for the comparison. On the territory of the Southern (Bashkir) Trans-Urals, copper ore mines were located and mapped, and copper-ore materials were collected.

If we take look at the map, it can be seen that all the mines except Sukhorechka are located almost on the same line with the length of 276.78 km, which is passing towards the north-northwest—the south-southeast (Fig. 1).

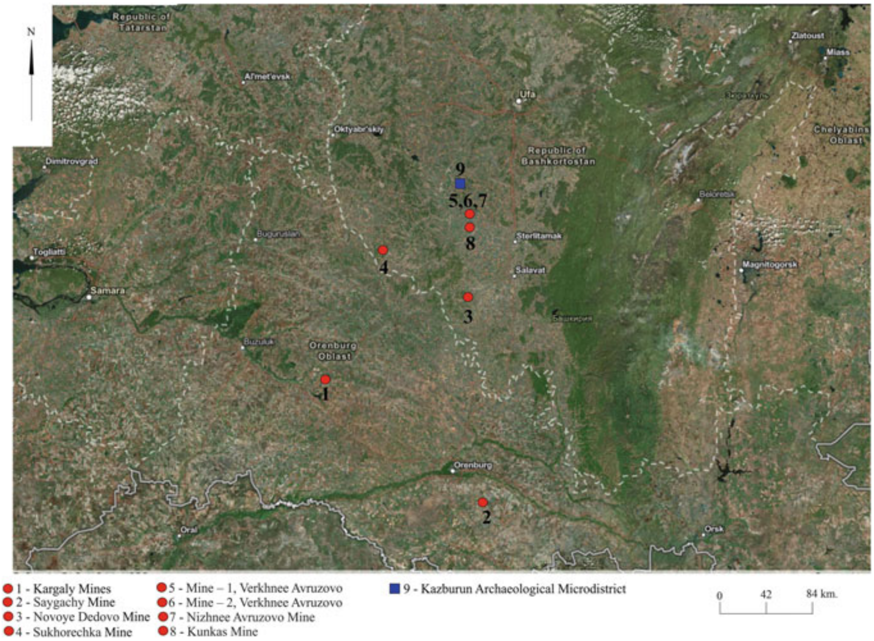

Fig. 1 Map of Mines

An attempt to apply modern data on the isotopic composition of ores to ancient mines and historical sources is extremely difficult, because, as a rule, the ancient mines have not been studied in their entirety or were completely exhausted during the work in the antiquity, or, completely developed and destroyed in during the industrial development of the 1700–1900s CE.

The explored mines are located in the Southern Urals, which geologically consists of the Devonian, Carboniferous, and Permian layers. It can be noted that the eastern part of the region is represented mainly by igneous rocks—tuffs and the ancient lava fields. The territorial location of the mines is characterized by the Permian sediments correlated with the lower and upper sections of the sediments. Lower ones were presented by the Asselian-Sakmarskaya reef arrays (the Shikhany mountains in Sterlitamak district of the Republic of Bashkortostan), as well as the Artinskian and Kungurian stages. The Upper Permian deposits are composed of the Ufa, Kazan, and Tatar stages located in the Trans-Urals fore deep, which are exposed along the banks of the Belaya and Bolshoy Ik Rivers occupying the watershed territories.

4 Conclusions

The study of the Late Bronze Age archaeological sites in the Southern (Bashkir) Trans-Urals has produced a massive database on the metal production in the region (waste products, casting molds, copper drops, and ingots, particles of copper ore, containers with traces of waste products) and also numerous artifacts made of bronze (knives, chisels, awls, holdfasts for vessels, sickles, ornamentals and so on). Metal was worked out on the Kazburun archaeological micro-district—refining, melting, casting. The primary (Cu) metal could have been imported from other regions as 'raw' ingots (bars)/artifacts. The UCL and RAN analyses show that there is significant number of pure copper artifacts that represent stock, ingots, working debris. The pure copper artifacts as implements (knives, etc.) still need a closer look in terms of typology (RAN analyses). Tin bronzes are already present as finished artifacts and there is no evidence for their production in this area. Due to the research, a new interesting problem in the Southern (Bashkir) Trans-Urals archaeology came up. Having a large number of copper sandstones and mines, developed in the Late Bronze Age (the Kargaly mines), we got the evidence for the ore export. Also, there are interesting problems. There are many hoards with bronze ware of the Late Bronze Age were found in the Urals. However, near the Kazburun archaeological micro-district only the Kuganaksky treasure with cast bronzes of the Early Iron Age (exports from Siberia) was found. Unfortunately, we have not found graves of metallurgist in the Kazburun archaeological micro-district. Only one such burial was found at Kargaly (the Pershin mound). As a result, deposits of copper sandstone of the Upper Permian red color formations in the Southern Urals from the Kargaly mines to Elek River in the area of 16,378 km^2 were examined. Probably in the Late Bronze Age, ore was imported the the Andronovo (Alakul) culture groups of south-eastern Kazakhstan (Shcherbakov et al. 2016a, b).

Thus, we can assert, firstly, that the number of copper-ore sources currently identified in the territory associated with the Kazburun archaeological micro-district is less than it could have been even in the 1700–1800 CE. Secondly, a small complex of bronze items found at the archaeological sites of the Kazburun archaeological micro-district may indicate that the ancient population did not have "direct" access to raw materials. They could have been supplied to the territory of the micro-district either in the form of finished products, in the form of raw materials or as prepared copper bars. Thirdly, today it is necessary to continue mapping the survived mines with sampling for metallographic analyzes and keep on searching for previously known, but "forgotten" over time, copper-ore outcrops.

This keeps the matter of exploration of copper ore mines for Kazburun archaeological micro-district open.

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Bioarchaeology and Residue Analysis

Diet and Mobility in the Pre-Urals Bronze Age, Russia (Preliminary Results of Stable Isotope Analysis)

Andrey V. Epimakhov and Elya P. Zazovskaya

Abstract The purpose of this work is to summarize and analyze all data on the composition of stable isotopes in human remains from the Bronze Age sites in the Pre-Urals region, as well as to draw preliminary conclusions about the diet of these groups. About 30 samples are at our disposal, covering a very long period (from the end of the 4th to the begging of the 1st-millennium cal BC). Despite a small sample size, some important conclusions can be drawn. First, livestock products were stapled foods of all cultural groups. Evidence for the fish consumption and related reservoir effect was diagnosed only in some individuals. Second, the scatter of values for the early period (the Yamnaya culture) correlates with a mobile lifestyle and animal husbandry. On the contrary, for the Late Bronze Age (the Srubnaya and Alakul cultures), we see very similar values of nitrogen and carbon isotopes within one locus, including cases of long-term residence of the collectives in these places (according to the $_{14}C$ data). This is probably due to the stability of the subsistence and settlement systems (stationary settlements). Finally, the obtained results differ from the previously obtained data for the adjacent territory (the Southern Trans-Urals). Interpreting this conclusion requires expanding the analysis base, including collecting the information on stable isotope values from the natural reservoirs.

Keywords Stable isotopes · Diet · Bronze age · Southern Urals

1 Introduction

Isotope analysis occupies a significant place in the list of geoarchaeological methods. The reconstruction of the diet of the ancient population (as, indeed, of animals) based on the composition of stable isotopes in ancient bones is one of the lines of research.

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The procedure and scope are well presented in the literature (Kuzmin 2017, etc.). The relative simplicity and availability of the method make it a good tool for solving the mentioned problem. Besides, it is often used in the radiocarbon dating process to test for the aging reservoir effect, because the consumption of aquatic products by an individual can significantly change the result of radiocarbon dating (Shishlina et al. 2012; Svyatko et al. 2017, etc.). Strictly speaking, only a small part of isotope studies in the Pre-Urals region have focused on diet, most of the results have been obtained from radiocarbon dating. For this reason, the information in the publications is incomplete in the aspect of interest to us.

The work aims to analyze the stable nitrogen and carbon isotope data for the reconstruction of the diet of the Bronze Age population in the Southern Pre-Urals. In total, we have at our disposal 35 samples originating from four burial grounds and one settlement of the steppe and forest-steppe zones (Fig. 1): Shatmantamak I, Kazburunovsky I, Krasikovsky I, Bulanovo (U Gory Berezovoi), and Muradymovo settlement. Kazburunovsky I burial ground and Muradymovo settlement form a single cultural-chronological complex.

The materials cover the period from the end of the 4th to the beginning of the 1st-millennium cal BC (29 dates) and belong to the Yamnaya, Abashevo, Sintashta, Srubnaya, Alakul cultures, and a single example comes from the burial of the transition

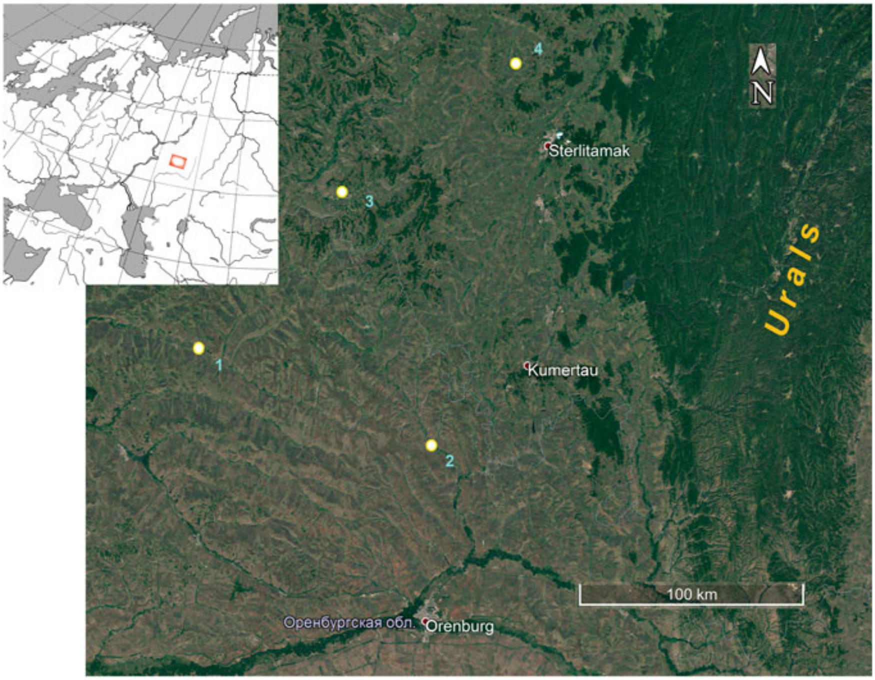

Fig. 1 The map of archaeological complexes (1—Krasikovsky I; 2—Bulanovo (U Gory Beresovoi); 3—Shatmantamak 1; 4—Kazburunovsky 1 and Muradymovo)

to the Early Iron Age period (Epimakhov and Tairov 2020). The Yamnaya culture is represented exclusively by burial mounds; later cultures (Sintashna, Abashevo, Srubnaya, Alakul') are well documented by stationary settlements and burial grounds, sometimes forming unified complexes. The transition to the Early Iron Age is documented so far by a few burials.

The territory is poorly studied regarding stable isotopes, in contrast to the Trans-Urals and the adjacent part of Kazakhstan (Ventresca Miller et al. 2014; Hanks et al. 2018, etc.). Moreover, we have analytical data only for human remains, although comparative materials on animals for a full analysis are needed. In our sample, as in most similar case studies, collagen from human bones ($n = 30$) was used for analysis, part of it was obtained from human teeth ($n = 5$). Keeping in mind the significant limitation of the informational capabilities of the source, we will focus on the internal characteristics of the series, their comparison with each other, and the explanation of differences.

2 Methods and Materials

The sites have been investigated by excavations since the 1990s, and materials have been introduced into scientific circulation with varying degrees of completeness (Khalyapin 2000; Shcherbakov et al. 2017; Morgunova et al. 2019; Epimakhov et al. 2020). Analytical data on some of them were published earlier (Rasmussen et al. 2015; Krzewińska et al. 2018; Morgunova and Kulkova 2019; Shcherbakov and Shuteleva 2020). The authors of the excavations carried out cultural and chronological attribution. The advantage of the sample is its serial nature: four loci, four chronological groups (the Early Bronze Age, the Abashevo-Sintashta, the Srubnaya-Alakul period, and the transition to the Early Iron Age). One burial could not be culturally attributed.

Sex and age definitions are available for 26 individuals. The share of children's burials is 27%. There are more male burials than female ones for the Yamnaya culture; the parity of sexes is recorded for other cultures. It is possible to compare the isotopic composition of teeth and long bones for one buried person (male, over 50 years old). The discrepancy turned out to be insignificant.

The data were obtained in five laboratories (the Center for Collective Use "Laboratory of Radiocarbon Dating and Electron Microscopy" in the Institute of Geography of the Russian Academy of Sciences; the Center for Applied Isotope Research at the University of Georgia (USA); Beta Analytic (Miami USA), The Ångström Laboratory Department of Physics and Astronomy, Uppsala University (Uppsala, Sweden); Oxford Radiocarbon Accelerator Unit (Great Britain); Laboratory of isotope studies of the Center for Collective Use "Geoecology" of the Russian State Pedagogical University named after A. I. Herzen (St. Petersburg)).

The analysis procedure is usually not described in the publications we used; moreover, some examples lack C/N_{at} values, i.e. it is impossible to assess the quality of collagen. For this reason, further conclusions are preliminary, require verification, and indicate the direction of further research. The results of isotope studies are presented in Table 1, and Table 2 presents the data summarized within the cultural-chronological groups. The way of presenting the results is the graph of the ratio of

Table 1 Data on stable isotope results for human remains sampled from the bronze age sites of the pre-urals region

Site	Complex (individual)	Bone	Lab code	$\delta^{13}C$, ‰	$\delta^{15}N$, ‰	C/N_{at}	C^{14}	Culture
1	1/1 (adult)	Bone	SPb-1853	−20.11	11,33	3.04	4779 ± 50	Ya
1	2/1 (adult, male)	Bone	SPb-2093	−18.41	12.38	3.22	4542 ± 70	Ya
1	2/2 (adult, female)	Bone	SPb	−18.16	12.31	2.52*		Ya
1	3/3 (infant)	Bone	SPb-1856	−18.41	14.28	3.04	4620 ± 55	Ya
1	3/4 (adult)	Bone	SPb-1857	−19.95	12.15	3.21	4565 ± 55	Ya
1	3/2 (adult)	Bone	SPb	−18.51	13.93	2.79*		?
1	4/1 (adult, male)	Bone	SPb-2095	−18.78	14.82	3.03	4610 ± 70	Ya
1	3/1 (adult)	Bone	SPb-2224	−18.57	11.97	3.17	3632 ± 55	Aba
2	4 (adult, male)	Tooth	OxA-30990	−20.9	14.1	3.3	3740 ± 33	Sin
2	- * -	Tooth	OxA-30991	−21.3	14	3.3	3775 ± 34	Sin
2	6/1 (adult, female)	Tooth	OxA-30993	18.7	12	3,3	3532 ± 34	Sin
2	8 (?)	Tooth	OxA-30992	−21	14.2	3.3	3822 ± 33	Sin
3	1/2 (infant)	Bone	$IGAN_{AMS}$-7054	−17.69	10.45	3.21	2615 ± 20	Tr
3	2/1 (adult, male)	Bone	$IGAN_{AMS}$-7050	−19.4	8.7	3.22	3575 ± 25	Al
3	3/2 (adult, female)	Bone	$IGAN_{AMS}$-7051	−19.16	8.91	3.23	3520 ± 20	Sru-Al
3	3/3 (adult, male)	Bone	$IGAN_{AMS}$-7051	−19.25	8.87	3.21	3460 ± 20	Al
3	3/4 (infant)	Bone	$IGAN_{AMS}$-7034	−19.37	9.21	3.21	3400 ± 20	Sru
4	4/1 (adult, male)	Bone	Beta-451579	−19.3	10.7		3440 ± 30	Sru-Al
4	- * -	Bone	Beta-439417	−19.1	11			Sru-Al
4	- * -	Tooth	Beta-347344	−19.7	11		3420 ± 30	Sru-Al
4	4/2 (infant)	Bone	Beta-451578	−19.3	10.8		3360 ± 30	Sru-Al
4	5/1 (?)	Bone	Beta-451577	−19.6	10.7		3410 ± 30	Sru-Al
4	23/2 (adult, female)	Bone	Ua-56444	−19.3	12.6		3415 ± 31	Sru-Al

(continued)

Table 1 (continued)

Site	Complex (individual)	Bone	Lab code	$\delta^{13}C$, ‰	$\delta^{15}N$, ‰	C/N_{at}	C^{14}	Culture
4	- * -	Bone	Beta-439414	−19.4	11.2			Sru-Al
4	23/3 (male)	Bone	Ua-56445	−19.2	12.2		3456 ± 30	Sru-Al
4	- * -	Bone	Beta-439416	−19	10.7			Sru-Al
4	23/4 left (adult, female)	Bone	Ua-56446	−19.4	12.1		3407 ± 30	Sru-Al
4	23/4 right (adult, male)	Bone	Ua-56447	−19.3	12.6		3422 ± 30	Sru-Al
4	23/5 (male)	Bone	Ua-56448	−19.4	11.9		3479 ± 30	Sru-Al
4	- * -	Bone	Beta-439415	−19.7	10.6			Sru-Al
4	23/6 (female)	Bone	Ua-55449	−19.7	12.5		3401 ± 29	Sru-Al
5	2 (infant)	Bone	Beta-497470	−19.8	11		3360 ± 30	Sru-Al
5	1 (infant)	Bone	Beta-497471	−20	10.7		3320 ± 30	Sru-Al
5	3 (adult)	Bone	Beta-451574	−19.2	11.3		3450 ± 30	Sru-Al
5	4 (adult)	Bone	Beta-451573	−19.1	10.4		3480 ± 30	Sru-Al

(Results marked with * are excluded from consideration because they signal unreliable or corrupted collagen)

List of sites 1—Krasikovsky I; 2—Bulanovo (U Gory Beresovoi); 3—Shatmantamak 1; 4—Kazburunovsky 1; 5—Muradymovo

List of archaeological cultures Ya—Yamnaya; Sin—Sintashta; Aba—Abashevo; Sru—Srubnaya (Timber-Grave); Al—Alakul; Tr—Transition to Early Iron Age

Table 2 Generalized values of stable isotopes data for the bronze age in the pre-urals

Period/culture	Site	Number of samples	Range of variation		
			$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N_{at}
Yamnaya	Krasikovsky I	6	−20.11 to −18.41	11.33–14.82	3.03–3.22
Abashevo	Krasikovsky I	1	−18.57	11.97	3.17
Sintashta	Bulanovo (U Gory Beresovoi)	4	−21.3 to −18.7	14–12	3.3
Srubnaya–Alakul	Kazburunovsky 1	14	−19.7 to −19.0	10.6–12.6	–
	Muradymovo	4	−20.0 to −18.1	10.4–11.3	–
	Shatmantamak 1	4	−19.4 to −19.16	8.7–9.21	3.21–3.23
Transition to early iron age	Shatmantamak 1	1	−17.69	10.45	3.21

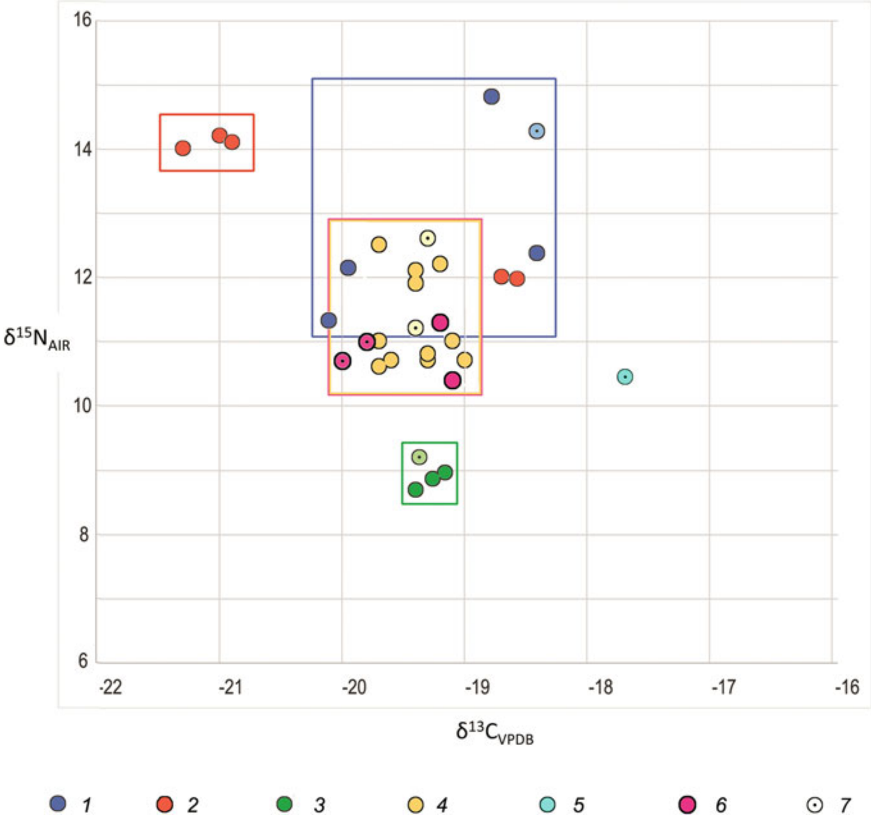

Fig. 2 The ratio of stable nitrogen and carbon isotopes from human remains in the Southern Urals Bronze Age. 1—Yamnaya culture (Krasikovsky I burial ground); 2—Abashevo-Sintashta period (burial grounds Krasikovsky I and Bulanovo (U Gory Beresovoi)); 3—Srubnaya-Alakul period (Kazburunovsky I burial ground); 4—Srubnaya-Alakul period (Shatmantamak I burial ground); 5—transition to the early iron age burial site (Shatmantamak I burial ground); 6—Srubnaya-Alakul period (Muradymovo settlement); 7—infants

$\delta^{15}N$ and $\delta^{13}C$ for each site and period (see Fig. 2). Two C/N_{at} values were outside the confidence range and were not used in further analysis.

3 Results and Discussion

The Yamnaya site demonstrates a relatively high degree of variability within the burial ground (Fig. 1) in comparison to other series. The range of values was from −20.11 to −18.41 for $\delta^{13}C$ and 11.33–14.82 for $\delta^{15}N$. If there is no measurement error behind this, then the explanation may be a noticeable difference in the characteristics of the diet of individuals. In this case, we are talking about the long-term accumulation of stable isotopes as we have diagnosed the nutritional characteristics of the recent years (up to 10). We have to emphasize that the only child burial in our series does not practically differ from adult individuals in the isotope ratio and all people look within one food chain. The causes for some heterogeneity may be related to the sphere of social relations, but more likely in the peculiarities of economic activity and the ratio of food sources. In this regard, the belonging of the deceased individuals to the same collective is in doubt, unless, of course, we record chronological changes for the necropolis, which was used for a long time (4779 ± 50BP (SPb-1853)–4542 ± 70BP (SPb-2092)). We emphasize that fluctuations in values are generally in the "corridor" of consumers of livestock products. The data of a single Abashevo analysis can be interpreted in the same way.

The Sintashta diet is reconstructed in a fundamentally different way (the Bulanovo cemetery). Three out of four results are very close to each other and reliably illustrate deviations towards the underestimated carbon isotope values and overestimated values for the nitrogen isotope (Fig. 2) –s from −21.30 to −20.90 for $\delta^{13}C$ and 14.00–14.20 for $\delta^{15}N$. This indicator usually signals a significant proportion of aquatic foods in a mixed diet (Rasmussen et al. 2015). In the light of the lack of additional data, we rely on the conclusion of analysts from the Oxford laboratory, as well as the differences between this series from the rest of the Urals materials of the Bronze Age. This conclusion contrasts sharply with the Trans-Urals single-cultural data as no reliable traces of fish consumption have been diagnosed here, although fish bones are found on the settlements (Stobbe et al. 2013). In this case, we are dealing with a reservoir effect and to determine its magnitude, additional studies of animal bones from the same context are needed. Three radiocarbon dates of these burials are significantly older than the date without traces of reservoir effect from the same burial ground (Bulanovo); they are also older than the rest of the Sintashta series. We have to emphasize the fact that all the results were obtained from the analysis of the teeth. Therefore, their direct comparison with the rest of the findings is impossible.

The series of the Srubnaya-Alakul sites are divided into two parts (Fig. 2, *3, 4*) since different results were obtained for each locus with compact samples of results (also within the framework of a comprehensive livestock diet). Despite the territorial proximity, their levels of nitrogen isotopes are significantly different: 10.4–12.6 (Kazburunovsky/Muradymovo) and 8.7–9.21 (Shatmantamak). At the same time, for the Shatmantamak burial ground, it is impossible to assume the cultural and chronological unity of materials, as the radiocarbon dates are stretched over the two centuries (3575 ± 25BP ($IGAN_{AMS}$-7050)–3400 ± 20BP ($IGAN_{AMS}$-7053)); the burials demonstrate differences in rituals and the appearance of material culture. Paradoxically, the available data indicate no change in diet for individuals of different traditions.

For the Kazburunovsky burial ground and Muradymovo settlement, the data are not entirely uniform, but the differences in nitrogen levels correlate with the laboratory in which the studies were carried out. Most likely, these differences reflect measurement errors. Radiocarbon dating indicates that the material was deposited within a short period. This series also does not show significant differences between the isotopic composition of adult and children's bones. This may be evidence of early weaning of children from breastfeeding (Ventresca Miller et al. 2017). Another point is important for the reconstruction of the diet. Peleogenetic analyzes of individuals from the Kazburunovsky burial ground showed that six out of ten individuals were intolerant to lactose (Shcherbakov and Shuteleva 2020). Thus, the thesis about the dairy diet requires adjustment and additional research.

A single measurement of the transition time from the Bronze Age to the Iron Age was obtained for an individual aged 5 years ± 16 months, the isotope data for which differ in increased values of $\delta^{13}C$ from all analyzed samples. It is premature to comment on this single result pending new data. New isotope data for adults and animals are critically needed.

4 Conclusions

The absence of isotope values for animals and the small sample size severely limit the possibilities for meaningful interpretation. Rather, the author focused on summarizing all the published data and proposing some explanatory hypotheses. Throughout the Bronze Age, livestock products remained the basis of nutrition. Fish diet markers were found only once and, possibly, reflect the local characteristics of the specific group. Adult individuals with a "fish" diet were found in the Bulanovo burial ground. The burials are attributed to the Sintashta culture with some reservations, perhaps this was a group of migrants since some features of rituals and funeral goods have the Seima-Turbino features. It is extremely important that the data on the isotopes of these individuals were obtained from the analysis of the teeth. It is not excluded that migrants followed a "fish" diet only at an early age in the place of origin. To test the diet at a later date, the study of long bones is required.

The Early Bronze Age is characterized by the variability in isotope indices, which may signal the accumulated differences in the constant nutrition system by individuals. We can propose that those, buried within the same necropolis, lived in various conditions (environmental and/or social). For the Late Bronze Age, on the contrary, we see the homogeneity of the series for each site, even in the case of their long-term functioning. This indirectly confirms the low degree of local mobility in the Late Bronze Age. Thus, according to the characteristics of nutrition, we propose different models of the subsistence system and the degree of group consolidation for the Bronze Age. Cattle-breeding specialization and the absence of reliable traces of stationary living are considered a confirmation of the mobile lifestyle for the Yamnaya culture of the Volga-Ural region. This does not imply the concentration of people and the unification of the food system.

Stationary dwellings and finds are set to confirm the relative settledness for the Late Bronze Age only. This lifestyle could be one of the reasons for less variability in the diet. In addition, the features of social heterogeneity for the Late Bronze Age are difficult to capture. This factor also did not significantly affect the variety of diets.

The further development of the research requires a serious increase in the analyses of human bone samples and the investigation of other isotope sources as a basis for comparisons. The second direction of verification of the conclusions about the mobility of individuals and groups is the study of radiogenic strontium isotopes and it is currently taking the first steps for the Urals region (Kiseleva et al. 2019 and others).

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Sampling Methodology for Assessing a Multi-proxy Bioavailable Strontium Isotope Baseline for the Orenburg Region (Russia): Fieldwork Results

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Abstract To assess the mobility of ancient populations and identify local/non-local individuals, it is necessary to compare their tooth and bone $^{87}Sr/^{86}Sr$ isotopic ratios with the local baseline (background) of bioavailable strontium, characteristic of each specific location or potential provenance region of an individual or artifact. This paper describes the results of a field expedition to the Orenburg region (Russia) to collect samples characterizing bioavailable strontium. This article presents the sampling strategy used to select samples that characterize the bioavailable strontium (proxies)—vegetation, soil, rocks, surface, and groundwater, as well as bone and dental remains of modern fauna, and mollusk shells. Further construction of maps of $^{87}Sr/^{86}Sr$ distribution (Sr isoscapes) will greatly expand the possibilities of historical interpretations and allow the traditional archaeological cultural and geographical models to be tested.

Keywords Sr isotopes · Provenance · Mobility · Bioavailable strontium · Proxy · Sr isoscapes · Orenburg region

1 Introduction

$^{87}Sr/^{86}Sr$ isotopic ratio, characteristic of a particular region of residence, is considered to remain unchanged when it enters the bone (dental) tissues of humans and animals from the underlying rocks through the soil and food chain, while Sr replaces Ca in the hydroxylapatite crystal lattice (Ericson 1985). Thus, to assess the mobility of ancient populations and identify non-local individuals, it is necessary to compare their dental (bone) $^{87}Sr/^{86}Sr$ isotopic ratios with the local baseline (background) of bioavailable strontium, characteristic of each specific location or potential provenance region of

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an individual or artifact. Consequently, in addition to obtaining Sr isotopic ratios in archaeological skeletal tissues, it is extremely important to have a database on the background strontium isotopes present within a studied location or potential provenance region of an individual or artifact.

Often, the use of a formal approach, which utilizes the isotopic data on bedrocks as a geochemical background, standardized at the regional level and not taking into account intra-regional variability in terms of homogeneity and heterogeneity, may be unjustified, since, for some regions (for example, the Urals with its complex block structure), the geological structure, and, consequently, geochemical features can dramatically change at a distance of several tens of kilometers. At the same time, to obtain correct conclusions about provenance (place of birth of a person or animal, the region of the raw material base, the area of production workshops, etc.), the comparison should be made with samples containing bioavailable strontium, that is, passed through the cycle of not only hydrochemical transformations and weathering, but also bio-purification in living organisms (plants or animals). For these purposes, several materials are used—tooth enamel of fossil and modern animals, river water, soil leachates, vegetation, wood, mollusk shells (Price et al. 2002; Copeland et al. 2008; Snoeck et al. 2020; Maurer et al. 2012; Scharlotta and Weber 2014; Hajj et al. 2017). All of these materials have their advantages and disadvantages. The above environmental materials (proxies) for assessing the local bioavailable strontium isotope baseline can be used both individually and in combination with each other (multi-proxy) (Ladegaard-Pedersen et al. 2020; Grimstead et al. 2013).

It should be noted that the sampling strategy and the number of samples taken may differ depending on the regional geology and archaeological material, the origin of which is planned to be identified (skeletal tissues, wood, textiles, etc.) (Grimstead et al. 2013). For a relatively homogeneous geological system, it is possible to carry out sampling in fewer places (1 sample per 500 km^2 is enough), but a significantly larger number of points should be sampled for regions with a more heterogeneous geological system (Grimstead et al. 2013).

The result of the study of such proxies is the construction of $^{87}Sr/^{86}Sr$ maps, or isoscapes (iso—isotope, scape—landscape), representing lines/areas with known isotopic ratios of bioavailable strontium in different territories, so the migration of humans and animals in antiquity can be tracked by referring to these isoscapes (Hobson et al. 2010). Such Sr isoscapes have been constructed for Central America (Hodell et al. 2004), Great Britain (Evans et al. 2010), Ireland (Snoeck et al. 2020), Cyprus (Ladegaard-Pedersen et al. 2020), Denmark (Frei and Frei 2010,2013), France (Willmes et al. 2014), and some other countries, based on multi-proxy combinations of various eco- and biological samples (plants, water, soil leachates, etc.).

In contrast to other countries we still only have a limited understanding of the Sr isoscapes of Russia, partly due to the sheer size of the country. Regions that have seen such work conducted include a part of the Black Sea coast, the lowland-foothill zone of the North-Western Caucasus (Shishlina and Larionova 2013), the forest zone of Eastern Europe and the Southern Trans-Urals (Shishlina et al. 2018), some regions of the Southern Urals (Kiseleva et al. 2018), and the Baikal region (Scharlotta and

Weber 2014). This current study presents the initial stages of work conducted in the collection of samples characterizing bioavailable strontium on the territory of the Orenburg region (Russia) to construct $^{87}Sr/^{86}Sr$ isoscapes.

2 Materials and Methods

2.1 Geological Setting

The Orenburg region covers an area of 124,000 km^2, encompassing the southeastern edge of the East European Plain, the southern tip of the Urals, and the southern Trans-Urals. The length of the region from west to east is 760 km and is 445 km from north to south. Due to its location, the territory of the Orenburg region has a complex geological structure (Chibilev et al. 2000). Since the isotopic composition of the bio-geosphere is due to the influence of the geology of the underlying rocks, the geological map of the Orenburg region was taken as the basis for the primary selection of points for mapping bioavailable strontium.

The oldest rocks of the Orenburg region that emerge on the surface are gneisses (a widely distributed type of metamorphic rock) with an age of 1.5–1.7 Ga. In the Precambrian, and, especially, in the Paleozoic, the development of the western and eastern parts of the region followed different paths. The western part was a passive margin (the transition between oceanic and continental lithosphere) of the ancient Russian platform and was practically amagmatic, i.e. not related to or involved in the magmatic activity. Here, sedimentary rocks from the Early Permian to Neogene appear on the surface. During the Paleozoic, the eastern part went through the full geodynamic Wilson cycle (a model that describes the opening and closing of ocean basins and the subduction and divergence of tectonic plates during the assembly and disassembly of supercontinents). It was characterized by the rift opening, ocean formation, subduction, and collision processes with widespread volcano-plutonic complexes and corresponding to the geodynamics of sedimentary rocks, currently exposed by the erosional truncation. Over the past two hundred million years, the entire territory of the region had turned into a young platform. Magmatism did not manifest, and tectonic movements were of a slow platform nature, as a result of which the easternmost part of the region was covered by a sedimentary cover. Thus, the majority of rocks of various geological natures and ages known to science occur in the Orenburg region (Chibilev et al. 2000).

2.2 Sampling Strategies

Geochemical mapping was carried out with the selection of samples characterizing bioavailable strontium (vegetation, soil, rocks, surface, and groundwater, as well as bone and dental remains of modern fauna, shells of bivalves and gastropods) across the territory of the Orenburg region over one month (mid-July–mid-August) field season. Besides its geological variability, the Orenburg region is home to unique and significant archaeological monuments. Analysis of the resulting patterning of bioavailable strontium and comparison with known archaeological artifacts will shed light on the history of peoples inhabiting the Orenburg region from the Mesolithic era to the Middle Ages.

At least several points were selected on each large geological unit to assess the variation in strontium isotope ratios. The need for several points per geological unit was due to local differences in the isotopic ratios of rocks belonging to the same geological structure and samples of biological origin in different areas, resulting from various factors (surface deposits, atmospheric precipitation—dust, and rainwater). About 260 points were tested (Fig. 1). The total length of the route was about 10,000 km.

Sampling was carried out as far as possible from cultivated fields and farmland because fertilizers represent a potential source of strontium with a modified isotopic composition (Thomsen and Andreasen 2019; Maurer et al. 2012). To assess the interspecific variations in strontium isotope ratios, herbaceous plants from the families Poáceae (bluegrass) and Asteraceae (wormwood) were collected. In some areas, river floodplains, and relict forests, the sampling included wood, bark, and leaves (needles) of trees. The surface soil layer, depending on the thickness, was sampled from a depth of up to 10 cm, where the bulk of plant roots was located.

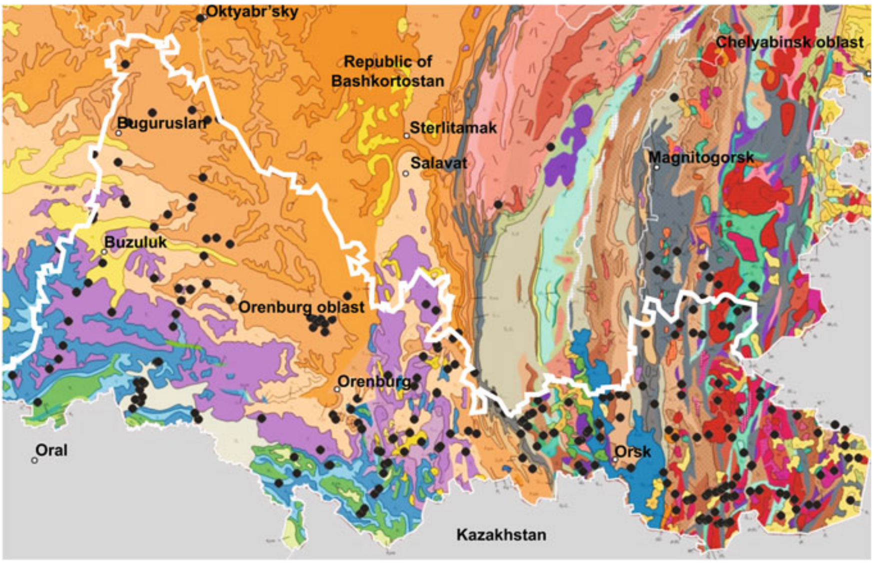

Fig. 1 Geological map and sampling locations across the Orenburg region and adjacent areas. Different colors correspond to different rock types; for legend see (Geologicheskaya … 2016)

Surface water was taken from permanent and temporary streams, from the large rivers of the Orenburg region—the Ural, Samara, Sakmara, and Ilek and their tributaries, and some lakes of natural and artificial origin. Several samples of groundwater were taken from springs and artesian wells. During the work, atmospheric precipitation (raindrops) was also collected in various parts of the region during intense rains. All water samples were acidified with 1 ml of purified concentrated nitric acid and stored in polypropylene test tubes with screw caps.

Mollusk shells (subsequently identified as *Unio pictorum*, *Unio tumidus, Anodonta sp*, *Lymnaea fragilis, Viviparus viviparus,* and *Planorbarius corneus*) were taken directly from their habitat.

Bone and dental tissues of the fauna (cattle *Bos taurus* and small cattle *Ovis aries, Ovis et Capra*, horse *Equus caballus*, dog *Canis familiaris*, marmot *Marmota bobak*, and bustard *Otis tarda*) were random finds and were taken from the surface (without excavations).

The stone material characterizing the underlying rocks was sampled in places of natural and artificial outcrops following its exposed stratigraphy without separating the parts not affected by weathering. In cases where the underlying rocks were severely destroyed, the zones of supergene enrichment were sampled as a source of strontium in the soil-vegetation layer.

For the most significant archaeological sites of the Orenburg region, osteological material (human bones and teeth) was obtained from several laboratories for comparative studies.

3 Results and Discussion

Sample types and their numbers are given in Table 1.

We were aimed at performing sample collection rather according to bedrock lithologies than using a regular grid since some small-scale geological changes could have been missed. And it also gave us the possibility of the variation of several collected samples at different lithological units so we could make lesser sampling points across relatively uniform lithologies omitting hard-to-reach locations, and perform more detailed sampling in the areas with contrasting bedrocks.

When sampling for the baseline data collection, we utilized the bottom-up approach (from bedrock to animal) following (Grimstead et al. 2013). Since the final objects of archaeological interest were bone and dental tissues of humans and animals, as well as plant and woolen textiles from the burials in the Orenburg region, the chain of samples was as follows: bedrock and/or supergene rock (sands and clays)—soil—vegetation (grasses with shallow roots)—water (including rainwater)—mollusks—modern fauna (teeth and bones).

Note that it was not possible to select the entire set of proxies at every point, for example, it was difficult to find mollusks in the study region outside the aquatic environment, and in some steppe regions there were very few rivers/streams/springs. Since there were many nature reserves in the Orenburg region, it was also problematic

Table 1 Sample description

Sample type	Number of samples	Note
Surface water	124	The Ural, Samara, Sakmara, and Ilek rivers and their tributaries, lakes
Groundwater	10	Springs and artesian wells
Rainwater	5	
Vegetation	213	Families Poáceae (bluegrass) and Asteraceae (wormwood) Wood, bark, and leaves (needles) of trees
Soil	214	
Mollusk shells	29	
Faunal bone and tooth remains (modern)	19	Cattle and small cattle, horse, dog, marmot, bustard
Total	763	

to take a large number of samples of modern animals. A bone that was later diagnosed as belonging to a bustard, a bird from the endangered species list, which, nevertheless, did not fly long distances and was an indigenous inhabitant of the steppes, could be considered a particularly successful find. Also, we were not sure that the found dead domestic animals (cattle and small cattle, horses, and dogs) had the strontium isotope ratio corresponding to the local bioavailable Sr signal due to the lack of information about their diets. Only wild marmot can be more or less considered local.

For many rivers that are significant both in archaeological and hydrological terms, several samples were taken at different points of their course, taking into account the rocks they drained. In general, rivers are mixtures in various proportions of different sources with strontium isotopic ratios characterizing the composition of the drained rocks (which can change dramatically along the course of the river), atmospheric precipitation (rain or snow at different times of the year, Aeolian particles from nearby or distant regions), and groundwater.

Some parts of the Orenburg region are characterized by a developed oil and gas production and processing, as well as mining industry; in others, agriculture is widely developed. Therefore, when analyzing the data obtained, it will be necessary to take into account the possible impact of the use of fertilizers and the scale of industrial pollution of the environment.

$^{87}Sr/^{86}Sr$ ratios were analyzed for some of the samples by multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) using a Neptune Plus (Thermo Fisher Scientific) and the standard-sample bracketing (SSB) technique with chromatographic separation of strontium. Preliminary data obtained for several archaeological sites of the Orenburg region (both local baseline of bioavailable strontium and archaeological skeletal tissues and wool textile) were used to discuss the provenance of the sheep fleece used for the manufacture of wool textile and accessories of the four Srubnaya culture burials (see (Shishlina et al. 2021)).

The rest of the samples will be analyzed and serve as the base for integrated Sr isoscape construction for the Orenburg region.

4 Conclusions

The determination of the local baseline of bioavailable strontium is a complex task that requires an integrated approach to the collection and analysis of several heterogeneous samples characterizing the ecosystem of the archaeological site under study. It is extremely important to identify the proxies most suitable for constructing local baselines of bioavailable strontium, as well as to unify and standardize the protocol for sampling and analysis of such samples.

The data obtained in the course of the research will greatly expand the possibilities of historical interpretations and allow the traditional archaeological cultural and geographical models to be tested. In addition to archaeological and archaeometric applications, the data obtained are planned to be used to study the hydrological features of the basins of large rivers in the Orenburg region—the Ural, Samara, Sakmara, and Ilek. Besides, such a database on bioavailable strontium created based on collected samples can be used for authentication and counterfeiting of food products, estimating the scale of anthropogenic pollution of water resources, as well as for studying the origin and mobility of groups and individuals in environmental and forensic science.

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The Provenance of the Bronze Age Wool Textiles from the Western Orenburg Region (Russia)

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Abstract The appearance of wool fabrics in the burials of the Srubnaya culture in the steppe zone of the Trans-Urals in 1925–1475 cal BC was a part of the general process of textile industrial transformation in the Bronze Age. This study aims to determine $^{87}Sr/^{86}Sr$ variations in the fragments of archaeological wool fiber from four burials of the Srubnaya culture and compare them with the local baseline of bioavailable strontium (mollusk shells, vegetation, soil leachates, river water, and modern animal bones) of the western Orenburg region. The conducted study has indicated that the samples of bioavailable strontium for the studied sites are characterized by complex isotope-geochemical interactions, and the "riverine" sample association (river water, wetland vegetation, shells) could not be excluded from the consideration and isoscape construction. For four studied archaeological textiles of the Srubnaya culture (from the burial grounds of Gerasimovka III, Pleshanovo, Kamenka, and Bogolyubovka), we assume the possible local origin of raw materials (wool) for textile production. The place of lambing and sheep/goat grazing could have been on pastures in the south-eastern slope of the East European platform.

Keywords Strontium isotopes · Archaeological textiles · Srubnaya (Timber grave) culture · Provenance · Sheep wool · Orenburg region

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1 Introduction

The expansion of the wool fiber production technology across the steppe zone of the Trans-Urals is a part of the general process of textile industrial transformation in the Eurasian Bronze Age. The results of direct ^{14}C AMS-dating of wool fibers and associated carbon-rich materials show a clear chronological sequence that correlates well with the relative chronology of Bronze Age cultures across northern Eurasia. This helps us identify the cultural communities associated with the transmission of innovative wool technologies. The pastoralist cultures of the Eastern European steppe transferred new wool fiber technology to their neighbors in the forest zone of Eastern Europe and further to the forest-steppe and steppe regions of the Volga region and the Urals. Between 1925 and 1775 cal BC there was the rapid eastward transmission of the wool (and associated technologies) across the steppe and forest-steppe of the Volga to southern Urals (Shishlina et al. 2020).

In this paper, we examine textile fragments from burials attributed to the Srubnaya (Timber-grave) culture of the Late Bronze Age from the western Orenburg region.

The local geochemical environment in different regions is characterized by specific ^{87}Sr/^{86}Sr ratios obtained from rock, groundwater, soil, plants, and animals because strontium is incorporated through the components of diet into an individual's hard tissues (teeth and bones) during the time of its formation. Thus, the variations in ^{87}Sr/^{86}Sr ratio in archaeological and modern objects are used to determine the place of birth of humans and animals (Ericson 1985; Bentley 2006).

Recently, this method has also been applied to the studies of the strontium isotope composition of archaeological textiles (Frei et al. 2009, 2015, 2017; Frei 2014, 2019; Kiseleva et al. 2019; Shishlina et al. 2019). The study of the strontium isotope composition of contemporary sheep fleece and archaeological wool textiles of the Bronze and Early Iron Age and the Middle Ages from Scandinavia demonstrates that the ^{87}Sr/^{86}Sr ratio in animal (sheep and Greenlandic musk ox) wool fiber corresponds to bioavailable strontium in grazing lands (Frei et al. 2009; Frei 2014). The pilot study of the strontium isotope composition of modern sheep fleece from the southern steppe region of Eastern Europe also indicates that the ^{87}Sr/^{86}Sr ratio in local sheep fleece is correlated with local bioavailable ^{87}Sr/^{86}Sr signatures of the pastures (Kiseleva et al. 2019).

We believe that wool textiles retain ^{87}Sr/^{86}Sr isotopic signature, which allows the information related to its probable provenance to be obtained, and the possible resource areas of the raw materials to be outlined. Such knowledge would contribute to the discussion on the developed resource areas and assessing the economic potential of ancient cultures.

This study aims to determine ^{87}Sr/^{86}Sr variations in the fragments of archaeological wool fiber from four burials of the Srubnaya culture and compare them with the local baseline of bioavailable strontium (mollusk shells, vegetation, soil leachates, river water, and modern animal bones) of the western Orenburg region. Such comparison would contribute to the discussion on the localization of grazing pastures of sheep, which fleece could have been used for the manufacture of wool textile and accessories of the Srubnaya culture.

2 Materials and Methods

2.1 Geological Setting

The territory of the Orenburg region has a complex geological structure (Chibilev et al. 2000). The Orenburg region in the Southern Urals is located at the border of two large structural and tectonic zones, i.e., the East European Craton and the Urals orogeny. The Craton includes the Volga-Uralian crustal segment, the Caspian Depression, and the Pre-Urals foreland basin.

The burial grounds where the fragments of the wool textiles have been found are located in the interfluves of the Tok and Samara rivers and the Salmysh and Ural rivers in the southeastern slope of the East European Craton. Clays, sands, and Quaternary gravel are abundant along the valleys of these rivers; Paleozoic argillites, aleurolits, sandstones, conglomerates, limestones, dolomitic rocks, gypsum, anhydrites, rock and potassium salts, as well as Triassic clay shales, aleurolits, sandstones, and conglomerates have been found in the Bolshoy Uran and Tok interfluve (the Bogolyubovka, Pleshanovo, and Kamenka burial grounds). Jurassic sands, sandstones, clays, marls, phosphorites, oil-shale, and lignite, as well as Neogene loam, clays, sands, and lignite, are found in the Kindelya and Ural interfluve. Quaternary deposits of the terraces above the flood-plain and the plain river terraces are made up of gravel, sand, and clay (Geologicheskaya 2016).

2.2 Archaeological Textile and Bioavailable Sr Local Baseline Samples

The fragments of wool textile are found in the female burials of the Gerasimovka III, Pleshanovo, Bogolyubovka, and Kamenka burial grounds (Orenburg region) (Fig. 1). All burials belong to the Late Bronze Age Srubnaya culture and are dated back to 1750–1650 cal BC. The textile has been preserved due to the presence of bronze decorations. One fragment of the wool cloth originates from sleeve edges (Pleshanovo, kurgan 2, grave 2); one is the fragment of a face accessory (Kamenka, kurgan 2, burial 1); the other two are the fragments of headwear (Bogolyubovka, kurgan 1, burial 31; Gerasimovka III, kurgan 1, burial 3) (Fig. 2).

The analysis of the fragments has determined the general technical characteristics of wool textiles. The yarn was spun. The thickness of the warp and the weft threads in various fragments of the textiles is ranging from 0.4 to 1 mm. There are threads with the Z-twist and the S-twist. All cloths have a tabby weave; the thread count

Fig. 1 The locations of the Gerasimovka III, Pleshanovo, Bogolyubovka, and Kamenka burial grounds (Orenburg region) of the Late Bronze Age Srubnaya culture (1750–1650 cal BC)

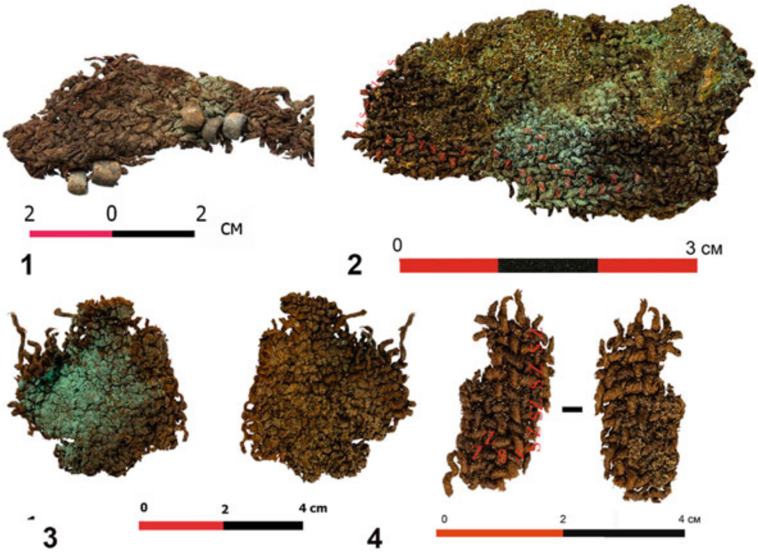

Fig. 2 Studied fragments of wool textiles from burials of the Srubnaya culture of the Orenburg Cis-Urals. 1—Gerasimovka III burial ground, kurgan 1, burial 3; 2—Kamenka burial ground, kurgan 2, burial 1; 3—Bogolyubovka burial ground, kurgan 1, burial 31; 4—Pleshanovo burial ground, kurgan 2, burial 2

varies; the band has a twill weave. In general, it may be noted that textile production was quite advanced, the weavers have used various technologies.

Thus, we believe that similarities in the technological characteristics of wool textile obtained from different graves could indicate the possible local production. Local craftsmen also used leather, fur, wood, metal jewelry to ornament clothes.

A pilot study of the relative provenance of four animal fibre textiles based on the strontium isotope ratios in textile was conducted to test this hypothesis.

To assess the local baseline of bioavailable strontium, many environmental samples (mollusk shells, vegetation, river water, soil, and modern animal bones) were collected near archaeological sites understudy and analyzed.

2.3 Strontium Isotope Analysis

The preparation and measurement of samples were carried out in cleanrooms (classes 1000 and 10,000) and laminar flow boxes (class 100) at the IGG UB RAS, Ekaterinburg (Kiseleva et al. 2019). Preliminary cleaning of wool textiles from external contaminants and silicate minerals was performed according to the protocol proposed by Frei et al. (2009) using 20% (v/v) HF and an ultrasonic bath. In the later works by Frei et al. (2015) and Frei (2014, 2019) an improved pre-cleaning/decontamination protocol was introduced including the preliminary stage of carbonate particle dissolution by 1 M HCl and a final step of oxidation by 0.2 M (NH4)2S2O8 ammonium peroxodisulfate (in case of dyed textile). In the absence of credible information about using organic dyes for studied textile samples, we tried to keep the cross-contamination and procedural blanks as low as possible by minimizing the number of reagents used. Besides, rather a low carbonate content in the rocks of the studied area (mostly sandstones) might have resulted in the small proportion of contaminating carbonate particles present in ancient textile, which could be effectively removed by centrifugation and filtration after their precipitation in the form of CaF_2 calcium fluoride.

Before analysis, rock, shell, and bone samples were manually ground in a jasper mortar. During on-site sampling, water samples were preserved with concentrated nitric acid. Ultrasonic cleaning of bone and shell samples using acetic acid was performed according to Corti et al. (2013). The vegetation samples were air-dried, ground in an electric mill, and cleaned from external contaminants by ultrasonication with ultrapure water, then ashed in a muffle furnace at 500 °C for 12 h (Snoeck et al. 2020). Soil leachates were obtained by shaking 1 g of soil, ground manually in a jasper mortar, with 10 ml of ultrapure water for 2 h, centrifuged, and filtered (Maurer et al. 2012).

Dried samples of textile, bone, shells and vegetation were dissolved in 3 ml of 14 M HNO_3 with the addition of 1 ml of 42 M H_2O_2 on a hotplate at 150 °C and evaporated to dry salts. Weighed portions of rock samples about 100 mg were taken into Savillex vials with a screw cap. A mixture of acids (HF, HNO_3, and HCl) was used for digestion in an oven at 120 °C for two days. Water samples were placed in PFA vials and evaporated to dry salts on a hotplate at 120 °C. After that, the dry residues in all samples were re-dissolved in 0.5 ml of 7 M HNO_3, placed in Eppendorf microtubes, and centrifuged at 6000 rpm for 15 min.

For the chromatographic separation of strontium, the SR resin (100–200 mesh, Triskem) and the one-stage scheme were used, adapted from Muynck et al. (2009), and described in detail in Kasyanova et al. (2019).

The strontium isotope composition was measured on a Neptune Plus (Thermo Fischer) magnetic sector multicollector inductively coupled plasma mass spectrometer (MC-ICP-MS) with double-focusing, according to Kiseleva et al. (2019). To control the measurements of the strontium isotope composition, the NIST SRM 987 isotope standard was regularly measured during 2019: $^{87}Sr/^{86}Sr = 0.71025$, 2SD = 0.00012 (104 measurements in 2 replicates). Uncertainty under the conditions of within-laboratory reproducibility (2σ) for NIST SRM-987 was ± 0.003%.

3 Results and Discussion

The results of strontium isotope analysis in the studied samples of archaeological textiles and local baseline of bioavailable strontium (grass, soil leachates, modern cattle bone, and mollusk shells) are shown in Table 1 and Fig. 3.

The assessment of the local Sr isotopic baseline is of crucial importance for provenance studies. For these purposes, several materials are used, such as tooth enamel of fossil and modern animals, surface water and groundwater, soil and soil leachates, vegetation, and mollusk shells (Snoeck et al. 2020; Ladegaard-Pedersen et al. 2020; Lengfelder et al. 2019; Hoogewerff et al. 2019; Frei 2019; Willmes et al. 2018; Hajj et al. 2017; Maurer et al. 2012). Such environmental materials (proxies) for assessing the local bioavailable strontium isotope baseline can be used both individually and in combination with each other (multi-proxy) (Ladegaard-Pedersen et al. 2020; Grimstead et al. 2013). $^{87}Sr/^{86}Sr$ ratio in each of those proxies is a mixed value resulting from the interrelations of lithospheric, biospheric, and atmospheric strontium uptake. Moreover, the local isotopic signatures of bedrock, soil, water, vegetation, and fauna do not always match with $^{87}Sr/^{86}Sr$ ratios in vertebrate body tissues since their strontium originates from various sources in different amounts and animal strontium uptake is heavily diet-dependent (Lengfelder et al. 2019).

It should be mentioned that until nowadays no unified methodology is elaborated for bioavailable Sr isotope baseline assessment (Frei 2019). Different scholars use different proxies and their combinations depending on their availability and correspondence to studied archaeological samples (thus, a combination of water and plants should be considered when dealing with animal fleece or ancient woolen textile). Such proxies can include soil leachates (Hoogewerff et al. 2019), plants (Snoeck et al. 2020), a combination of plant samples, and soil leachates (Willmes et al. 2018), a combination of soil leachates, plants, groundwater, and surface water (Ladegaard-Pedersen et al. 2020).

Table 1 $^{87}Sr/^{86}Sr$ in archaeological textiles and local baseline samples of bioavailable strontium

	Sample name	Sample coordinates	Sample description	$^{87}Sr/^{86}Sr$	± SE, abs
1	GER 1	N51 46.146 E53 16.553	Grass from the burial ground	0.709266	0.000008
2	GER 2	N51 46.354 E53 16.226	Grass (sedge)	0.708956	0.000008
3	GER 3	N51 46.222 E53 15.117	Grass (sedge)	0.708844	0.000011
4	GER 4	N51 46.556 E53 15.510	Grass (sedge)	0.709078	0.000027
5	GER 5	N51 46.759 E53 15.460	Grass (sedge)	0.709114	0.000024
6	GER 2 U	N51 46.354 E53 16.226	Mollusk shell	0.708790	0.000005
7	GER 3 U	N51 46.222 E53 15.117	Mollusk shell	0.708924	0.000004
8	GER 4 U	N51 46.556 E53 15.510	Mollusk shell	0.708922	0.000008
9	GER 5 U	N51 46.759 E53 15.460	Mollusk shell	0.708889	0.000007
10	Gerasimovka III burial ground, kurgan 1, burial 3	N51.76963 E53.27698	Archaeological wool textile, Srubnaya culture	0.709158	0.000009
11	PL 1	N52 50.606 E53 30.549	Grass	0.709408	0.000008
12	PL 2	N52 51.069 E53 30.644	Grass	0.707806	0.000005
13	PL 3	N52 51.189 E53 30.769	Grass (sedge)	0.707591	0.000005
14	PL 4	N52 51.174 E53 31.118	Grass (sedge)	0.707525	0.000007
15	PL 5	N52 51.261 E53 30.530	Grass (sedge)	0.707582	0.000006
16	Plesh-1	N52 50.651 E53 30.522	Grass	0.709075	0.000011
17	Plesh-2	N52 50.651 E53 30.522	Soil leachate	0.708562	0.000016
18	PL 3 U	N52 51.189 E53 30.769	Mollusk shell	0.707502	0.000010
19	PL 4 U	N52 51.174 E53 31.118	Mollusk shell	0.707500	0.000006
20	PL 5 U	N52 51.261 E53 30.530	Mollusk shell	0.707519	0.000012

(continued)

Table 1 (continued)

	Sample name	Sample coordinates	Sample description	$^{87}Sr/^{86}Sr$	± SE, abs
21	Plesh-3	N52 50.972 E53 37.550	Water from the Tok river	0.707460	0.000010
22	Pleshanovo burial ground, kurgan 2, burial 2	N52 50.651 E53 30 522	Archaeological wool textile, Srubnaya culture	0.709534	0.000013
23	KAM 1	N52 27.373 E53 22.030	Grass (sedge)	0.708373	0.000006
24	KAM 2	N52 26.869 E53 21.160	Grass (sedge)	0.708842	0.000019
25	KAM 3	N52 27.475 E53 22.471	Grass (sedge)	0.708547	0.000023
26	KAM 4	N52 27.903 E53 20.688	Grass	0.709205	0.000021
27	KAM 5	N52 28.393 E53 18.965	Grass	0.709122	0.000022
28	KAM 6	N52 28.542 E53 18.852	Grass	0.709665	0.000012
29	Kamen-1	N52 28.508 E53 18.700	Grass	0.709783	0.000007
30	Kamen-2	N52 28.508 E53 18.700	Soil leachate	0.708419	0.000009
31	KAM 1 U	N52 27.373 E53 22.030	Mollusk shell	0.708302	0.000006
32	KAM 2 U	N52 26.869 E53 21.160	Mollusk shell	0.708291	0.000005
33	KAM 3 U	N52 27.475 E53 22.471	Mollusk shell	0.708308	0.000005
34	Kamen-3	N52 28.508 E53 18.700	Clayey soil	0.710107	0.000012
35	Soroch-3	N52 24.831 E53 14.022	Water from the Sorochinskoe reservoir, Samara and Bolshoy Uran rivers	0.708541	0.000008
36	Kamenka burial ground, kurgan 2, burial 1	N52 28 33.2 E53 18 57.0	Archaeological wool textile, Srubnaya culture	0.709773	0.000009
37	BG 1	N52 24.096 E53 47.455	Grass	0.709101	0.000005
38	BG 2	N52 24.224 E53 47.696	Grass	0.708799	0.000005

(continued)

Table 1 (continued)

	Sample name	Sample coordinates	Sample description	$^{87}Sr/^{86}Sr$	± SE, abs
39	BG 3	N52 24.298 E53 47.848	Grass (sedge)	0.708343	0.000006
40	BG 4	N52 24.439 E53 47.597	Grass (sedge)	0.708307	0.000006
41	BG 5	N52 24.245 E53 48.127	Grass (sedge)	0.708516	0.000006
42	Bogol-1	N52 24.093 E53 47.427	Grass	0.709334	0.000007
43	Bogol-1	N52 24.093 E53 47.427	Grass (wormwood)	0.709300	0.000008
44	Bogol-2	N52 24.093 E53 47.427	Soil leachate	0.708511	0.000009
45	BG 3 U	N52 24.298 E53 47.848	Mollusk shell	0.708220	0.000005
46	BG 4 U	N52 24.439 E53 47.597	Mollusk shell	0.708172	0.000007
47	BG 5 U	N52 24.245 E53 48.127	Mollusk shell	0.708206	0.000008
48	Bogol-3	N52 25.213 E53 46.180	Water from the Bolshoy Uran river	0.708072	0.000008
49	Bogolyubovka burial ground, kurgan 1, burial 31	N52 24.096 E53 47.455	Archaeological wool textile, Srubnaya culture	0.709262	0.000020
50	Bogol-4	N52 25.213 E53 46.180	Cattle (*Bos taurus*) sacrum	0.709147	0.000013

(grass, soil leachates, modern cattle bone, and mollusk shells). SE—single measurement error, 2σ = 0.003% (SRM 987, $n = 123$)

To generate predictive models of $^{87}Sr/^{86}Sr$ local variability, a novel geostatistical framework including kriging is used (Willmes et al. 2018) as well as mixing models are established using several two-component mixture systems (Lengfelder et al. 2019) or based on Bayesian modeling (Hoogewerff et al. 2019).

It is noteworthy that the sampling strategy and the number of samples taken may differ depending on the regional geology and archaeological material, the origin of which is planned to be identified (skeletal tissues, wood, textiles, etc.) (Grimstead et al. 2013). So, for a relatively homogeneous geological system, it is possible to carry out sampling in fewer places, but with a larger heterogeneity, a significantly larger number of points should be sampled (Grimstead et al. 2013). The sampling grid can be regular or irregular, featuring geological and geochemical properties of the underlying bedrock.

Since our isotopic study is a pilot, we have tried to use as many proxies as possible to characterize four archaeological sites, and have found rather significant variations

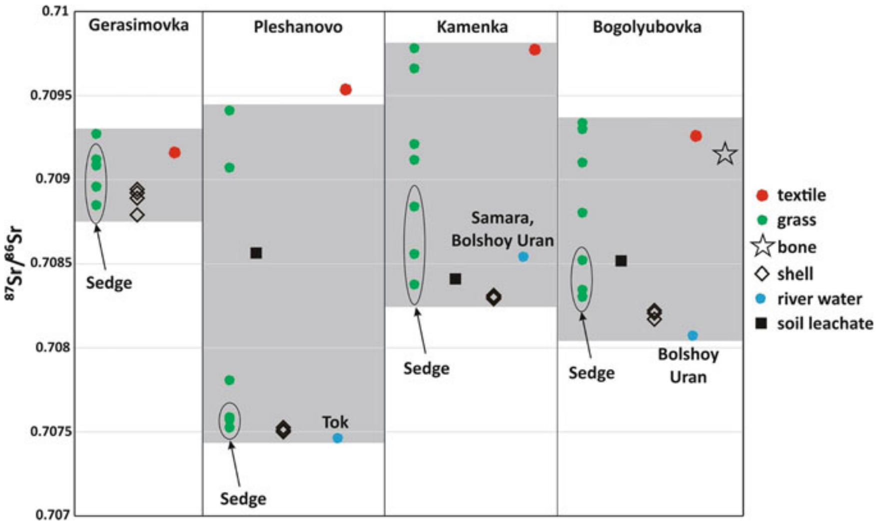

Fig. 3 $^{87}Sr/^{86}Sr$ in archaeological textiles and local baseline samples of bioavailable strontium (grass, river water, soil leachates, mollusk shells, and modern cattle bone). The grey rectangles are the ranges of bioavailable strontium isotope ratios for different localities of the Orenburg Cis-Urals

in $^{87}Sr/^{86}Sr$ ratios of different proxies, especially between terrestrial samples and water-related samples (river water, wetland vegetation and mollusks, including water-soluble or labile Sr fraction of soil leachates) (Fig. 3).

All three soil leachates have close $^{87}Sr/^{86}Sr$ ratios (0.7084–0.7085), probably due to the mixing of strontium from two major sources: the weathering of the underlying rock and atmospheric input (precipitation and dust) (Hajj et al. 2017). Since Sr from atmospheric precipitation is deposited on the soil surface, while soil weathering releases Sr from deep horizons (Hajj et al. 2017), similar strontium isotope ratios in leachates of the surface soil layers are more likely due to the predominant influence of atmospheric input than by the processes weathering of the underlying Middle Permian rocks of the Tatarian Stage. In general, the Sr isotope ratios in soil leachates are shifted from the corresponding grasses (0.7091–0.7098) towards less radiogenic values. An additional study of Sr isotope ratios in atmospheric precipitation, underlying rocks, and groundwater is required; however, the soil leachates fall within the local baseline of bioavailable strontium for the studied sites.

All four localities are characterized by a wide range of $^{87}Sr/^{86}Sr$ in the samples characterizing bioavailable strontium, reflecting a complex system of interactions between water and rocks, vegetation, and animals.

River water in the Tok (in the vicinity of Pleshanovo) and Bolshoy Uran (in the vicinity of Kamenka) rivers, as well as the Sorochinskoe reservoir located at the confluence of the Samara and Bolshoy Uran rivers, is characterized by low $^{87}Sr/^{86}Sr$ values: Bolshoy Uran (0.708072), Sorochinskoe Reservoir (0.708541), and the least radiogenic $^{87}Sr/^{86}Sr$ ratio is observed for the river Tok (0.707460). These ratios are likely to reflect the average composition of the rocks drained by these rivers along their course.

The ranges of Sr isotope ratios in vegetation are: 0.708790–0.708924 (Gerasimovka), 0.707525–0.709075 (Pleshanovo), 0.708373–0.709783 (Kamenka), 0.708307–0.709334 (Bogolyubovka). Moreover, wetland vegetation (sedge) has a smaller scatter within each locality and lower Sr isotope ratios, and tends towards the river water and mollusk shells.

Note that mollusk shells are characterized by extremely low variations within each locality: 0.708790–0.708924 (Gerasimovka), 0.707500–0.707519 (Pleshanovo), 0.708291–0.708308 (Kamenka), 0.708172–0.708220 (Bogolyubovka), and are located in the areas of the lowest (least radiogenic) $^{87}Sr/^{86}Sr$ ratios, close to river water and wetland vegetation (sedge), which may reflect their isotopic-geochemical relation.

The Gerasimovka III site has a rather narrow range of bioavailable strontium (0.708790–0.709266), which corresponds to the isotopic signature of archaeological textile (0.709158), while the grass from the Gerasimovka III burial ground (0.709266) does not differ significantly from the sedge. This allows us to make an assumption about grazing sheep on the flooded meadows in the flood-plain of the Kindelya river, which does not contradict the geographic location and bedrock.

The Pleshanovo site is characterized by the largest scatter of bioavailable strontium. Nevertheless, the isotopic signature of the archaeological textile is very close to the vegetation near the Pleshanovo burial ground, although slightly higher. It is quite different from the "riverine" sedge-shell-water sample associated with the lowest isotopic ratio among all the studied localities. We believe that taking into account the technological features of the Pleshanovo textile indicating its probable local origin, and the greatest bioavailable $^{87}Sr/^{86}Sr$ variation for the Pleshanovo site, the difference in $^{87}Sr/^{86}Sr$ ratios between the grass and ancient textile can be considered negligible contributions to the version of its local origin and production.

Wide $^{87}Sr/^{86}Sr$ variations are observed for the Kamenka site, where the "riverine" sedge-shell-water sample association has low strontium isotope ratios, while the terrestrial vegetation collected near the Kamenka burial ground has the highest radiogenic $^{87}Sr/^{86}Sr$ of all studied localities and coincides with archaeological textile. Such a high $^{87}Sr/^{86}Sr$ ratio is probably inherited from clayey soil (0.710107).

For the Bogolyubovka site, a similar situation is noted: archaeological textile coincides with terrestrial vegetation and the bone of a modern cattle (0.709147), while "riverine" sedge-shell-water samples are characterized by less radiogenic $^{87}Sr/^{86}Sr$.

The variations of strontium isotope ratios in the samples of Srubnaya wool textiles from Gerasimovka III, Pleshanovo, Kamenka, and Bogolyubovka fall within the corresponding ranges of local bioavailable Sr for each site. Thus, a comparative analysis of the local baseline of bioavailable strontium (grass, soil leachates, mollusk shells, river water, and modern cattle bone) and four archaeological wool fibers suggests that the place of lambing and sheep/goat grazing could have been on pastures in the south-eastern slope of the East European platform.

Sheep grazing at Gerasimovka could occur on flooded meadows in the flood-plain of the Kindelya river and other localities—in the meadows located on hills (gentle slopes of syrts), far from river valleys. Wetland vegetation (sedge), mollusk shells, and river water samples are grouped according to the sampling sites and characterized by close (and lowest) $^{87}Sr/^{86}Sr$ isotope ratios within each locality.

4 Conclusions

The conducted study has indicated that the samples of the local baseline of bioavailable strontium (grass, soil leachates, mollusk shells, river water, and modern cattle bone) for the studied sites are characterized by complex isotope-geochemical interactions, and the “riverine” sample association (river water, wetland vegetation, shells) couldn’t be excluded from consideration and isoscape construction.

For four studied archaeological textiles of the Srubnaya culture, we assume the possible local origin of raw materials (wool) for textile production. This result corresponds to the technological analyses of wool textile.

The results obtained might confirm that the technology for the production of wool fiber from local raw materials in the steppe Trans-Urals by the end of the first quarter of the 2nd millennium BC was a part of the overall transformation process of textile production in the Bronze Age. We may infer from our analysis that in 1750–1650 calBC the production of wool textiles in the southern Urals steppe belt was integrated into the economy of the local Srubnaya Ural population.

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Preliminary Results of the Analysis of REE Distribution and $^{87}Sr/^{86}Sr$ Ratios in Organic and Mineral Sources from Paleolithic Sites in the Orkhon Valley, Mongolia

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Abstract We present a description of stratigraphic profiles and paleontological remains from three Paleolithic sites in the Orkhon River valley, central Mongolia. The Orkhon-1 and Orkhon-7 sites contain cultural sequences spanning the Final Middle through Upper Paleolithic periods (ca. 50–12 kya), where cultural horizons are divided by archaeologically sterile layers of significant thickness. The Moiltyn-am site is an exception where archaeological materials were found in every lithological layer, albeit impacted by post-depositional changes. The analysis of the distribution of rare, trace, and rare earth elements (REE) and Sr isotopic composition indicate that accumulation of sediments at the Moiltyn-am site occurred under semi-arid to semi-humid climatic conditions and that the climate did not change significantly during the period of the site's occupation. $^{87}Sr/^{86}Sr$ ratios for samples extracted from ungulate teeth found at the Orkhon-1 and Orkhon-7 sites indicate that these animals lived in another region during the first years of their lives. This constitutes evidence of equids and bovids migrating between regions.

Keywords Mongolia · Orkhon Valley · Paleolithic · Pleistocene · Paleoclimate · Ungulates · Sr isotopes · $^{87}Sr/^{86}Sr$ ratio · REE · *Bos* (*Poephagus*) *baikalensis*

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1 Introduction

The human occupational history of different geographical regions during the Pleistocene depended on several factors including migrations of human populations and their interactions with autochthonous settlers, climatic conditions and environmental productivity, routes of migrating ungulate prey suitable for human hunters, and the availability of high-quality lithic raw material appropriate for knapping. These factors predetermined the character of regional exploitation as discontinuous or sporadic occupational episodes. In the first case, it is possible to trace gradual technological evolution through changing lithic industries or the rapid replacement of local populations by newcomers. In the second case, human groups with different or the same cultural suite left evidence of their sporadic appearances. Reconstruction of past climatic and environmental conditions is key to understanding the character of human occupation and cultural adaptation.

2 Materials and Methods

Several Paleolithic sites in Mongolia reflect distinct occupational episodes. Cultural horizons embedded in stratigraphic profiles without sterile dividing sublayers have been identified at sites in northern Mongolia including Kharganyn Gol-5, Tolbor-4, Tolbor-15, and Tolbor-21, but radiocarbon and OSL dates indicate significant hiatuses in the archaeological records in this region. The cultural sequence there includes assemblages from the Final Middle through the Upper Paleolithic. A different situation has been identified at archaeological sites in the Orkhon Valley in central Mongolia where cultural sequences spanning the Middle-Upper Paleolithic were revealed at the Orkhon-1 and -7 sites, in which cultural horizons are separated by archaeologically sterile layers of a significant thickness (Derevianko et al. 2010). The only known exception to this pattern, the Moiltyn-am site, contains cultural material impacted by significant post-depositional alteration (Khatsenovich et al. 2019) (Fig. 1).

A new course of research initiated in Mongolia in 2018 focuses on paleoenvironmental studies based on Sr isotopic and REE analyses, faunal and pollen analyses, grain size measurements, and OSL and radiocarbon dating to reconstruct paleoclimatic and paleoenvironmental records for the Orkhon Valley. Here, we present the methods employed and preliminary results of our REE and isotopic studies.

The Moiltyn-am site is situated in central Mongolia on the second terrace of the Orkhon River at the confluence of the currently dry Tuul (Tola) River at the elevation of 1482 m above sea level. Here, six lithological layers were identified in the 1.7 m deep 2018–2019 excavation stratigraphic profile. Every layer contained archaeological material, redeposited to greater (Layer 2) or lesser (Layers 4–6) degrees. The deposits of layers 2–4 are deformed in the one vertical line, which is probably associated with cryogenic processes. The lithic industry from Layers 4–6 is considered

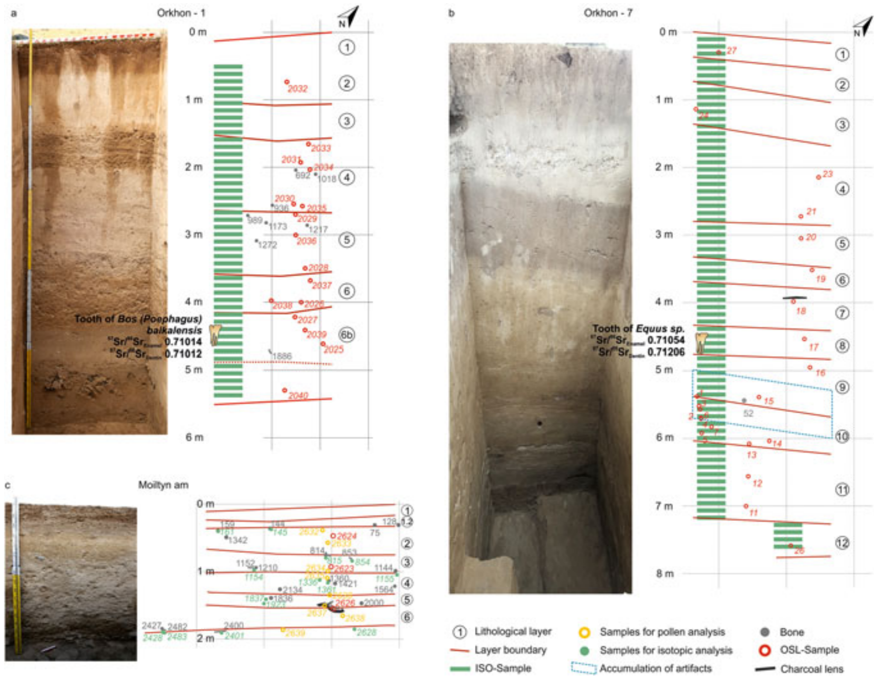


Fig. 1 Stratigraphic profiles: **a** Orkhon-1; **b** Orkhon-7; **c** Moiltyn-am, indicating sample locations. Locations of mammalian teeth were analyzed for $^{87}Sr/^{86}Sr$ ratios

Initial Upper Paleolithic, reflecting specific knapping techniques and a Levallois component based on local pebble raw materials. The most common faunal remains belong to the marmot, *Marmota* sp. (Layers 5 and 6), typical of the Late Pleistocene. A humerus fragment of *Bos* sp. (Layer 2) and a scapula of *Equus* sp. (Layer 5) record the presence of large mammals at the site.

The Orkhon-1 site is also situated on the second terrace of the Orkhon River, at an elevation of 1482 m above sea level. The stratigraphic profile includes seven lithological layers accumulated during the first half of the Marine Isotope Stage (MIS) 3.Artifacts are dispersed vertically within each stratigraphic unit. Large artifacts occur as a single horizon in the upper part of Layer 4 and are associated with the Early or Middle-Upper Paleolithic. Layer 7 includes a Final Middle Paleolithic cultural horizon including the mandible of an extinct yak, *Bos* (*Poephagus*) *baikalensis.*

The geomorphology of the Orkhon-7 site is similar to the six kiloPameter distant Orkhon-1 localities. The stratigraphic profile revealed at Orkhon-7 provides the most complete paleoenvironmental records in Mongolia associated with ancient human occupation. Its initial stage of sedimentological accumulation began during the first half of MIS 3. The 2019 stratigraphic profile revealed 12 lithological layers and cultural horizons in Layers 8, 9, and 10. Faunal remains of *Equus* sp. in Layers 8 and 9, *Bos* sp. in Layer 8, and *Ovisammon* and a rhinoceratid in Layer 10were uncovered.

All three sites in the Orkhon Valley can be preliminarily described as short-term episodic occupations. The lithic assemblages indicate that human activity was associated with a workshop for knapping pebbles collected from local alluvium. Radiocarbon dates point out significant temporal gaps in the exploitation of this workshop, probably caused by paleoclimatic changes. It is not clear where these people hunted, but a large amount of recovered butchered faunal remains may inform us about the behavioral traits of these past human societies.

The integrated study of various isotopic systems (C, O, N, Sr) reveals the paleodiets of both animals and humans and can facilitate the reconstruction of their migrations (Scharlotta and Weber 2014). This approach assumes, first, the study of archaeological material, and the sampling of relevant remains minimally impacted by post-depositional changes. Based upon research conducted both in the field and in the laboratory, we sampled visually intact animal teeth. We also sampled sediments underlying the analyzed bones. These sedimentological samples create an isotopic and geochemical baseline for comparison with results obtained from locally sourced bones. We studied ten sedimentological samples from Moiltyn-am, an equid tooth from Layer 8 at Orkhon-7, and a tooth identified as *Bos* (*Poephagus*) *baikalensis* from Layer 7 at Orkhon-1. We used the $^{87}Sr/^{86}Sr$ ratios of modern horses' teeth as the additional check-data of local determination.

Isotopic studies were carried out in the laboratory of physical and chemical methods of analysis, the Zavaritsky Institute of Geology and Geochemistry, Ekaterinburg, Russia. We employed methods described in Kiseleva et al. (2017) to analyze the chemical and isotopic composition of Sr in mammalian teeth. Unpretreated sediment samples weighing 30–50 mg were placed in polytetrafluoroethylene (PTFE) sample bottles containing a mixture of concentrated HF and HNO_3acids at a ratio of 3:1. After resolution, we evaporated the preparation to a dry state and added a mixture of HCl and HNO_3 acids to the dry residue at a ratio of 3:1. After subsequent evaporation at a temperature of 190 °C, the dry residue was treated with 10 N HCl and dried again at a temperature of 190 °C.

We used the following protocol to pretreat samples for analyses of trace and rare earth elements (REE): five-milliliter portions of each sample were placed in polypropylene containers to which 100 μl of In solution (internal standard) (1 mg/l) and 15 μl of 14 N HNO_3 diluted with ultrapure water to 10 ml to achieve a final 3% concentration of HNO_3. Calibration curves were created using Inorganic Ventures multi-element standard solutions. A NexION 300S (PerkinElmer, USA) quadrupole mass spectrometer was used to quantitatively determine the isotopes. We used an Inorganic Ventures certified multi-element solution to control the precision and accuracy of determining microelement composition. Concentrations of microelements fell within acceptable deviations of 15%.

We used the following protocol to pretreat samples for analyses of Sr isotopic composition: ion-exchange chromatography using Triskem Sr-Spec 100–200 mesh and the stepwise elution technique in 7 N and 0.05 N HNO_3 were applied to extract Strontium. The eluate was evaporated down to wet salts which were dissolved in 5 ml of 0.5% HNO_3. Isotopic ratios were determined on a Neptune Plus ICP-MS.

Mass was corrected with normalization to a ratio of $^{88}Sr/^{86}Sr = 8.37861$ and the method of bracketing every two samples concerning the standard NIST SRM-987 with a ratio of $^{87}Sr/^{86}Sr$ 0.710245 (GeoReM database, http://georem.mpch-mainz.gwdg.de/). Interference of the isotopes ^{86}Kr and ^{87}Rb were factored into normalization concerning $^{83}Kr/^{86}Kr = 0.664162$, $^{83}Kr/^{84}Kr = 0.201579$, and $^{87}Rb/^{85}Rb = 0.386$.

3 Results and Discussion

The composition of rare, trace, and rare earth elements are homogeneous in Layers 1–6 at the Moiltyn-am site, except for one sample from Layer 5 (MA 19 1837), which contains twice the number of elements (Table 1). This results from the distinct lithological composition of this layer which contains more gravel and debris than in overlying layers. Nonetheless, the plotted compositions fall within the narrow area on the triangular Nd-Gd-Yb diagram.

Concentrations of REE were normalized regarding PAAS (Post-Archean Australian Shale)(Taylor and McLennan 1985)—the standard for Phanerozoic sedimentary rocks (Fig. 2). All spectra have a similar shape, approximating a horizontal line. However, the ratios of LREE/HREE (light and heavy REE) or La/Yb vary insignificantly (0.8–1.0 and 0.67–0.99, respectively). There is no cerium anomaly (Ce/Ce* 0.9–1.0), but a low positive europium anomaly is evident (Eu/Eu* 1.1–1.3), and it is negative in one sample (MA815: Eu/Eu* 0.95). Ce/Ce*, Eu/Eu* rations were calculated according to Bau and Alexander (2006). A Y anomaly is characteristic of almost all samples, its value varying by 100%. Y/Ho falls within an interval from 0.43 to 0.98, and anomalies are absent in sample MA 19 1155. The spectrum of sample MA 19 1837 (Layer 5) is similar to the others but contains twice the concentration of elements. In Fig. 2, the Graph provides supplemental data on the average composition of loess from the Chinese Loess Plateau (CLP; formerly known as the Central Loess Plateau of China) (Yokoo et al. 2004). The graph demonstrates the differences between samples from the Moiltyn-am site and average loess composition: a europium anomaly is positive for the first and negative for the second, which may indicate different amounts of plagioclase in the rocks and the degree of reworking. The distribution spectra are similar, but it seems as if the sources of these rocks were different.

It is possible to reconstruct some aspects of paleoclimate, including accumulated precipitation. It is known (Ronov et al. 1967) that anon-normalized LREE (La + Ce + Pr + Nd + Sm + Eu)/HREE + Y(Gd + Tb + Dy + Ho + Er + Tm + Yb + Lu + Y) ratio indicates climate conditions: <2.5—arid, 2.5–4—semi-arid—semi-humid, >4—humid. The LREE/HREE ratio for massive material from the Moiltyn-am profile varies between 2.9 and 3.8 (average 3.5). This characterizes rocks and other massive material accumulated in semi-arid—semi-humid climate conditions. Data from Th/U ratios (Sikosek and Goikovi 1966) support these results since it varies between 2.6

Table 1 REE and Sr isotopic composition of sediments in the Moiltyn-am section

	MA 19 144	MA 19 161	MA19 815	MA 19 854	MA 19 1154	MA 19 1155	MA 19 1336	MA 19 1361	MA 19 1837	MA 19 2401
La	18	20	29	22	15	23	19	19	27	17
Ce	40	40	60	50	33	48	43	38	60	35
Pr	5	5.1	7	6.1	4	5.5	5.6	5.2	8	4
Nd	20	20	29	24	17	21	22	20	32	17
Sm	3.8	4.2	6	4.4	3.5	4	4.7	3.9	6	3.4
Eu	0.9	1.1	1.1	1.1	0.9	1.1	1.1	0.9	1.6	0.7
Gd	3.5	4	5	4	3.1	4	4	3.5	6	3.1
Tb	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.9	0.4
Dy	2.8	3.4	4	3.2	2.8	3.1	3.8	3.1	5	2.8
Y	15	17	11	16	13	17	18	14	25	8
Ho	0.6	0.7	0.8	0.6	0.5	0.6	0.8	0.6	1	0.5
Er	1.6	2	2.2	1.8	1.6	1.8	2.3	1.8	3	1.6
Tm	0.23	0.29	0.32	0.26	0.23	0.26	0.33	0.26	0.4	0.23
Yb	1.5	1.9	2.1	1.7	1.5	1.7	2.1	1.7	2.8	1.5
Lu	0.24	0.3	0.3	0.26	0.22	0.25	0.3	0.25	0.4	0.2
Total REE	114	121	158	136	97	132	128	113	179	95
Ce/Ce*	0.98	0.92	0.95	1.01	0.97	0.99	0.99	0.90	0.96	0.95
Eu/Eu*	1.16	1.26	0.95	1.23	1.29	1.29	1.19	1.15	1.25	1.01

(continued)

Table 1 (continued)

	MA 19 144	MA 19 161	MA19 815	MA 19 854	MA 19 1154	MA 19 1155	MA 19 1336	MA 19 1361	MA 19 1837	MA 19 2401
La_N/Yb_N	0.89	0.78	1.02	0.96	0.74	1.00	0.67	0.83	0.71	0.84
$LREE_N/HREE_N$	0.76	0.68	0.81	0.82	0.70	0.80	0.66	0.72	0.69	0.70
Y_N/Ho_N	0.92	0.89	0.50	0.98	0.95	1.04	0.83	0.86	0.92	0.59
$^{87}Sr/^{86}Sr$	0.709265	0.709595	0.709401	0.709588	0.709543	0.709381	0.709255	0.709549	0.709101	0.708936
$\pm 2\sigma$, abs	0.000013	0.000012	0.000006	0.000016	0.000014	0.000016	0.000016	0.000013	0.000018	0.000009

Notes Ce/Ce*, Eu/Eu* are calculated according to equations from Bau and Alexander (2006); the "N" index denotes normalization to PAAS (Taylor and McLennan 1985)

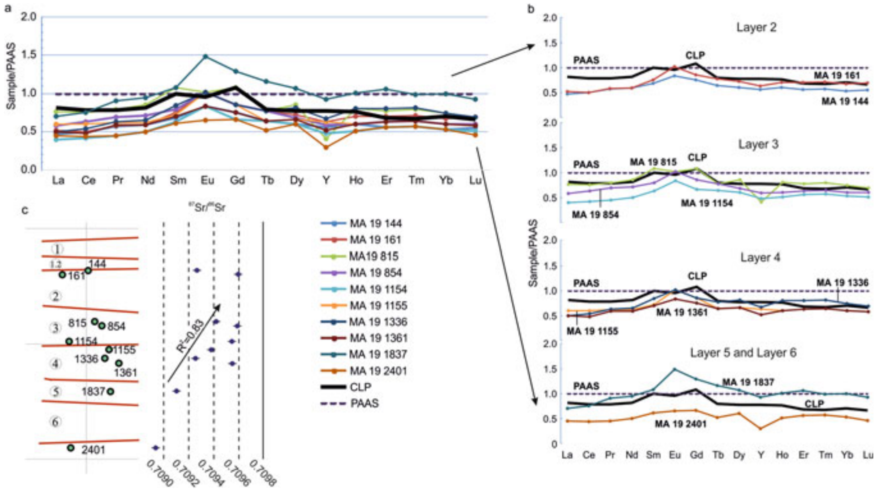


Fig. 2 Results of the analysis of massive material from the Moiltyn-am profile. **a** spectra of REE distribution normalized to PAAS from the analyzed sediment samples **b** the same, for each layer; **c** variation in Sr isotopic composition in the profile. R^2 is the coefficient of correlation; PAAS—Post-Archean Australian Shale, (Taylor et al. 1983; Taylor and McLennan 1985); CLP—Chinese Loess Plateau (Yokoo et al. 2004)

and 3.8 (average 3.1) which falls between typical arid and typical humid climate parameters.

The isotopic composition of Sr varies from 0.7089 to 0.7096 (Fig. 2, Table 1) with $^{87}Sr/^{86}Sr$ values increasing up the stratigraphic section. The coefficient of correlation (R^2) is 0.83, but several samples fall out of this value. We endeavor to explain each such case, beginning with the significance of the variability of $^{87}Sr/^{86}Sr$ ratios in the samples derived from Layer 2. Different contents of diagenetic carbonate material in these samples may impact this ratio. Layers 2–4 were deformed vertically, probably due to cryogenic processes (Khatsenovich et al. 2021). The Sr isotopic composition of sample MA 19 1361 supports the conclusion of vertical mixing. The $^{87}Sr/^{86}Sr$ ratio for this sample is 0.70955; close to the values for Layer 3.

It is believed (Price et al. 2002; Kasiri and Karimi 2017) that samples of teeth and bones can be considered local if they fall within the range of two standard deviations (±2 SD) from local background values. In our case, the ±2 SD range is from 0.70894 to 0.70978 (Fig. 4).

The chemical and isotopic composition of animal bones and teeth depends directly on the food individuals consumed (Bentley et al. 2002; Barberena et al. 2019). Teeth grow within a short period relative to an animal's lifetime. The chemical and isotopic composition of enamel remains fixed after competing for the mineralization and does not change, even in diagenesis. This is not characteristic of dentin, because it is porous and less resistant to the impact of environmental degradation. Depending upon conditions of preservation, the isotopic and chemical composition of teeth may be minimally affected by internal changes and become a good source material for reconstruction of the trophic chain and possible migrations of animals (Kohn et al. 1999; Bentley et al. 2002; Frei et al. 2009, 2015). REE distribution, normalized to chondrite (Sun and McDonough 1989), in tooth enamel and dentin of *Bos* (*Poephagus*) *baikalensis* from Orkhon-1 (Layer 7) is presented in Fig. 3. The resulting spectra are nearly horizontal, and the content of REE in enamel is ten times greater than in dentin (Fig. 4).

Heavy lanthanides overwhelm their light counterparts in enamel (La/Yb 0.89) while, in dentin, the situation is reversed (La/Yb 1.23). Both spectra are characterized by a low negative cerium anomaly (Ce/Ce* 0.5–0.7) and a significant positive europium anomaly (Eu/Eu^*_{enamel} 12, Eu/Eu^*_{dentin} 114). The difference in REE composition in the tooth enamel and dentin from Orkhon-1 is especially evident in heavy REE: here it is the so-called "saw". One possible cause is ultra-low concentrations of heavy REE, close to the detection threshold. The $^{87}Sr/^{86}Sr$ ratios of enamel and dentin are similar, amounting to 0.71013 ± 1, although the spectra of REE distribution are different. It is most likely that the post-diagenetic equation of isotopic composition took place.

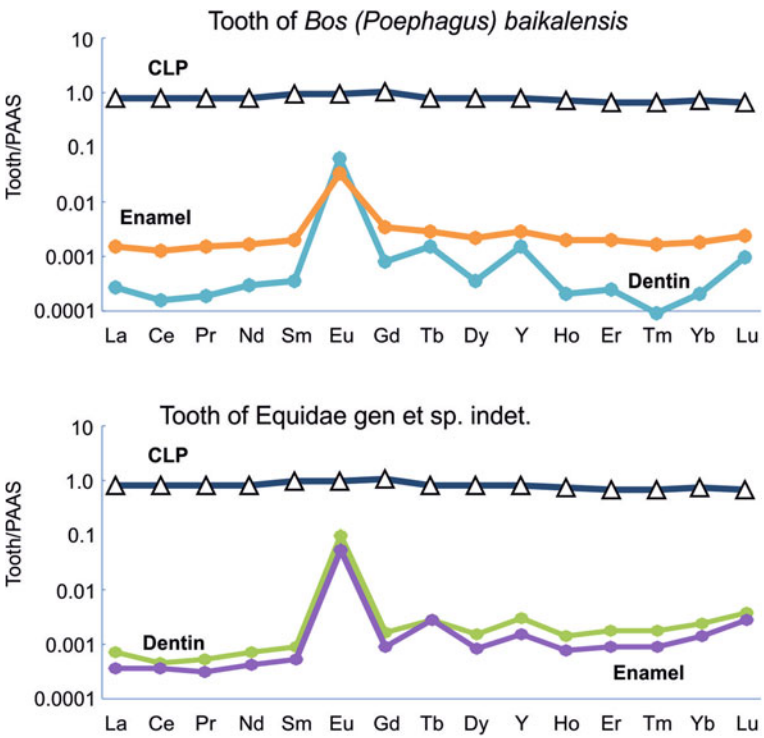
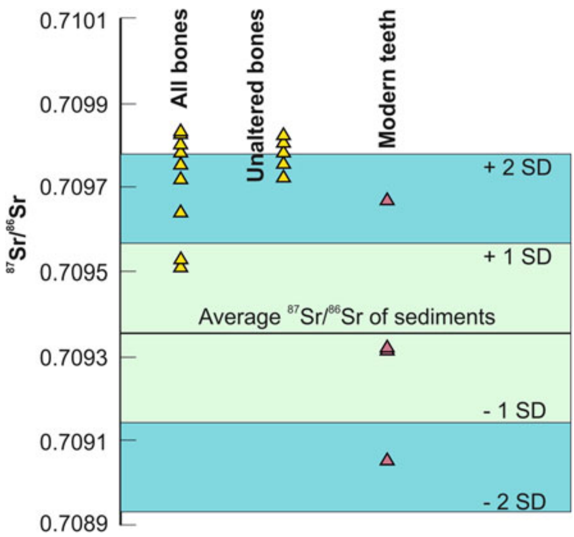


Fig. 3 REE distribution spectra in tooth enamel and dentin normalized to PAAS. CLP—Chinese Loess Plateau (Yokoo et al. 2004)

Fig. 4 Comparison of Sr isotopic composition ±1 SD and ±2 SD in sediments (shaded area), bone samples, and modern teeth. The juxtaposed areas indicate overlapping results for bone samples and sediments



The graph reflecting the fractionation of light, medium, and heavy REEs makes it possible to identify a group of bone samples fossilized in an environment not affected by soil processes (Fig. 5a). Those samples of bones, the composition of which differs from the composition of the soil, we considered the least altered. These results are confirmed by the plot of the dependence of the Sr isotopic composition on its reverse content (Fig. 5b). The least altered bone samples were found in layers 3 and 4, which accumulated 36–28 ka. The Sr isotopic composition of these samples varies from 0.70973 to 0.70983.

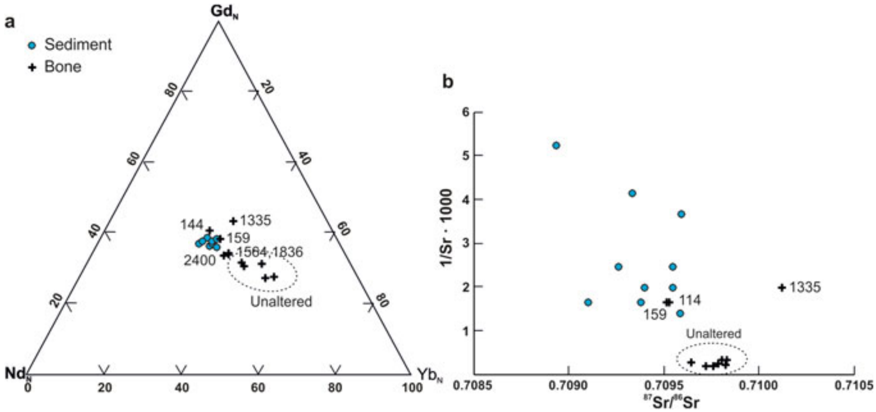


Fig. 5 **a** Comparison of REE compositions in bones and sediments from the Moiltyn-am site, Mongolia; **b** Dependency diagram of Sr inverse content from Sr isotopic composition

Tooth enamel and dentin of an equid from Orkhon-7 (Layer 8) are similar in REE composition and close in REE concentration, where heavy lanthanides overwhelm their light counterparts (La/Yb 0.3). The resulting spectra are characterized by a low negative cerium anomaly (Ce/Ce* 0.5–0.7) and a significantly positive europium anomaly (Eu/Eu* ~ 70). One specific feature of this tooth is that the content of all REE in the dentin is nearly double that in the enamel. Within the realm of heavy REE, it is the same "saw" as in the teeth from Orkhon-1. The Sr isotopic composition of equid tooth enamel from Orkhon-7 is similar to the yak tooth from Orkhon-1, amounting to 0.71055. The $^{87}Sr/^{86}Sr$ ratio is higher in the dentin of this tooth, amounting to 0.71207.

Sr isotopic composition of modern horses enamel placed between 0.70906 and 0.70966 and completely falls within the range from 0.70894 to 0.70978, described above. It supports our supposition that studied sediment samples, as well as the methods of their pretreatment together with criteria of their selection, can be used as the characteristic of Sr local sources.

The Orkhon Valley is geologically homogenous (Badarch et al. 2002) and the sites studied here are located within 8 km of one another, so, we can tentatively conclude that the isotopic and chemical composition of sediments from Moiltyn-am and Orkhon-1 and -7 are similar at this stage of our research. It is known that the dental enamel of herbivores reflects the Sr isotopic composition of grass consumed by animals during their first years of life (Bentley et al. 2002; Scharlotta and Weber 2014; Barberena et al. 2019). The $^{87}Sr/^{86}Sr$ ratios of teeth analyzed here differ from the isotopic composition of the archaeological sediments that enclosed them, thus we conclude that these animals—yak and equid—initially grazed in some other region during the first years of their lives, not in the Orkhon Valley. The chronometric age estimate of both animals from Orkhon-1 and -7 is about 40–45 kya.

Based on this assumption, we conclude that the herbivores spent the last years of their lives in the Orkhon Valley at a short distance from the Moiltyn am site. Our assumption about the size of the range of possible values of the Sr isotopic composition is confirmed by the results obtained for the teeth of modern equines. The 87Sr/86Sr ratio in tooth enamel varies in the range from 0.70906 to 0.70966, which is consistent with the proposed range for local representatives of the fauna.

4 Conclusions

The Moiltyn-am site sediments do not reveal any anomalous elemental contents. Admixtures and their geochemical characteristics are comparable to argillaceous rocks of PAAS: $^{87}Sr/^{86}Sr$ ratios of these rocks are typical of the upper continental crust, indicating that these rocks were well-mixed (Jahn et al. 2001). The spectra of REE + Y distribution are stable within the studied stratigraphic profiles. Sr isotopic composition has changed gradually, without "migrations," indicating that the climate did not change significantly while sediments were accumulating, and prevailing environmental conditions were semi-arid to semi-humid. This is supported by data on paleoclimatic changes in Khangai Mountains, based on other sources (Khatsenovich et al. 2021). Upcoming results of additional Sr isotopic and geochemical compositions of the stratigraphic profiles at Orkhon-1 and -7 will hopefully yield additional relevant data.

The Sr isotopic composition of the teeth of *Bos* (*Poephagus*) *baikalensis* from Orkhon-1 and the equid from Orkhon-7 indicates that these animals grew up grazing in an area far removed from the Orkhon Valley.

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Mining of Ores and Minerals in the Past

Starodubtseva Yama—A New Ancient Mine of the Southern Trans-Urals Steppes

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Abstract The research aims to determine the morphology and preliminary dating of the ancient mine Starodubtseva Yama. The mine is located 250 km southwest of Chelyabinsk, Russia. It was first identified with geological prospecting, and then in 2020, it was surveyed during a geoarchaeological expedition. The main research methods included a description of the geomorphological position of the ore occurrence, a topographic survey of the mine, and excavation of test pits along the edges of the site. The ore occurrence is confined to the central part of the Kulikovsky ultramafic massif; schlieren accumulations of copper-magnetite ores in serpentinites are noted. The ancient mine is an oval depression of 16 m × 13 m and up to 2 m deep, surrounded by a ring of dumps up to 1 m high from the modern surface; the diameter along the outer circle of the dumps is 30–35 m. Geomorphological features, its localization within the distribution zone of metal-producing communities of the Late Bronze Age, and the proximity to the Novotemirsky mine allow preliminary dating of the Starodubtseva Yama mine to the 1st half of the 2nd millennium BC.

Keywords Ancient mine · Bronze Age · Southern Trans-Urals · Sintashta culture · Alakul culture · Copper metallurgy

1 Introduction

The widespread metal production in the steppes of the Southern Trans-Urals began at the turn of the 3rd to the 2nd millennia BC. Evidence of metal smelting from copper ores appeared en masse on the fortified settlements of the Sintashta culture in this region (c. 2050–1800 BC (Hanks et al. 2007; Epimakhov 2020)). They are represented by fragments of ores and slags in the cultural layer, ingots, technological ceramics, furnaces, and metal artifacts. The post-Sintashta period is represented by

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the sites of the Alakul culture (c. 1900–1500 BC (Hanks et al. 2007; Epimakhov 2016; Krause et al. 2019))—unfortified settlements and burial grounds. Despite reducing the amount of slag in settlements, evidence for developed metal production in this period is evident. It was represented by copper and bronze tools and jewelry, ceramic and stone foundry molds for casting, metal ingots, and heat engineering structures with signs of metallurgical operations (Grigoriev 2015; Alaeva et al. 2021).

The question remains about the sources of ore raw materials and mining technologies of the population of the above cultural assemblages. Most of the discussions about the role, scale, and degree of specialization of metal production are based only on materials from settlements and burial grounds (Vinogradov 1995; Grigoriev 2015: 313–322; Epimakhov and Berseneva 2016; Chechushkov and Petrov 2021; Vinogradov 2021, etc.), drawing little information about mining. Many regions of North Eurasia characterized disproportion between the number of the identified settlement of metal producing communities and related mines. The southern Trans-Urals of Russia are no exception: identifying ancient mines in the modern Chelyabinsk region and adjacent areas is difficult. Most of them are disturbed or destroyed by the Russian industry in the Modern Age.

Nevertheless, the early attempts to find the ore base of the Alakul populations began in the 1950s (Salnikov 1967). The dense network of Bronze Age archaeological sites in the central part of the modern Chelyabinsk region of Russia made it possible to assume the use of the surrounding ore occurrences of copper, traces of the development of which in the pre-industrial period have survived in the form of the so-called "The Chud mines" (i.e., the mines of non-Russian peoples). The next stage of the search for mines is associated with the expedition headed by E. N. Chernykh in the 1960s–70s. Chernykh proposed the concept of metallurgical provinces that existed in the dawn of the Bronze Age on the territory of the former USSR and were based on the exploitation of various sources of copper. The Eurasian steppe metallurgical province was the largest province of the Late Bronze Age. The Ural Mining and metallurgical region were one of the centers of metallurgy and metalworking (Chernykh 1978, 1992). Surveys of its deposits made it possible to distinguish several metallurgical groups, which included copper products.

In the eastern part of the Ural mining and metallurgical region obtained metal artifacts can be assigned to two groups. They are the Tash-Kazgan (TK) groups and the Yelenovsko-Ushkattinskaya (EU) group, and in chemical characteristics, they are close to the Tash-Kazgan deposits in the southern Urals and Yelenovskoe-Ushkatinskoe in the north part of Mugodzhary, respectively. In Chernykh's opinion, these mines of the Trans-Ural mining and metallurgical center became the basis for the Andronovo (Alakul) metallurgical center (Chernykh 1970: 37–45, 124).

The Bronze Age attribution of the discovered mines has been exclusively justified by their localization in the zone of Late Bronze Age sites in all of these cases, as well as during the recent exploration at the Stepnoye archaeological district (Doonan et al. 2014). So far, such interpretation has not been yet supported by the results of excavations, radiocarbon dating, comparative mineralogical and geochemical analysis of ore composition from these mines and close-by settlements. In the 1990s, the geoarchaeological expedition founded by V. V. Zaykov at the Institute of Mineralogy of the

RAS began to examine copper deposits in the steppe zone of Central Eurasia to search for ancient mining sites. To date, the deposits and ore occurrences with evidence for pre-industrial mining have been discovered in the Ural-Mugodzhary region. The ore bodies' occurrence near to the surface allowed for their development during the Bronze Age (Zaykov et al. 2002; Zaykov et al. 2013). In the Southern Trans-Urals, only three mines have archaeological evidence of the Bronze Age exploitation; they are mines of Vorovskaya Yama, Novonikolaevsky, and Novotemirsky (Zaykov et al. 2000; Ankushev et al. 2018; Ankusheva et al. 2021). We believe this list is not complete yet. The discovery and further research using high-precision methods of new mining sites is the first step towards solving the problem of assessing the level and scope of ancient metallurgical technologies. This article presents the results of the primary field survey of the Starodubtseva Yama copper ore occurrence in the steppe zone of the Southern Trans-Urals. The main task of the expedition was the identification and preliminary dating of prehistoric mines at this ore occurrence.

2 Materials and Methods

The Starodubtseva Yama ore occurrence is located in the Chesma District, 250 km southwest of Chelyabinsk (Russia). This area is included in the modern landscape steppe zone Transural elevated peneplain and represents a hilly plain sufficiently saturated birch groves. The ore occurrence called 'Starodubtseva Yama' (also referred to in geological reports as Kulikovskoe, Novotemirskoe 7) is confined to the central part of the Kulikovsky ultramafic massif. It has a complex structure and consists of tectonically combined blocks of apogharzburgite and apolerzolite serpentinites, gabbroid, and host volcanogenic-sedimentary rocks (Fig. 1).

Schlieren accumulations of copper-magnetite ores in serpentinites were noted during the previous work at the ore occurrence. Magnetite predominates; pyrrhotite, chalcopyrite, and bornite are found. Content (%): Cu 0.37–1.56; Fe 59.8–69.2; Ag 3.2–7.5 ppm. (Tevelev et al. 2018: 109).

Primary data on pre-industrial mining appear in the reports on geological prospecting works in the former Troitsk district of the Ural region (Shilnikov 1932; Bukina and Glushkova 1953; Tevelev et al. 2018: 109). According to the location from the reports, we identified a characteristic structure—a depression surrounded by a shaft or dump—from satellite images from Google Earth software. A visual inspection of the ore occurrence area and its surroundings with an area of 1 × 1 km was carried out during a field survey in September 2020.

The topographic survey of the Starodubtseva Yama mine consisted of instrumental measurements of heights using a Sokkia CX-62 total station. The survey of high-altitude landmarks of the site's relief was made with a step of 2–4 m. The orthophoto- and situational maps of the site were made using aerial photography on a DJI Phantom 4 Pro quadcopter.

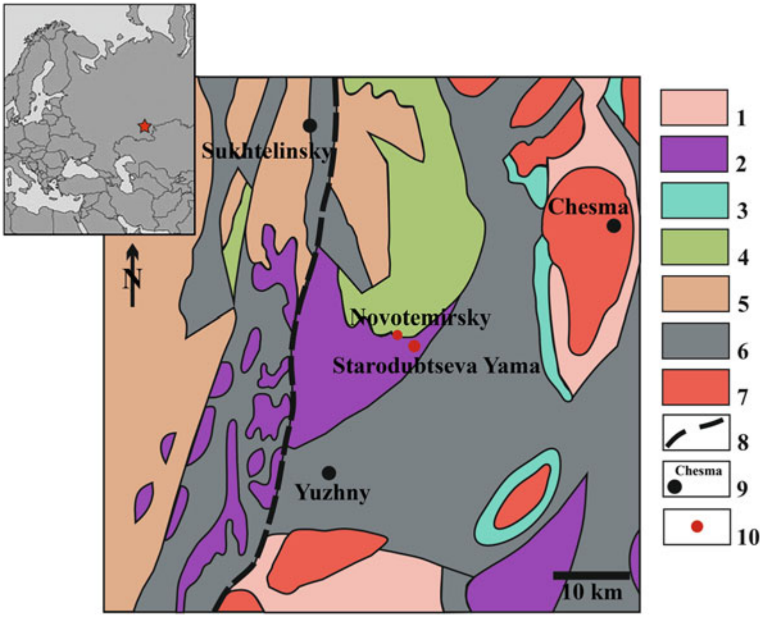

Fig. 1 Geological scheme of Starodubtseva Yama and Novotemirsky ancient mines region. 1—Riphean schists and quartzites; 2—Ordovician ultramafic rocks; 3—Ordovician volcanic and terrigenous rocks; 4—Silurian carbonate, terrigenous and volcanogenic rocks; 5—Devonian volcanic, terrigenous, and carbonate rocks; 6—carbonian carbonate, terrigenous and volcanogenic rocks; 7—Permian intrusions of granitoids and diorites; 8—faults; 9—towns; 10—ancient mines (according to the Geological map of the Russian Federation and the adjacent territory of the Republic of Kazakhstan. Scale 1: 1 000 000. Sheet N40, (41) (Ufa). OJSC "Bashkirgeologiya". Compiled by Kozlov et al. 2001).

Three test pits 1 m × 1 m in size were laid along the outer edges of the dumps to study the structure of strata of the cultural layer and the boundaries of its distribution. The depth of the pit included the entire thickness of the soil horizon to the culturally sterile subsoil (weathering crust) with a control digging of 10 cm.

3 Results and Discussion

An artificial structure resembling a prehistoric mining site was revealed during the inspection of the ore occurrence territory. This site was named Starodubtseva Yama, following the existing geological reports toponym. The mine is located in the valley of the Temir-Zingeyka River, 2.6 km southeast of the Novotemirsky village. It is situated on a relatively flat area with a slight slope to the north-east to the southwest on the old arable land, sod currently steppe vegetation. The partially overgrown with

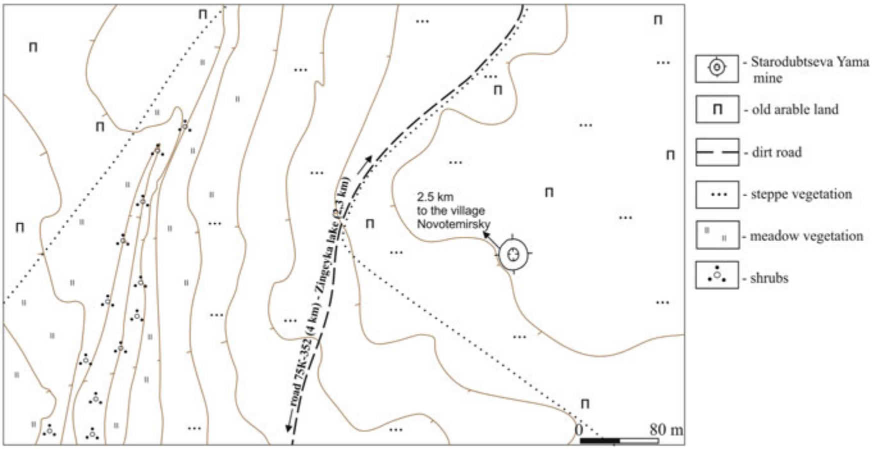

Fig. 2 Plan of the surrounding area of the Starodubtseva Yama mine. The contours are drawn every 0.5 m

bushes and detached birches ravine is located 330 m west of the site—it is an oxbow of the river flowing into another ravine, designated on the maps as Sporny (Fig. 2).

The Starodubtseva Yama mine is an oval-shaped depression of 16 m × 13 m and up to 2 m deep (on the present-day surface). It is aligned with the NNE-SSW direction. The meadow vegetation of the hygrophilous species covers the center of the depression. The depression is surrounded by dumps with soddy steppe vegetation up to 1 m high from the present-day surface. The height of the dumps is the lowest on the southwest side and it is up to 0.5 m, which suggests the presence of an entrance to the working area. The diameter of the mine along the outer circle of the dumps is 30–35 m (Figs. 3, 4).

The outer part of the northwestern dump is shaped like a step 8 m × 1 m in size—probably cut off by earth-moving equipment during the present-day plowing. A similar step is also observed on the ridge of the northern dump, closer to the inner side, up to 8 m long. Large (up to 50 cm) serpentinite boulders, fragments of oxidized copper ores—malachite and azurite—are discovered at the top of the dump (Fig. 5). No artifacts were found on the site.

Three test pits 1 m × 1 m were dug to identify the boundaries of distribution and the specifics of the cultural layer (dumps).

Test pit no. 1

Test pit no. 1 is located at the southeastern edge of the site, in the outer field of the dump. The modern surface of the site is covered with steppe vegetation. The variation of the heights on the surface of the pit was up to 6 cm; the highest northwestern angle of the pit was taken as a conditional zero. The sides of the pit are aligned with the cardinal directions; the features of the cultural layer were recorded every 10 cm at levels of −10, −20, −30, −40 cm (sterile subsoil) from the zero. The pit depth was 40 cm.

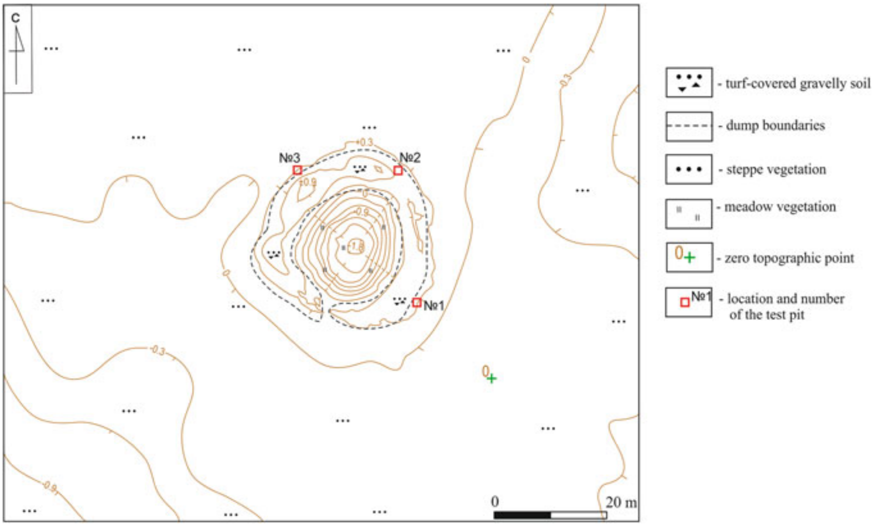

Fig. 3 Topographic map of the Starodubtseva Yama mine. The contours are drawn every 0.3 m

Fig. 4 The Starodubtseva Yama mine, view from the southwest *(*quadcopter photo)

Fig. 5 The mine's dump surface, view from the northeast

The following stratigraphy has been revealed by the test pit (Fig. 6, *1–4*):

0cm/−10 cm—Sod (Soil-Vegetation Layer with Plant Roots).

−10 cm/−25 cm—dark gray humus soil with a small amount of serpentinite crushed stone 1–2 cm in size, up to 5 cm; two small rounded sandstone fragments were found in the layer.

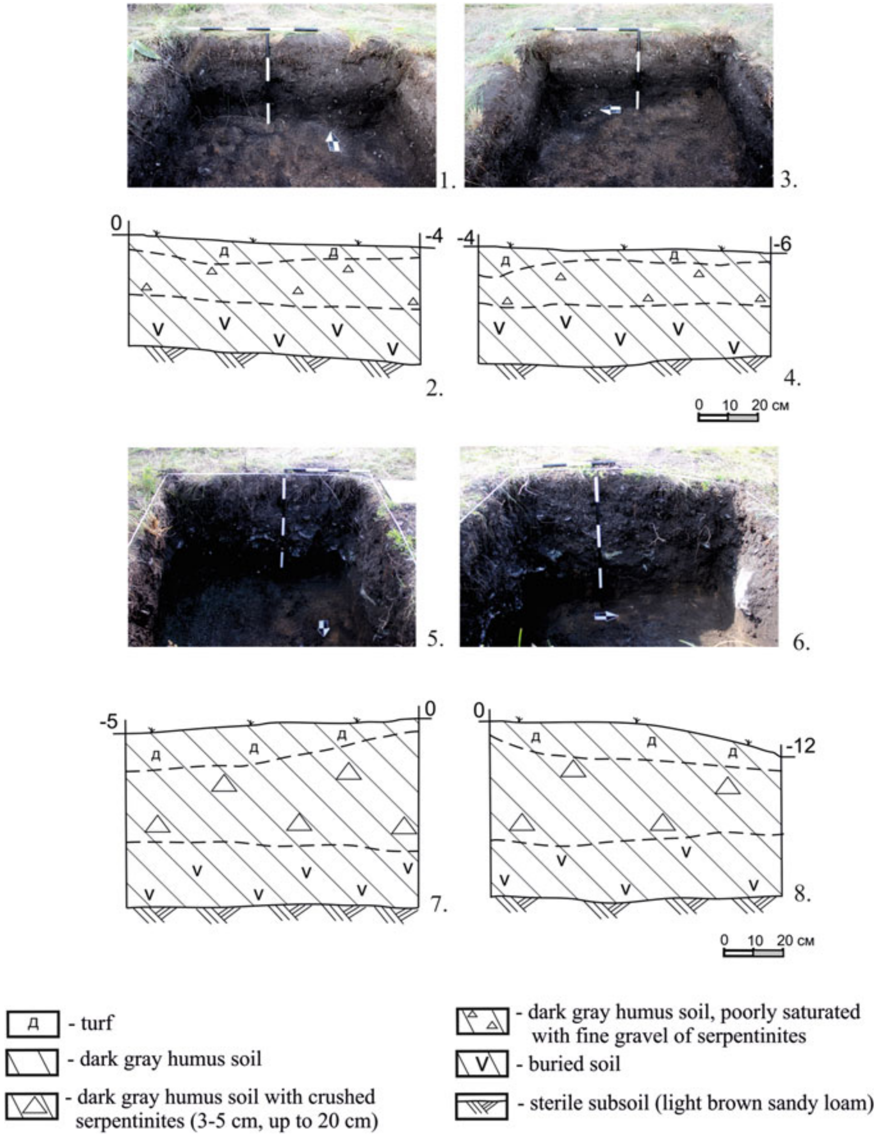

Fig. 6 Test pits profiles through Starodubtseva Yama mine: 1, 2—No. 1, north profile; 3, 4—No. 1, east profile; 5, 6—No. 2, south profile; 7, 8—No. 2, west profile

−25 cm/−40 cm—dark gray, wetter, humified soil interspersed with brown sandy loam (buried soil). The layer contains small rounded sandstone fragments 2–5 cm in size.

−40 cm—the sterile layer represented by light brown sandy loam (weathering crust).

The location of the pit and its stratigraphy reflect the periphery of the southeastern dump, which is confirmed by a small amount of serpentinite crushed stone in the cultural layer. No finds were found in the pit.

Test pit no. 2

Test pit no. 2 is located on the outer part of the northeastern dump, which is flattened and shaped like a 'step'—probably due to undercutting with earth-moving equipment during plowing. The modern surface of the site was covered with steppe vegetation. The variation of the heights on the surface of the pit was up to 13 cm; the highest south-western corner of the pit was taken as a zero point. The sides of the pit are aligned with the cardinal directions; the features of the cultural layer were recorded every 10–20 cm at the levels of −10, −20, −30, −40, −60 cm (sterile subsoil) from the zero. The pit depth was 60 cm.

The following stratigraphy has been revealed by the test pit (Fig. 6, *5–8*):

0 cm/−10 cm—sod (soil-vegetation layer with plant roots). A fragment of an iron plowshare was found in the sod layer in the northwestern corner of the pit at a depth of 5 cm from the surface.

−10 cm/−40 cm—dark gray humus soil, abundantly saturated with serpentinite crushed stone 3–5 cm in size (individual fragments are up to 25 cm), copper ores (malachite), single rounded sandstone fragments. The layer is a waste rock dump. It becomes thinner in the direction from south to north, which is well observed in the profile. In the upper horizons of the layer, organic remains are present (rotted sod layer).

−0 cm/−60 cm—dark gray, wetter, humified soil interspersed with brown sandy loam (buried soil).

−60 cm—sterile layer represented by light brown sandy loam (weathering crust).

The location of the test pit and its stratigraphy reflect a part of the northeastern dump of the waste ore-host rock, which is confirmed by the abundance of crushed stone of serpentinites and copper ores in the cultural layer. The upper horizons of the dump have been disturbed and loosened by modern plowing. This is evidenced by the significant thickness of the sod layer (up to 20 cm), the abundance of humus and the loose nature of the dump, the presence of remnants of old, redeposited sod in the layer, and the iron fragment of the plow in the near-sod layer. No ancient artifacts were found in the pit.

Test pit no. 3

Test pit no. 3 is located on the outer part of the northwestern dump. The modern surface was covered with steppe vegetation. The variation of the heights on the surface of the pit was up to 14 cm; the highest southeastern corner of the test pit was taken as a zero point. The sides of the pit are aligned with the cardinal directions;

the features of the cultural layer were recorded every 10–20 cm depending on the context at the levels of −10, −20, −30, −50 cm (sterile subsoil) from the zero. The test pit depth was 50 cm.

0cm/−15 cm—Sod (Soil-Vegetation Layer with Plant Roots).

−15 cm/−30 cm—dark gray, dense humus soil with fine gravel of serpentinite 2–5 cm in size, individual fragments of serpentinite reach 20 cm. Serpentinite contains separate malachite and azurite veins. The layer contains brown sandstone pebbles, as well as a fragment of silicite, in which numerous quartz crystals are visible in the fracture.

−0 cm/−50 cm—dark gray, wetter, humified soil interspersed with brown sandy loam (buried soil).

−50 cm—the sterile layer represented by light brown sandy loam (weathering crust).

The location of the pit and stratigraphy reflect the periphery of the northwestern dump, which is confirmed by the presence of crushed stone of serpentinites and copper ores in the cultural layer. No ancient artifacts were found in the pit.

The discovered structure has the following evidence of mining activities: the location on the territory of ore occurrence, presence of copper-bearing minerals on the surface (malachite and azurite), stratigraphic features of the cultural layer, represented by crushed stones of waste ore-hosting rock. The good sodding and the high degree of flattening of the dumps indicate that the mine was used in antiquity. Let us now consider the facts that suggest the use of the Starodubtseva Yama during the 2nd millennium BC by the Sintashta-Abashevo and/or Alakul populations.

Firstly, geographically, Starodubtseva Yama is located in the center of the region of localization of the Sintashta fortified settlements (Zdanovich and Batanina 2002; Koryakova and Epimakhov 2007: 66–98); the unfortified settlements of the Alakul culture and the final Bronze Age were also identified in the Temir-Zingeyka river valley at a distance of 3–15 km from the mine. The Novotemirsky mine is dated to the 2nd millennium BC according to its artifact complex and the radiocarbon dating. The site is located only 1.45 km northwest of Starodubtseva Yama (Ankusheva et al. 2021).

Secondly, the remaining shape and size of Starodubtseva Yama possess much resemblance with other Late Bronze Age mines of the Southern Trans-Urals, namely: Novotemirsky, Vorovskaya Yama, Novonikolaevsky. All of them today look like a single central depression (quarry) of a rounded or oval shape, surrounded by a circle of flattened soddy dumps of crushed rocks (Table 1). The Alakul culture mines in the Main Ural fault zone (Ishkininsky, Dergamyshsky) and the Mugodzhary Hills (Elenovsky, Sarlybay II) also demonstrate a similar morphology (Zaykov et al. 2005; Tkachev et al. 2013).

Excavations at the Novotemirsky mine have shown that its present-day appearance differs significantly from the buried structure. The latter is a system of backfilled mines and adits and dumps of waste rock and copper-bearing minerals. In addition to the central pit, the main structure of the site, a rectangular shaft of 8 m in depth, a narrow winding manhole, small pits left after sampling of thin ore veinlets were found at the southeastern edge of the site. All mine workings were covered with waste

Table 1 Morphological features of the Bronze Age mines in the Southern Trans-Urals

Mine title	Coordinates (latitude, longitude)	Period, culture	Central quarry shape	Size (with dumps), m	Central quarry size, m	Dump height, m	Central quarry depth (current state), m
Novotemirsky	53.6738, 60.1594	LBA (Sintashta/Abashevo, Alakul)	Oval	30 × 40	20 × 15	0.2–2	3
Vorovskaya Yama	53.0364, 59.5840	LBA (Alakul)	Round	55 × 60	30 × 40	0.8–1,5	3–5
Novonikolaevsky	53.1550, 60.8941	LBA (Alakul?), FBA	Oval	65 × 40	35 × 20	0.5	2
Starodubtseva Yama	53.6640, 60.1745	?	Oval	30 × 35	16 × 13	0.5–1	2

The table is compiled according to: (Zaykov et al. 2000; Yuminov et al. 2015; Ankushev et al. 2018; Ankusheva et al. 2021) rock and weathering crust soil, so they were difficult to identify on the surface. We assume a similar system at the Starodubtseva Yama mine, the features of which can be established with the help of geophysical exploration and archaeological excavations.

Thirdly, the type of copper ores presented at Starodubtseva Yama—oxidized copper ores in ultrabasites—was the preferred raw material of the Sintashta metallurgists. This is confirmed by the mineralogical and geochemical features of slags found in the Sintashta fortified settlements: relict inclusions of serpentinite and Cr-spinels, high content of chromium, nickel in slag, and arsenic in melt inclusions (Grigoriev 2015; Ankushev et al. 2021).

In sum, the location, morphological, geological, and mineralogical features of the Starodubtseva Yama mine make it possible to preliminarily date this site to the Late Bronze Age (the first half of the 2nd millennium BC).

4 Conclusions

We assume that the Starodubtseva Yama mine is another perfectly preserved object of the earliest mining activity in the Southern Trans-Urals. A further test of this hypothesis is possible with the employment of archaeological excavation to find chronology-related artifacts and other evidence of human activity, suitable for absolute dating. Nevertheless, it is already possible to ascertain both, the regular nature of such mines in the Southern Trans-Urals and relatively common features of their morphology and cultural layers. Further understanding of these features contributes to our knowledge of the nature, role, and scale of the most ancient mining activities of the population of the Ural Region and helps to preserve this cultural heritage in the active industrial region of Russia.

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The Paleosoils Properties of Vorovskaya Yama Copper Mine and the Late Bronze Age Climate on the Trans-Urals Plateau

Liudmila N. Plekhanova

Abstract The paleosoil layers from under the dumps of the Late Bronze Age copper mine "Vorovskaya Yama" in the Southern Urals are studied. Based on the morphological and chemical properties of the buried soil and modern surface soil, the climatic conditions that existed during the Late Bronze Age in the Trans-Ural peneplain have been reconstructed. It has been found that the soils of this time contained more organic carbon than at present day. This allows us to conclude that the precipitation in the period of the mine use (2nd millennium BC) was somehow higher compared to the present day. We also highlight the consequences of the ancient anthropogenic pressure visible in the buried soil in the form of highly soluble salts and carbonates drawn up to the surface. It was shown that in the area of distribution of the ancient copper mines, soils under dumps of mines are a unique source of information about the climatic conditions that existed during the period of the mine existence. Taking into account that in ancient times a large number of mines simultaneously operated on different elements of the relief within the same ore-bearing province, the soils buried under the dumps of the mine allow us to reconstruct the soil cover as a whole on different elements of the relief.

Keywords Paleosoils · Paleoclimate · Mine · Urals · Steppe · Buried soils · Bronze Age

1 Introduction

Soils are practically the only natural formations that integrally reflect the climatic, biological, and geomorphological conditions of their formation.

As a source of climate reconstructions, the soil is studied by two principal methods that can provide information about the paleoclimate: the palynological spectra

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(Ryabogina et al. 2019; Stobbe et al. 2016) and the paleosoil method. The methodological basis for reading soil properties allows obtaining data on morphology, granulometry, aggregate composition, hummus, carbonate and gypsum profiles, mobile phosphates as an indicator of anthropogenic impact, and the microbial component of paleosoils.

The comparative analysis of soil profiles located within the same element of the landscape but formed during different periods allows building a directly comparable chronosequence. This comparison provides insights into the soil dynamic through time and helps to reconstruct the climatic conditions in which the soil was formed. The main diagnostic features of the paleosoil that reflect the state and temporal dynamics of moisture are described as the chronosequence of the steppe zone of southern Russia (Demkin et al. 2012; Demkina et al. 2017; Rusakov et al. 2019). The diagnostic features include the humus layer and the reserves of humus; the composition of humus; the change of the magnetic susceptibility; the depth of the soil profile; the carbonate accumulation; gypsum and soluble salts and their reserves in layers up to 1.5 m; the forms of carbonates precipitation; sodic horizons; the severity of signs of alkalinity.

The aridization is diagnosed with complex stratigraphic methods as the decreasing proportion of woody flora and forbs in the pollen spectra, the decreasing proportion of xerophytic plants, the decreasing depth of the humus horizon, and the decreasing magnetic susceptibility which is caused by the depressed growth of plants due to lack of moisture, accessible accumulation of salts, carbonates, and gypsum, approaching the surface, increase of their stocks, transformation of carbonate precipitation forms.

The humidization of the climate is diagnosed by the opposite set of changes in the properties of the profile. There is the desalination of the soil and underground layer, the increase in the humus content, and the magnitude of the magnetic susceptibility. In addition to the morphological, physical, and chemical properties of paleosoils, there are microbiological parameters that can be identified. They provide contrasting characteristics of the microbial community in the steppe paleosoils during the arid and humid climatic periods. A more humid climate leads to an increase in the productivity of phytocenoses, and, consequently, to large biomass of plant litter entering the soil, an increase in the biomass of active microorganisms, and a high proportion of soil organic carbon. Also, in the ecological-trophic structure of microorganisms, those using readily available organic matter predominate.

2 Materials

Ancient mines are not common objects for the analysis of paleosoils. It can be argued that the study of paleosoils under the mine dump of the Bronze Age is pioneering for the Southern Urals, where this type of work was carried out only at three sites—Vorovskaya Yama and Novotemir mine in the Chelyabinsk region and Ishkinino mine in the Orenburg region.

Good preservation of soils buried under the embankments is required to fulfill the conditions for building the chrono-series of buried soils and carrying out paleoclimate reconstructions. This condition is fully met by the embankments of mine outflows, which provided the isolation of the ancient soils from wetting and other damage as a result of the mine development. Also, the embankments are voluminous and have a stony character, which makes it possible to compare the soils there under with buried soils under the ramparts of other archaeological sites.

The study area is located in the temperate zone of the West Siberian region which determines the continentality of the modern climate. The climate is sharply continental with little snow and cold winters, dry and hot summers. There is 250–330 mm of precipitation per year, of which 45% is in summer and 12% is in winter, and only 130–180 mm during the growing season. The character of summer precipitation is mainly stormy. The annual evaporation rate is 1.5–2 times higher than the annual precipitation. The moisture coefficient is 0.44–0.77; the hydrothermal coefficient (Selyaninov's GTK) does not exceed 0.8–1.0.

The Vorovskaya Yama mine is located in the southern part of the Chelyabinskregion, on the territory of archaeological sites called the "Country of Towns" dating back to the Middle Bronze Age. Cross-Section 1 is represented by the background soil (Chernozem type, develop on the same deposits as the surface of the entire mine, fine earth of copper-mine rocks with transitions to brown iron ore), cross-Section 4 by the soil buried under the embankment, compared with the development of the mine by the population of the Andronovo cultural community.

3 Results and Discussion

Only a small number of archaeological objects on the territory of the Trans-Ural steppe have been studied regarding their paleosoils (Khokhlova et al. 2019; Plekhanova and Demkin 2008; Plekhanova 2017, 2019; Kashirskaya et al. 2017; Thiemeyer et al. 2013). The diagnosis of paleoclimate changes in the Urals requires more detail. The results of the chemical analysis of the Vorovskaya Yama mine soils are presented in Tables 1 and 2, as well as the granulometric composition which makes it possible to compare the soil data.

Soils under the mine's dump differ from the modern soil by a stronger carbonate accumulation, which lies at a depth of 40–80 cm, as well as by a high content of biogenic elements, namely mobile forms of phosphorus and potassium. The enrichment with mobile phosphates is typical for the possible exploitation of the buried area by a human.

The humus content in the buried soil is 3.8–1.6%; when applying the conversion factor for the Bronze Age (Demkin et al. 2012), high humus content is obtained in the buried soil (9.5–4%) of the time of dumping. This is a very high value. This correlates with an increased value of magnetic susceptibility at a depth of 20–40 cm in the buried soil. According to the humus data, one could assume a warm climate of that period, but carbonates in the upper part of the soil profile (10–12% at a depth

Table 1 Granulometric composition of soils at Vorovskaya Yama mine

Sampling depth, cm	Fraction content (mm), %							Silt/clay
	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01	
Cross-section 4, ancient soil								
0–15	39	27	15	3	7	9	19	0.48
20–40	19	20	18	6	16	21	43	0.48
40–60	15	17	23	8	20	17	45	0.39
60–80	16	22	23	7	18	14	39	0.36
Cross-section 1, background soil								
0–10	22	28	24	4	11	11	26	0.43
20–30	29	25	20	5	11	10	26	0.39
40–50	26	29	19	8	8	10	26	0.38
50–70	20	37	24	5	7	7	19	0.36

Table 2 Chemical composition of the soils from Vorovskaya Yama mine

Sampling depth, cm	pH	Humus	$CaCO_3$	$CaSO_4$	P_2O_5	K_2O	CEC	Exchangeable cations				η*10^5 units SI
					According to Machigin			Ca^{++}	Mg^{++}	Na^+	K^+	
		%			mg-eq/100 g of soil							
Cross-section 4, ancient soil												
0–10	7.3	3.8	–	–	4.3	24	29	19.8	8.2	0.36	0.61	0.53
20–40	8.4	1.6	2.5	–	0.8	31	41	12.3	18.6	9.72	0.55	1.63
40–60	8.6	0.8	10.4	0.51	0.6	32	66	19.1	26.4	19.97	0.48	0.85
60–80	8.3	0	11.8	2.00	–	–	–			–	–	0.32
90–110	8.0	–	5.3	3.05	–	–	–			–	–	1.31
110–130	8.2	–	7.0	–	–	–	–			–	–	0.32
130–135	9.4	–	50.3	–	–	–	–			–	–	0.13
140–170	9.0	–	4.1	–	–	–	–			–	–	4.35
Cross-section 1, background soil												
0–10	6.8	7.1	–	–	2.9	42	–	–	–	–	–	0.55
20–30	7.4	3.5	–	–	1.0	31	31	22.5	7.42	0.38	0.68	0.63
40–50	7.8	2.2	2.8	–	1.3	21	44	33.0	10.31	0.41	0.42	0.56
50–70	7.9	1.6	6.5	0.10	1.3	20	–	–	–	–	–	0.33
80–100	8.2	0.3	6.2	0.07	–	–	–	–	–	–	–	0.18
100–120	8.5	–	6.2	0.11	–	–	–	–	–	–	–	0.04

η—magnetic susceptibility
CEC—cation exchange capacity

of 40–80 cm) contradict this. Also, the carbonate crust is pronounced (50% $CaCO_3$) and lays at a depth of 130–135 cm. Highly elevated carbonates of the buried soil can be an indicator of the effective redistribution of carbonates along with the profile due to good wetting in spring and intense drying in summer (Khomutova et al. 2019). This may be a result of the sharp continentality of the more humid and hot climate of that period, compared to modern. Also, highly elevated carbonates in the buried soil make it possible to formulate a hypothesis about the time of the early exploitation of the mine. The dumping, perhaps, occurred during the period of the crisis, as in the Volga steppes (Demkina et al. 2017).

4 Conclusions

Ecosystems of various landscapes, as well as societies, reacted differently to the same changes in climatic conditions. To date, it has been identified (Demkin et al. 2012; Plekhanova and Demkin 2008) that the different compositions of rocks and the degree of drainage of the territory determine different responses of soils to the same climate changes. For the drained territories, the evolution of soils proceeded according to the same type (Chernozem or Kastanozem), changes occurred at the level of the subtype (Demkin et al. 2012; Demkina et al. 2017). For undrained areas, such as low terraces, during the second half of the Holocene, a repeated alternation of soil salinization-desalinization processes was noted. The plausible reason for the more clear reflection of climatic fluctuations and their preservation in the soils of the valleys is the difference in the diurnal variation of temperatures in watersheds and valleys.

Based on the latest developments in the field of paleoclimate reconstructions and studies of cultural layers of archaeological sites, special approaches are needed to soils under the mine dump. In particular, the study of microbiological components is needed (Khomutova et al. 2019; Kashirskaya et al. 2019, 2020; Evgrafova et al. 2008; Thiemeyer et al. 2013), as one cannot be limited only to traditional chemical analysis. There is a need to perform a complex comparison with cultural layers of objects of a similar time, where most of the criteria have yet to be adapted or developed.

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New Objects of Geoarchaeology of the Baishevsky Archaeological District and the Adjacent Territory of the Bashkir Trans-Urals (The Southern Urals)

Peter V. Kazakov

Abstract The paper presents the study of gold placers in the Shuralinsky placer field, where the Baishevsky archaeological district is located. The attractiveness for site location on the banks of residual lakes of the paleorivers in the Kizilo-Urtazym foothill depression of the Bashkir Trans-Urals is analyzed. The discovery of a lake depression from a dry lake named "Sagylkul" allow proposing the expansion of the Baishevsky archaeological district.

Keywords Geoarchaeology · Gold placers · Baishevsky archaeological district · Lake depression · Southern urals

1 Introduction

The study area is located on the eastern slope of the Southern Urals, on the southern closure of the Irendyk ridge and its southeastern spurs. Geomorphologically, it is located in the zone of the transition of the residual mountains of the southern Urals to the elevated peneplain. Administratively, it belongs to the Baymak district of the Republic of Bashkortostan, Russia (Fig. 1).

The main research objects are placer deposits of gold from the upper reaches of the Bolshaya Urtazymka River, the right tributary of the Ural River. The tasks are (1) to reveal the conditions for the formation of placers of the Shuralinsky placer field and the features of the material composition of the host sediments; (2) to characterize the nature of their formation; (3) to describe the morphology; (4) to reveal the composition of concentrated gold.

A survey of the Shurale, Bezymyanny II, and Ulak placer deposits on the right tributaries of the Bolshaya Urtazymka River was carried out. In addition, in the middle part of the Sagyluzyak stream (the left tributary of the Bolshaya Urtazymka river), the depression from the dry Lake Sagylkul was discovered and examined.

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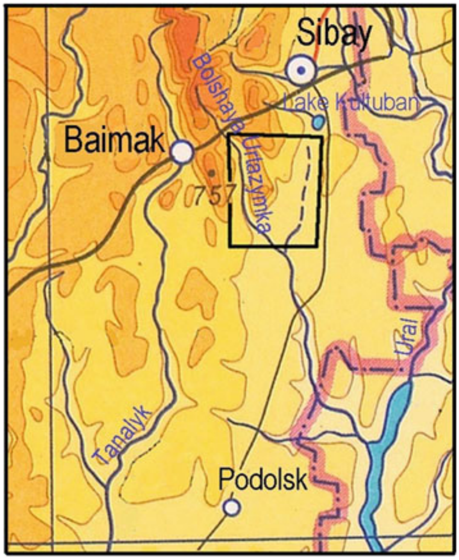

Fig. 1 Layout chart of the territory of research (black rectangle)

Regarding archaeological sites, the Baishevsky archaeological district (AMD) and the Historical, Archaeological, and Landscape Museum-Reserve "Irendyk" are located on the territory of the Shurale placer field.

2 Materials and Methods

The key method at Stage I was collecting, studying, and analyzing archival and published materials. During Stage II, topographic maps were analyzed; various altitude aerial photographs and satellite images were analyzed by applying a universal scheme for describing principal landforms. Finally, during Stage III, the acquired landforms and geological sites were located on the landscape and tested during the survey.

The history of gold mining is inextricably connected with the history of ancient societies. The use of gold is visible, along with the evidence for extraction of copper and iron, through the proof of gold mining in ancient and historical times.

Below, I provide examples that indicate the presence of ancient mining of gold placer and ore in the southern Urals within the borders of Bashkortostan.

3 Results and Discussion

1. The survey of gold-containing sites and the plausible arhaeological application of the survey data

In recent times, gold deposits in the Southern Urals were developed by the owners of the Rameyev, Goryaev, Pribylevsky, and other mines yielding hundreds of kilograms of metal.

In the Bolshaya Urtazymka river basin, the Shurala placer field was identified, uniting the Shurale, Bezymyanny II, and Ulak placers (Fig. 2) (Kazakov and Salikhov 2006). A brief description of the results of the study of these placers is provided below.

The Shurale Late Neopleistocene-Holocene alluvial placer is located 7.5 km NW of the village of Baishevo in the valley of the stream with the same name. It begins on the section located from the mouth to the middle part of the valley. After the initial discovery in 1877, it was exploited until 1910. The equivalent of 180 kg of gold was extracted during this time. According to the 1984–85 exploration, the gold-bearing placers are associated with the sand and gravel channel facies of floodplain alluvium and the first terrace. In the horizontal section, the placer has a ribbon-like shape. The total length of the industrial part of the placer is 1830 m, the average width is 48 m, and the average thickness of the rock mass is 2.9 m.

The Bezymyanny II placer is located 6 km NW of the village of Baishevo and 1 km southwest of the Shurale placer. The diluvial-alluvial placer is dated to the Late Neopleistocene-Holocene and confined in the middle and upper parts of the log. According to the geological survey of 1984–1985, the loose deposits containing the placer are represented by clays, loams with angular-rounded pebble material (up to 30–45%) with a thickness of up to 4–6 m. In the horizontal section, the placer has a ribbon-like shape. The length of the industrial part of the placer is 330 m, the average width is 30 m, and the average thickness of the rock mass is 3 m. In the vertical section, the productive layer "hovers" over the placer basis and lies on loam and weathering crusts.

The Shurale and Bezymyanny II placer gold concentrations belong to the Type IV (large) industrial classification. The shape of gold grains varies from oval and rounded to sub-rectangular. Medium and highly rounded gold grains have up to 10–20%. The gold sample is 952. In the Shurale placer, there is gold in the form of distorted octahedral crystals.

The uniformity of the chemical composition, morphology, and size of gold indicates the uniformity of the local sources and their territorial proximity to placers. During the survey of gold placers, the author found that the Shurale and Bezymyanny II streams intersect a well-defined early Eopleistocene paleo-valley of the meridional direction, composed of variegated clay with pebbles.

Also, along the Shurale stream, past gold developments have affected deposits on the first floodplain terrace. Thus, the presence of well-rounded gold in the late Neopleistocene-Holocene placers indicates that it was repeatedly redeposited from intermediate sources of the paleo-valley and the terrace of the modern river's network sediments. In the sides of the valleys of the Shurale and Bezymyanny II streams, there

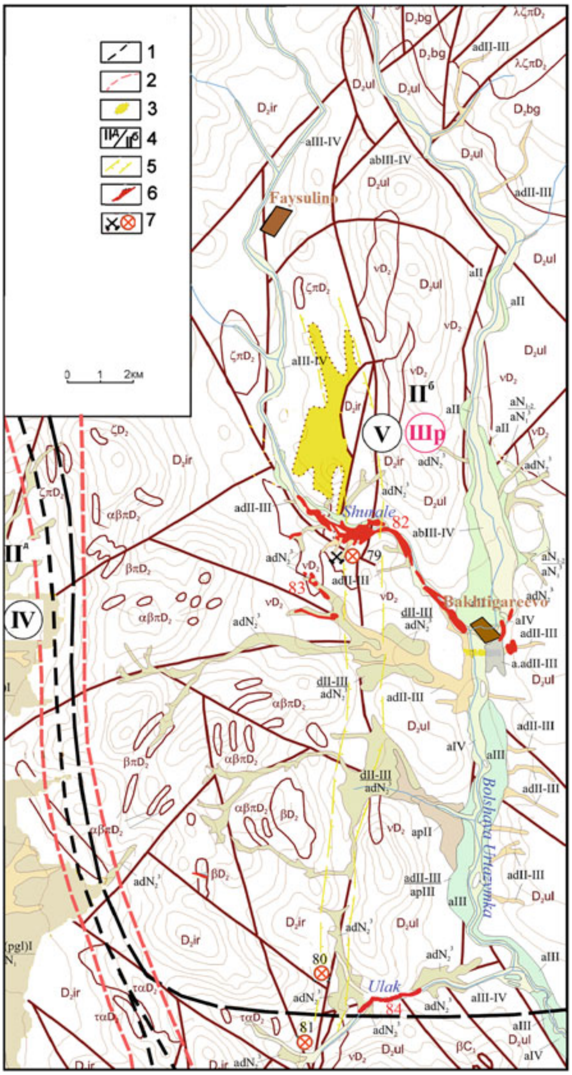

Fig. 2 The map of gold content of the Shuralinsky placer field (according to (Kazakov and Salikhov 2006), modified). Minerogenic zones: 1—placer zones: IV—Sakmaro-Tanalyk, V—East-Irendyk; 2—placer fields: Shuralinskoye (Шр); 3—metasomatized zone; 4—geomorphological zones: IIб—elevated mountain massifs of the Southern Urals, IIд—the residual mountains of the eastern slope of the Southern Urals; 5—fragments of an eopleistocene paleo-valley; 6—placer gold, worked-out in a muscular way; 7—the primary deposits and ore occurrences of gold. List of deposits and gold discoveries: 79—Urtazym-Goryaevskoe, 80—Ulak-I, 81—Ulak-II (ore); 82—Shurale, 83—Nameless II, 84—Ulak (placer)

is a group of the Urtazym-Goryachevsky deposits of gold of the gold-quartz mineral type. This group is the source of placer gold.

The *Ulak placer* is located to the S from the Shurala placer field. In the sides of the Ulak river valley, the quartz-stranded gold deposits Ulak-1 and Ulak-2 are developed. Like in the Shuralinsky area, they are sources of placer gold.

A total of 374.7 kg of ore and placer gold was obtained at the Urtazym-Goryaev mine between 1877 and 1910.

Currently, the Baishevsky AMD is located within the Shuralinsky placer field. About two hundred settlement, burial, and industrial archeological sites dating from the Stone Age to the Late Middle Ages and historic times have been identified within its borders (Gusev et al. 2010).

Ancient placer gold mining operations can be identified almost only/exclusively indirectly, based on the following archaeological facts discovered during the surveys for gold (Iessen 1948):

- About 50 km N of the Baishevsky archaeological micro-district (AMD), at the Rameyev mine (located on the Sultanka river, the right tributary of the Kizil river), copper and bronze tools were found in the gold-bearing sand: an ax with eyelets and two pieces of ceramic vessels (Iessen 1948). These finds are dated to ca. the 1st millennium BC (the inventory of the former Orenburg Museum, No. 11). Additionally, traces of ancient mining of gold-bearing quartz veins were found (apparently, earlier than 1900 AD), in the form of simple scraping of metallic gold inclusions with stone tools;
- About 20 km W of the Baishevsky AMD, at the Goryaev Tanalyk mine, a copper or bronze dagger and a sickle dated to the beginning of the 1st millennium BC were found (the inventory of the former Orenburg Museum, No. 14 (Iessen 1948));
- About 95 km SE of the Baishevsky AMD, on the Suunduk River near the Kvarkeno railway station, a copper ax with two ears (a celt) was found during the extraction of gold-bearing sands. The artifact is dated to the first half of the 1st millennium BC (inventory of the former Orenburg Museum, No. 6).

According to Gusev et al. (2010), the following archaeological sites are known in the area:

- Burele-1 campsite of the late Mesolithic and Burele-2 campsite of the Neolithic;
- Ulak-1 and Ulak-2 settlements that form a single complex; they belong to the Alakul culture of the Late Bronze Age;
- The Baishevsky burial ground of the 3rd and the early 2nd millennia BC;
- The Late Bronze Age burial mounds, located to the NE of the village of Baishevo.

Due to these archaeological sites within the Baishevsky AMD, the Historical, Archaeological, and Landscape Museum-Reserve “Irendyk” was created according to the Resolution of the Cabinet of Ministers of the Republic of Bashkortostan No. 354 from November 29, 2002.

2. The survey of the paleolake and probable site locations

The Irendyk ridge sharply expands by more than 20 km in its southern closure. In 1988, in the SE part of this extension at the junction with the geomorphological area of peneplain, 7 km northeast of the village of Baishev (in the SE edge of Karyshkin), I discovered a dry Sagylkul lake, distinguished by the well-preserved coastal dikes. The lake is located directly East of the Baishevsky AMD, which potentially makes it a very attractive archaeological research polygon (Kazakov 2017).

The lake was discovered employing the complex methodology that consisted of the work in state archives and fieldwork. As a result, a dried-out lake was located while studying loose deposits of the western side of the Kizilo-Urtazym foothill depression and by deciphering aerial photographs of the 1:17.000 scale and analyzing maps of the Sagyluzyak stream valley (the left tributary of the Urtazymka River, 9 km south of the epi-Lake Kultuban). This depression looked like a sub-meridionally elongated oval measuring 5.5 × 2.3 km (Fig. 3). On a 1:50,000 topographic, the oval shape of the bottom with the elevation of 351 masl is emphasized by the 355 masl contour line.

The western side of the basin is abrasive, steep, 15 m high above the bottom, and behind the edge, it takes a slightly convex shape, which is extended 4 km to the south and is the surface of an alluvial bed of the Karasaz stream, the right tributary of the Bolshaya Urtazymka River. The top of the creek originates from the Irendyk ridge with absolute heights of individual peaks of 643 masl and 757 masl. On the plowed

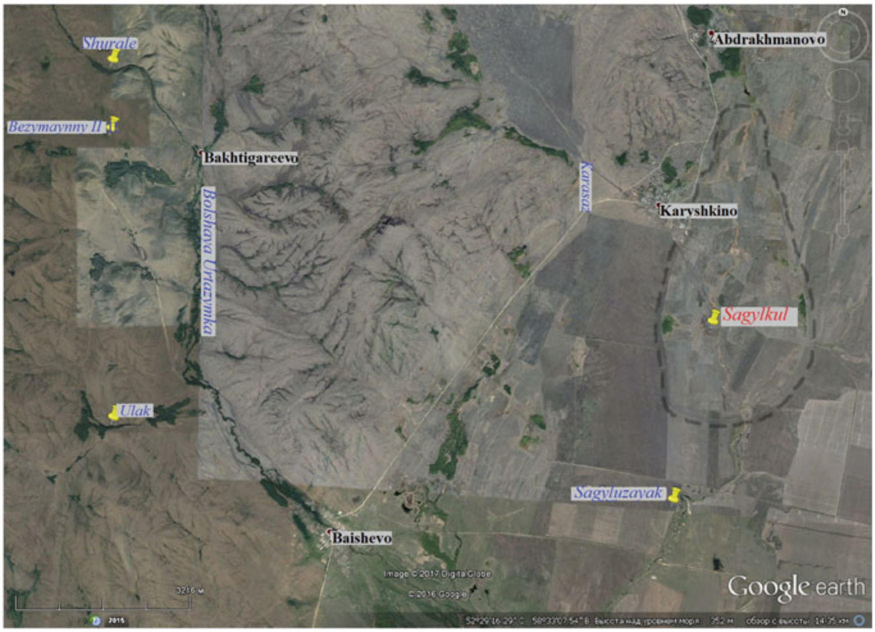

Fig. 3 The lake depression Sagylkul (named by the author) on the Google Earth satellite image

surface of the western side, there are numerous rounded pebbles and small boulders of colored jasper.

The Eastern side of the lake depression is more sloping, cut by small shallow ravines. The southern part of the lake, broken through and lowered by the Sagyluzyak stream, has a horseshoe shape, which is emphasized by a radial fold overlying Devonian age limestone. A ridge of native tuff-sandstone is observed at the break-through of the lake on the right bank of the Sagyluzyak creek. The ridge is latitudinal, 7–10 m in height, 5–12 m in width, and 350-m-long. On the opposite left bank of the stream, symmetrically ridges of bedrock were found, and three coastal lake dikes were examined. Their height ranges from 0.3–0.5 m to 1.5–2.2 m, with the width of 2 to 4 m, and the length of 20 to 50 m, with the distance between shafts of 1–3 m. The shafts are represented by poorly sorted sand-gravel material with fine and medium-rolled pebbles of polymictic composition.

In my view, the most plausible locations of archeological sites are on the banks of this large (5.2 × 2.3 km) lake, around the territory and surroundings of the village of Karyshkino. The lake was favorably located near a mountain stream from the wind-protected side of the southeastern spur of the Irendyk ridge on a terrace with a height of 360–365 m asl (5–10 m above the reconstructed water table) (Kazakov 2018).

Moreover, in 1988, as a part of the mapping of Pliocene–Quaternary deposits on a scale of 1:25000 for the local survey, the author mapped and tested for gold dikes of the lakes in the coastal zones of the Sultankul, Atavdy, and Kultuban lakes in the Baimak and Abzelilovsky districts of the Bashkir Trans-Urals. Later, gold has been found by the additional testing. Most of the surveyed lakes are residuals. They belong to the surviving fragments of the ancient river network of the Kizil and Urtazymska rivers or their tributaries within the Kizilo-Urtazym foothill depression. In the depression along the lakes, small ponds from the ancient pre-Atavdinskaya and pre-Koltubanskaya paleolakes are visible in the modern landscape (the Late Neopleistocene-Holocene). Their lake regime was established in the early Neopleistocene and existed until the first half of the middle Quaternary. The pre-Atavda lake basin can be traced to having 20 km in length with a width of up to 4 km; the pre + Koltubanskaya lake is located 15 km S of the Kultuban lake. The thickness of the lake-alluvial deposits varies from 6–13 m to 53 m. The now-dead channels connected many lakes, but some still function today. These include, for example, the Yangelka river, which flows from the lake Subakti in the Kizilo-Urtazymskaya depression.

Lake Kultuban was probably connected to the Sagylkul lake by the Sagyluzayak stream. The discovery of the coastal lake dikes in the southeastern part of the lake basin of the dry Sagylkul lake allows for identifying the climatic conditions of their development. This is possible because the lake deposits are similar in composition and morphology to those on other residual lakes, confirming their similar Late Neopleistocene-Holocene age.

The Karabalykty lake is on the northern rim of the Kizilo-Urtazym depression, 3.5 km NW of the Sabakty lake. Here, on the western shore of the lake, the Ural's oldest Upper Paleolithic site—the Mysovaya campsite—was found (Bader and

Matyushin 1973; Matyushin 1973). Mesolithic sites are also known on the Sabakty, Surtanda, and Chebarkul lakes, located south of the Mysovaya (Matyushin 1976).

Stone tools from these lake sites are made of siliceous shales, jasperoids, and siliceous tuffites. Rocks of this composition are found in the form of separate lenses, interlayers, and horizons in the volcanogenic-sedimentary strata of the Middle Devonian from the Krykty and Irendyk ridges that are adjacent from the west.

4 Conclusions

1. Regarding the Shurala placer field:

    - It was demonstrated that the Shurale, Bezymyanny II, and Ulak valleys intersect a reconstructed paleo-valley of the early Eopleistocene age. The valley is well-defined in the landscape; it is composed of variegated clays with the inclusion of well-rounded quartz pebbles; the paleo-valley is confined to the meridional zone of tectonic faults, accompanied by the gold-sulfide-quartz and sulfide mineralization;
    - The presence of well-rounded gold, along with poorly rounded gold, discovered at the late Pleistocene-Holocene placers of Shurale, Bezymyanny II, and Ulak, indicates both the proximity of indigenous sources of gold and its repeated redeposition from intermediate sediments of the paleo-valley and terrace sediments of the modern river network.

2. For Baishevsky archaeological district and, accordingly, the Historical-Archaeological and Landscape Museum-Reserve "Irendyk":

    - With the opening of the basin of the Sagylkul lake, the expansion of the Baishevsky AMD to the East is desirable, with the most probable location of ancient sites in the area of the village of Karyshkino, on the coastal terrace on the wind-protected side of the Irendyk ridge;
    - For visitors to the Museum-Reserve, an additional attraction may be the washing of gold-bearing sands of residual dumps of placer development along the Shurale stream.

The current analysis of archival and research materials on the territory of the Baishevsky AMD and residual lakes of the Kizilo-Urtazim foothill depression, the western side of which is the "Jasper belt" with numerous outcrops of multi-colored jaspers and flint-like jaspers, allows us to hope for new archaeological discoveries.

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Assessment of Excavated Volume and Labor Investment at the Novotemirsky Copper Ore Mining Site

Igor V. Chechushkov, Polina S. Ankusheva, Maksim N. Ankushev, Evgeny A. Bazhenov, and Irina P. Alaeva

Abstract In this work, we attempt to estimate the volume of excavated material at the prehistoric mining site of Novotemirsky. We gather field data and employ computer-aided modeling to reconstruct the unknown three-dimensional geometry of the copper ore quarry and calculate the volume of a vertical shaft located near the quarry. To achieve this, we create a three-dimensional model of the dump around the quarry using the photogrammetric data and the cross-sections; a three-dimensional model of the quarry using the excavation data; a three-dimensional model of the shaft. Each model allows calculating the object's volume and then estimating the amount of excavated rock. Finally, we apply the ethnographic and experimental data to calculate the labor investment and compare this estimation with the archaeological period's length. We conclude that the work could be done in a relatively short period of 2–7 years by one full-time worker. As the work most likely was collective and was stretched during some 300 years or more, the actual annual labor investments were relatively small. Perhaps, the mining work was carried out on a seasonal basis by small groups of miners.

Keywords Bronze age mining · Prehistoric metallurgy · Computer-aided design · Sintashta

1 Introduction

The Bronze Age/Early Iron Age Novotemirsky mining site is located in the south part of the Chelyabinsk region. Two objects have been identified and investigated at the site: (1) a 30 × 40 m oval quarry, surrounded on three sides by dumps of waste

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rock up to 1 m in height, and (2) a smaller Object 1 located to the SE from the quarry (Fig. 1). The multi-phase research methodology included the geophysics survey of the quarry, the aerial-photogrammetric survey, and the topographical survey, which provided data to create various surfaces and their profiles, and excavations. The latter included the five trenches across the dump, partial excavation of the quarry, and complete investigation of Object 1. As a result, various data were obtained to characterize the site's geometry, chronology, and function (Medvedeva et al. 2019).

In this work, we aim to estimate the volume of excavated rock and the amount of invested labor to assess the magnitude of annual mining operations. In turn, the necessity for complex social structures and community organization can be reasonably guessed. To achieve this goal, we aim to answer the following research questions:

1. What is the volume of Object 1?
2. What is the volume of the quarry?
3. What amount of work corresponds to the excavation of both objects?
4. How does the estimated labor investment corresponds with the site's chronology?

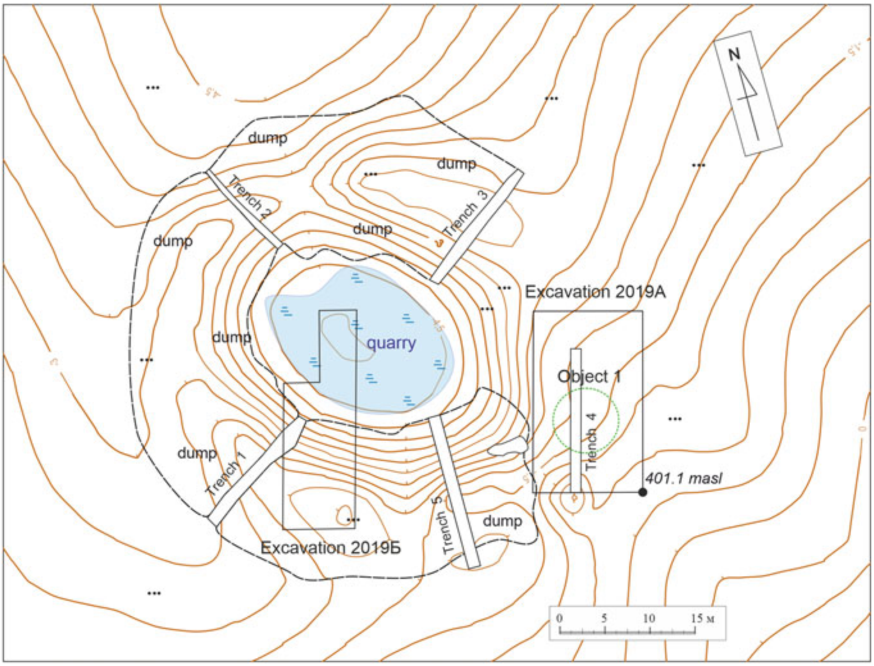

Fig. 1 The map of the Novotemirsky copper ore mining site with the principal objects indicated

2 Materials and Methods

Object 1 was excavated completely. The excavation revealed that what looked like an amorphous pit on upper horizons turns to a 2.9 × 2.3 m rectangular shaft at a depth of 2.5 m from the surface and with an overall depth of 9 m from the surface. The shaft was almost completely backfilled with wasted rock, sand, and soil. Various animal bones and ceramic sherds were found at the shaft's bottom. The cultural attribution of the ceramics allows dating the object as belonging to the Alakul' period of the Late Bronze Age (ca. 1850–1650 BCE). A fireplace was located 4 m north of Object 1. Some smelting operations took place in this fireplace, as suggested by the presence of metallurgical slag, and the ceramic sherd typology allows for the fireplace assignment to the Sintashta-Abashevo period of the Late Bronze Age (ca. 2050–1850 BCE) (Ankusheva et al. 2020).

The quarry was studied only partially. First, the five 1-m-wide trenches were located across the dump to reveal its shape and stratigraphy. The 160 m^2 excavation unit was located in the southern part of the site, covering parts of the dump and the depression. The dump is composed of crushed serpentinite, brown iron ore, rodingite, magnetite, and copper ores with layers of organic material that delineate phases of the site use. The overall thickness of the dump from the modern to the buried ancient surface is 1.6 m. The profiles provide information on the upper and lower filling of the dump, allowing for the reconstruction of the shape of the dump. The excavation unit also covered approximately 12% of the swampy depression of the quarry, allowing for obtaining data on its depth, shape, and filling. At a depth of 7.6 m from the surface, the excavation process was ceased due to the technical difficulties not reaching the quarry's bottom. At this depth, the quarry area significantly smaller resembles the shape of Object 1, which also agrees with the GPR data that show the shaft-like structure in the center of the quarry. The excavation revealed that the shaft and the lower part of the quarry were partially backfilled with the waste rock, which upper boundary is visible in the cross-section 2 m below the modern surface. The upper part of the quarry is filled with natural sediments. Animal bones and stone tools confirm the Bronze Age date of the site.

The information obtained helps estimate the total volume of excavated rock in both objects, including the unexcavated part of the quarry. We employ computer-aided modeling to determine unknown volumes of complexly shaped three-dimensional objects after gathering all information together (Fig. 2). The method's advantage is the ability to learn about a volumetric object of complex structure and reconstruct its main parameters based on the limited data.

The data to estimate the volume of excavated material in Object 1 consists of its field drawings that allow for the direct calculation of the volume. But the upper bell-shaped part still needs to be modeled.

The initial data to model the quarry are provided by the field surveys and excavation records and include: (1) the records of cross-sections of the dump around the quarry; (2) the elevation model of the quarry and the dump created from with the photogrammetric survey; (3) two cross-sections of the quarry. Their combination

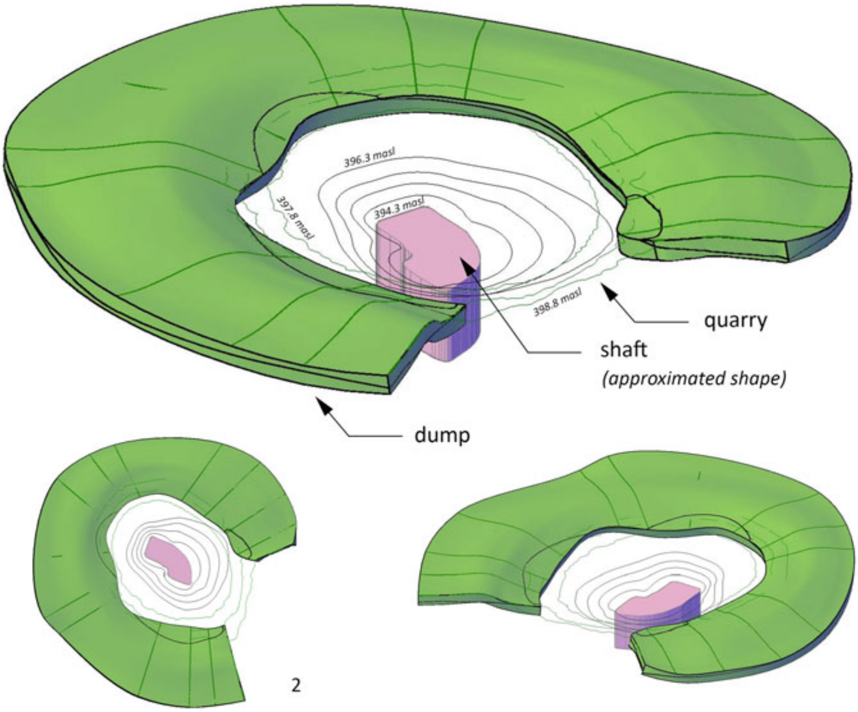

Fig. 2 The three-dimensional model of the quarry, including the dump and a reconstructed shaft: 1—the south-east view with the elevations labeled in the WGS84 elevation system; 2—the view from the top with the north up; 3—the north-east view

provides the initial data for the automated design process to calculate the object's total volume. It is important to note that the underlining assumption is that the volume of irretrievably removed rock, including the excavated ore, would not comprise a significant part of the excavated material. The exact amount of extracted ore remains unknown.

The step-by-step description of the modeling process is the following:

(1) The digital elevation model is calculated from the photogrammetry data obtained by an unmanned aerial vehicle (a drone).
(2) The thirteen upper profiles of the dump were obtained from the digital elevation model and combined with the upper limits of the five trenches. The buried soil's upper boundary marks the dump's lower boundary, and it was obtained from the profile records. These upper and lower boundaries are combined in a single volumetric space to model the dump as the three-dimensional object.
(3) The three-dimensional model of the dump is calculated using the WGS84 elevation model with the reference point at the southwestern corner of the excavation unit at Object 1 with an elevation of ~ 401.1 masl (according to the model with a 0.2 m resolution).

(4) At the quarry, the profiles revealed with the excavation unit indicate the locations of the quarry's outer limits, the upper boundary of the quarry's filling, and the shape and location of the shaft at a depth of 7 m from the present-day surface.
(5) The excavation profiles are extrapolated in four directions to the quarry's limits, and a spatial model of the quarry is calculated. Thus, the modeled shape of the quarry is an assumption. However, about 12% of its area was excavated, taken as a sufficient representation to reconstruct the whole object with computer-aided modeling.
(6) The model of the upper filling is calculated as located between the upper limit of the backfill and flattened upper surface representing the initial unexcavated surface and reconstructed from the profiles in the dump.
(7) Volume of each three-dimensional object is calculated and summed up to estimate the total volume of the quarry.

3 Results and Discussion

The volume of Object 1 calculates as following. The upper bell-shaped part measures 2.4 m in the vertical dimension (from −210 cm to −450 cm in the excavation units). The three-dimensional object of this part calculated with the upper and lower outlines corresponds to 34 m^2. The volume of the shaft from the −450 cm to −500 cm is $2.9 \times 2.2 \times 0.5 = 3.2\text{m}^2$. The volume of the shaft from −500 cm to −900 cm is $1.8 \times 2.7 \times 4 = 19.4\text{m}^2$. The total volume of Object 1 is $34 + 3.2 + 19.4 = 56.6\text{m}^2$. This number is taken as the estimation of the volume of excavated material.

The volume of the quarry is calculated as follows.

(1) The volume of the dump around the quarry is ~1025 m^3.
(2) The volume of excavated materials that comprised the volume between the reconstructed ancient surface and the upper limit of the backfill is ~660 m^3.
(3) The estimated volume of the backfill inside the quarry is ~145 m^3.
(4) The estimated volume of the quarry between the reconstructed surface and the excavation limit is ~805 m^3 (thus, $660\text{m}^3 + 145\text{m}^3$).

The unknown variable is the quarry's depth, as its excavation has not been completed. Thus, the obtained and estimated data are used to calculate its depth as following.

(1) From the estimated volume of the dump, subtract the reconstructed volume of the upper fill, as follows: $1025 - 660 = 365\text{m}^3$.
(2) From the remaining volume of the dump, subtract the volume of the backfilled dump, as follows: $365 - 145 = 220\text{m}^3$. This number is the estimated volume of the shaft's filling.
(3) Assuming that the shaft had a near-cylindrical shape, its depth can be calculated with the cylinder's volume formula:

$$V = Sh, \quad (1)$$

$$h = \frac{V}{S}, \quad (2)$$

where V is the volume of the cylinder (220 m^3); S is the cylinder base area, calculated as 45 m^2, according to the outline recorded at a depth of 7 m in the excavation unit; h is the required depth.

Substituting the data in formula (2), we reach the following estimation: $h = \frac{220}{45} = 4.9m^3$. The further application of this estimation to model the three-dimensional object shaped by the reconstructed upper outlined of the shaft, as expected, results in the same volume of 220 m^3.

Considering that the shaft's upper outline was recorded at a depth of 3.6 m from the surface, assuming that the part of excavated material is replaced by crumbling and newly-formed soil, the estimated depth of the quarry is about 8–9 m from the ancient surface. The estimated depth agrees well with the known depth of Object 1 and thus can be accepted as a reasonable assessment.

In turn, it allows us to assume that the volume of the quarry can be calculated with the estimated above numbers and follows: $\sim 660+ \sim 145+ \sim 220 =\sim 1025m^3$. While losses due to the ore extraction will remain unknown until the excavation of the quarry is completed, the number above remains the most reasonable estimation of the conducted surface mining.

The estimated volumes of the quarry and Object 1 can now be used to calculate the labor investment in mining. Ethnography and experimental archaeology indicate that soil excavation with a wooden tool produces 1.6 m^3/person-day, and granite quarrying produces 0.4 m^3/person-day (based on 7200 kg/person-day at a density of 2900 kg/m^3). As we do not know how the mining process looked like, we will use these numbers as the lower and upper limits for the estimation. The overall labor costs at the Novotemirsky mining site are calculated as follows:

(1) The total amount of excavated material is 1084 m^3.
(2) Labor investment at 1.6 m^3/person-day is 677 person-days or 1.85 years.
(3) Labor investment at 0.4 m^3/person-day: 2710 person-days or 7.4 years.

Thus, one full-time working person could spend 2–7 years conducting the excavation work, excluding the ore processing operations. These operations also took place at the site, as the fireplace near Object 1 contained a small amount of metallurgical slag and somehow contributed to the overall labor investment. The ceramic typology suggests that the site was functioning throughout the Late Bronze Age, as the Sintashta and Alakul ceramics types are encountered, and during the Early Iron Age. The Late Bronze Age period's length can be roughly determined as some 300 years during which people were conducting mining. The Early Iron Age mining episode was relatively short as the excavators have encountered only a few artifacts. Thus, in comparison with the length of the period, the labor investment is relatively small as the work was somehow stretched across the period—as even the sterile soil layers formed on top of the early dump layer, and, perhaps, conducted seasonally in a relatively small scale by small groups of miners.

4 Conclusions

The current work has helped to estimate the volume of excavated rock and demonstrated the relatively small annual scale of extraction. We have established a foundation for the future research of prehistoric metallurgy, including assessments of the amount of extracted ore and produced metal.

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Archaeological Pottery

Middle Eastern Glazed Ceramics of the 11th Century in Bilyar, the Capital of Volga Bulgaria

Svetlana I. Valiulina

Abstract This work presents the analysis of Middle Eastern artistic ceramics of the eleventh century, obtained during the excavation of the city of Bilyar (the capital of Volga Bulgaria in the 11th—first third of the thirteenth centuries) and Bilyarsky II settlement. Among the artifacts found in Eastern Europe, these items represent a rare and unique category of eastern imports. For smore complete characterization and reliable attribution, the chemical composition of glaze and clay matrix was determined using scanning electron microscopy (SEM–EDS); the mineral composition of clay matrix of most informative artifacts was identified by the X-ray phase analysis. As a result, the origin and dating of Mesopotamian luster-painted tableware and Iranian vessels of the eleventh century of the "Sari" type were established. The emergence of imported Middle Eastern artworks in the Middle Volga Regioniis evidence for the initial stage of formation of the Volga Bulgarian urban culture in the eleventh century.

Keywords Volga Bulgaria · Eleventh century · Mesopotamian luster-painted vessels · Iranian glazed ceramics · Morphological analysis · X-ray structural method · Scanning electron microscopy (SEM–EDS)

1 Introduction

Middle Eastern glazed ceramics is a source of particular interest as it allows for looking for the priority direction of economic and cultural relations of Volga Bulgaria. First of all, the example of the capital city of Bilyar is valuable. Taking into account the stratigraphy and the archaeological context, in which Middle East glass was the most significant accompanying material, the collection of the Iranian imported ceramics allows us to trace the dynamics of intercultural interaction and highlights the main stages of the development of the Bulgarian urban culture.

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The tenth century is the period of the emergence of the Volga Bulgaria state in the Middle Volga region. This period was also the apex of the silver and fur trade along the Volga Baltic way. Islam has adopted a state religion but did not fortify its positions. Cities were established only as intermediary shopping centers. Import of art products, including glazed tableware, was practically absent.

In the eleventh century, Islam fortified its positions all over the territory of Volga Bulgaria, according to the historic sources as well the funeral rituals; it was a period of active urban construction and the development of the urban Islamic culture. In these conditions, works of the eastern artistic craft, including glazed ceramics, become popular. The most vivid examples are an Iraqi luster-painted bowl and Iranian "Sari" type ceramics.

2 Methods and Materials

A morphological and stylistic analysis based on a wide range of analogies was carried out to study Mesopotamian luster-painted tableware which is unique for European and Iranian vessels of the eleventh century of the "Sari" type ceramics.

The physical characteristics of the vessels are the mineral and phase composition of clay matrix and non-plastic inclusion (stabilizer), the firing temperature was identified by the X-ray structural method. Body analysis includes the mineralogical characterization by X-ray diffraction (XRD). The mineralogy of body sherds has been studied by XRD directly on the fragments, without powder sampling, using a D8 ADVANCE (Bruker Axs) diffractometer with a Göble mirror, with radiation from a copper anti-cathode, with a wavelength of 0.154178 nm, and diffraction angles of 2θ = 3° to 40° explored with 0.02° scan steps and 2 s integration time. X-ray diffraction determines the initial mineral composition of the sample, and the phase composition, i.e., the phase transformations of minerals during the firing process under the influence of high temperatures and the atmosphere in the furnace. Knowing the temperature behavior of transformations, such as the temperatures of calcite decomposition, the formation of quartz, the formation of tridymite and cristobalite, etc., the firing temperature of pots can be determined.

The chemical composition of the glaze and clay matrix was determined by scanning electron microscopy (SEM–EDS) on the Carl Zeiss EVO 50 instruments with an X-ray spectral microanalyzer (Bruker EDS). The studies were carried out at accelerating voltages of 20 kV to increase the sensitivity of such elements as Pb, Sn, Sb, As, Ba. The current mode was varied in the range from 5 to 12 nA for a better locality/analysis speed ratio. The microscope imaging mode is backscattered electrons (BSE). This mode makes it possible to distinguish as accurately as possible the phase composition in samples (layers, inclusions).

Data on quantitative and qualitative analyses are presented in the form of oxides to process the experimental data and find the composition directly in the course of measurements. We have used a calculation algorithm based on the ZAF model scheme, which takes into account corrections for the emerging effects of generation and absorption of characteristic X-ray radiation, as well as for fluorescence from the X-ray radiation bremsstrahlung spectrum.

The earliest and most informative finds came from pre-Mongol Bilyar of the 11th—first third of the thirteenth century. In the central part of the inner city, fragments of pottery with luster paintings were found, belonging to the same vessel: a wide-open bowl, about 21 cm in diameter with a 2.2 cm wide rim, which was horizontally bent outward (Fig. 1, *2*).

The remaining fragments do not provide information on the structure of the bottom. Usually, such vessels had a ring base, and the total height of the item could be 5–6 cm. The bowl was made of dense light yellow clay with rare inclusions of detrital albite, the wall thickness reached 0.8 cm, and the surface was covered with opaque white glaze and richly decorated with olive-green luster. On the edge of there is a chain of semi-ovals, which are more significant on the outer surface; on the inner side, their contour repeats a thin line, then a series of dots, palmettes, and simple heavy curls are sequentially located. In the center of the vessel, a large image of a bird or an animal with its paw bent at the knee, and a part of the body is visible; a white background outline is left around the figure, bounded by a thin line. The

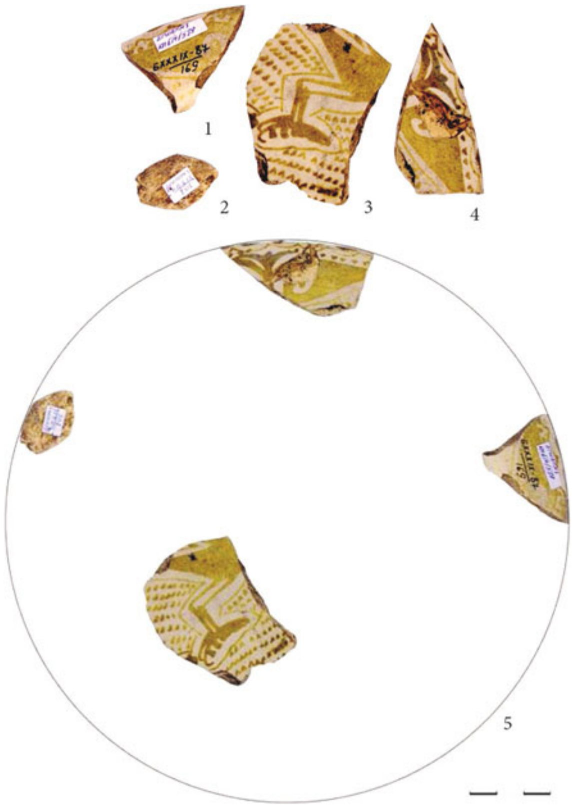


Fig. 1 The fragments and reconstructed version of Irag luster painted from Bilyar (BXXXIX/1191)

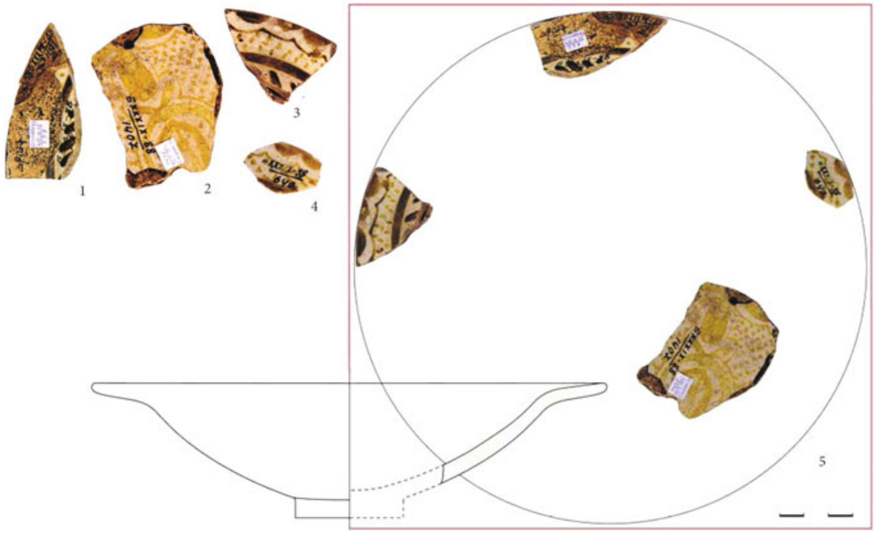


Fig. 2 The fragments and reconstructed version of Irag luster painted from Bilyar (BXXXIX/1191)

rest of the space is filled with rows of dots. If the inner side demonstrates a rather complex decoration, the outer one is simpler and standardized: along the edge, the semi-ovals are outlined with a thin line at intervals; the dots are drawn in oblique rows (2–3 each). The bend of the edge is marked by a wide strip of dense luster, under which the same luster the oblique strokes were painted. The body of the vessel was decorated with circles and almond-shaped figures, the background around them was filled with rows of dots-strokes. This part of the vessel was decorated with pale yellow-green luster (Fig. 2).

The structures from which the fragments of the Bilyar bowl came are poor in finds. The dating material is an armor-piercing arrowhead with a massive diamond-shaped combat head and a rhombic section with a neck[1]; arrowheads of this type are very typical for the eleventh century, and were widespread in the eleventh century throughout the territory of ancient Rus, in Volga Bulgaria, among the Finno-Ugric peoples of the Volga and Kama regions (Medvedev 1966).

Thus, the structures in which the fragments of the bowl were found can be approximately dated to the beginning of the first half of the eleventh century and thus are the earliest objects of Bilyar.

[1] B XXXIX-88/1353, BGIAMZ: КP.615/806.

3 Results and Discussion

Technological and morphological features, the decoration of the vessel, allow us to attribute it to a relatively well-known and well-studied group of the early Middle Eastern lusters. The scheme of the ornamental composition of the luster painting is characterized by a stable combination of typical elements: a semicircle-tympanum along the rim, a concentric composition with a large central image, which usually looks like a decorative floral subject, and, more often, so-called "figurative" elements that include the man's figure (the standard-bearer, the dancer, the musician) (Miroudot 2008; Atil 1973; Rante 2012) or the animal (the hare, the gazelle, the elephant, the donkey, the camel), or the bird in a white outline on a dotted background (Catalog 2007). The dotted background of luster bowls of this type is compared either with the texture of woven textiles (Watson 2004) or with the basis of metal products decorated with chasing (Feherwari 2000). Birds are perhaps the most common objects for luster painting (Watson 2004: 193; Kühnel 1970; Feherwari 2000). Around the image, there is almost always a narrow white outline, like a shadow, which is usually the main element of the composition. In some cases, instead of a contour, a white background without dotted filling fills the space around the central figure, as in an exquisite Iraqi Xth century bowl (Miroudot 2008). Low bowls with a diameter of 12.5–27 cm were made in a similar style, with a straight side bent outward, placed on a small ring base.

With an obvious decorative and morphological unity, at present, researchers clearly distinguish two artistic and craft centers for the production of such tableware on the territory of modern Egypt and Iraq. Also, the dynamic of its development from the 9th to the beginning of the eleventh century has been demonstrated. The names of the leading masters of the early Fatimid period are known from the signed items: Ibrahim, Muslim, and Baytar (Feherwari 2000).

The earliest artifacts date back to the ninth century. Usually, a bowl from the collection of David in the Copenhagen Museum is given as an example; and Iraq is named as the place of its production in the catalog. A similar vessel in the collection in the Museum Tareq Rajab of G. Fehervari refers to the early Fatimid production, considering the Egyptian pre-Islamic 6th—seventh centuries vessels of the identical shape with brownish-yellow glaze to be prototypes of early lusters. Also, the presence of glaze on the ring base is cited as a defining feature of Egyptian products, while the ring base of Iraqi vessels was not covered with glaze (Feherwari 2000).

According to Fehervari (2000), Fatimid and Abbasid vessels with luster painting have other differences, first of all, the base material: fragile, crumbling faience (frittware, stone paste) in Egypt and light yellow dense clay in Iraq; polychrome luster accompanied with yellow-green complemented by red-brown luster on outer sides of vessels in Egypt, and monochrome luster in Iraq. Due to the high cost and labor intensity, it is likely that polychrome lusters were produced in Egypt for a short time: in the second half of the ninth century (Feherwari 2000). Abbasid vessels also had polychrome paintings. The works of Samarra, Basra, and Susa were polychrome at the beginning of production and became monochrome during the tenth century

(Rio et al. 2010). The ornamentation of Iraqi vessels is characterized by the depiction of almond-shaped figures (Feherwari 2000). In Egyptian chandeliers, epigraphic elements are often present as an integral part of the ornament. According to Khalili (2008), the "figurative" style of images on early luster bowls was deeply rooted and continued the traditions of the fine Egyptian arts in the design of wall panels and pre-Islamic glaze was determinedceramics. The emergence of the "figurative" style is now attributed to the tenth century.

In Iraq, Basra is one of the likely places for the production of such dishes in the tenth century. Thus, the origin of two bowls of the 10th—early eleventh centuries in the Victoria and Albert Museum was attributed (Nos. C. 350–1930; C. 62–1981).

A wonderful bowl in the collection of the Museum of History of Armenia (Inv. No 2040–145) can be considered as an example of the interaction of two art schools—Mesopotamian and Egyptian. The bowl was found in the layer of the ninth century, in the central quarter of Dvin (Dzhanpoladyan and Kalantaryan 1988). The vessel is 26 cm in diameter and 7 cm in height and is decorated with monochrome luster; in the center of the composition, there is an image of a bird; on the outer side, on a glazed ring base, there is an inscription "Made by Taha" written in the Kufic script. The character of the font and the name of the master allow us to attribute it to it a Tulunid Egypt (Zhamkochyan 2009). The problem of locating the emergence place of the ceramics luster painting technique (Egypt vs Mesopotamia) remains unsolved. Meanwhile, the fact of the appearance of such dishes at the beginning of the ninth century for the elite use is recognized as eloquently evidenced by their findings in palace complexes of eastern cities and rare presence in any other contexts. For several centuries, luster-painted tableware retained its status as tableware for aristocratic feasts (Sciau 2012).

Comparing the source material for the production of luster-painted tableware in Egypt and Mesopotamia, Watson (2004) has demonstrated obvious advantages of so-called Basra clay, from which Abbasid chandeliers were made. This clay in its natural state is relatively pure and free from contaminants, does not require much effort and innovation in preparation for use, and is an excellent material for the manufacture of products of various volumes and pale yellow color. Unlike the Mesopotamian potters, the Egyptian potters had to spend time and effort mixing different materials and adding special fillers in their clay to achieve high-quality products (Watson 2004).

In Iran, the imitations of such dishes were produced (Watson 2004; Khalili 2008; Curatola 2007). The finds of early polychrome and monochrome luster products in Nishapur, obtained as a result of archaeological excavations by an expedition of the Metropolitan Museum, are considered to be imports from Egypt and Iraq (Wilkinson 1973). As an illustration, a bowl from the collection of the Tareq Rajab Museum, painted with olive-green glaze imitating monochrome lusters, can be used (Feherwari 2000). According to Fehervari, although the potters of Nishapur did not know the secret of painting lusters, given the huge interest and demand for such products, they made every effort to imitate both polychrome and monochrome types of early lusters. Moreover, these bowls repeated shapes of luster vessels or shapes of Chinese products. Proceeding from the fact that today no other archaeologically known center of Iran and Central Asia has yielded similar imitations of luster, Fehervari concludes that this production was the prerogative of Nishapur workshops, and imitations date as well as original prototypes from Iraq and Egypt (Feherwari 2000).

In Central Asia, the imitation of the style of early luster painting was created with polychrome glazes on the clay basis (Shishkina 1986; Brusenko 1986). In this way, bowls and jugs were decorated, for example, a jug of the tenth century from Afrasiab in the Hermitage collection (Curatola 2007).

The analytical results of the luster ceramics from Medina al-Zahr turned out to be especially important to reveal the technological characteristics of the Bilyar bowl. This city in Spanish Cordoba lived for a short period from 936 to 1013 AD. However, the excavation yielded a rich collection of luster ceramics and the composition of sherds reflects the dynamics of production, the origin of imports, and peculiarities of the technology. The informative possibilities of luster paintings products were fully realized through the use of a wide range of modern analytical methods, which are capable of solving the problems of technological reconstructions at the level of nanometric measurements (Rio et al. 2010).

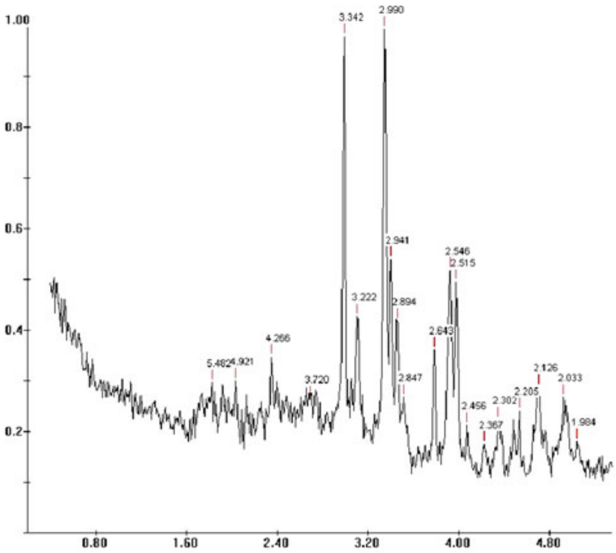
The mineral composition of clay of the Bilyar luster-pained bowl was determined by the x-ray phase analysis. The result is presented as the diffractogram (Fig. 3).

In addition to the diopside phase ($MgCaSi_2O_6$) and albite (Na [$AlSi_3O_8$]), the presence of quartz in the composition of clay is noteworthy (see Fig. 3). It would seem that this fact contradicts the general characteristics of pure and finely dispersed Mesopotamian clay, but quartz was also detected by analysis of the Mesopotamian luster in several samples from Medina al-Zahra (Del Rio et al 2010. 161). This similarity suggests that the luster-painted bowl from Bilyar, as well as the samples of the similar composition from Medina al-Zahra, were made of carefully cleaned and processed homogeneous clay, in which the prolonged firing at a temperature of 850–950 °C or close to 1000 °C (Sciau 2012: 534) caused the complete thermal transformation of paste, that resulted in the crystallization of the initially purified material. That is, the presence of quartz in the clay of the Bilyar bowl, as well as in lusterware from Medina al-Zahra, should be considered as an acquired technological feature (Del Rio et al 2010. 161).

Using the method of scanning electron microscopy (SEM–EDS), the chemical composition of glaze was determined (Table; wt %) (Table 1).

The analysis showed the use of lead-alkaline glaze, while the chemical composition in terms of the concentration of lead and tin oxides corresponds to the composition of the glaze products produced in the Iraqi workshops, at the end of the period of the appearance of luster decor (Rio et al. 2010). It was found that the early products of the Abbasid luster had an alkaline glaze; later, lead and, in some cases, tin was introduced (Sciau 2012; Rio et al. 2010; Koval 2010). Fatimid lusters from Fustat have a higher lead content (Rio et al. 2010; Koval 2010).

The mineral and chemical composition of the base and the chemical composition of glaze of the Bilyar bowl with luster painting show that the product was made in one of the workshops of Samarra, Basra, or Susa, and later it was imported to the Middle Volga at the beginning of the eleventh century.



d, Å	Mineral	d, Å	Mineral
5,482	Albite	2,643	Diopside
4,433	Quartz	2,546	Diopside
4,266	Quartz	2,515	Diopside
3,720	Albite	2,456	Quartz
3,342	Quartz	2,367	Diopside
3,22	Albite+ Diopside	2,302	Diopside
2,990	Diopside	2,205	Diopside
2,941	Diopside	2,126	Diopside
2,894	Diopside	2,033	Diopside + Quartz
2,847	Diopside	1,984	Albite

Fig. 3 The X-ray analysis of the fragments of the Irag luster painted bowl from Bilyar (BXXXIX/1191), analysts G.M. Eskina and V.P. Morozov

Table 1 Analysis by method of scanning electron microscopic (SEM–EDS) of Mesopotamian luster-painted bovl (of the sample from Bilyar State Historical < Archaeplogical and Natural Museum-Reserve, BXXXIX-88/640 ,KP.615/805 (analysts A.A.Trifonov)

Na_2O	MgO	Al_2O3	SiO_2	P_2O_5	K_2O	CaO	Fe_2O_3	CuO	SnO_2	PbO
3.31	2.87	1.26	68.98	2.22	4.71	8.19	0.72	0.02	1.03	3.67

A sample of the Abbasid luster of the late 10th—early eleventh century should be considered as another archaeological argument for the contact existence between Volga Bulgaria during its early statehood and the Baghdad Caliphate.

In the 9th and early eleventh centuries, the vessels of Mesopotamian luster were popular on the vast territory of the Islamic culture from Spain to India (Atil 1973).

In Eastern Europe, such finds are extremely rare; at present, in addition to our bowl, two more similar examples are known: a bowl of the ninth century in Staraya Ladoga and a fragment of a dish in Sarkel, found in a 10th-century layer (Koval 2010).

The finds of early luster bowls highlight the route of their arrival to Eastern Europe along the Volga river and key points on the Volga-Baltic trade route in the 9th–eleventh centuries; at the same time, the Transcaucasia, Dvin in particular, acted as an intermediary in the movement of handicraft products and other goods from the Near and Middle East countries to the north.

A different type of Middle Eastern (Iranian) ceramics could have entered the Volga region through Central Asia from the southeast of the Caspian Seam and not only through the Trans-Caucasus.

The fragments of the edge and the wall of a vessel 6.0 × 5.3 cm, 0.5 cm thick (B XXIII75/2920) are from a bowl made of light red dense, fine structure clay, with polychrome painting on white engobe under colorless transparent glaze on the inner side (Fig. 4, *1*).

The nature of the decor and the analysis of the glaze allow identifying the bowl as belonging to the so-called "Sari" ceramic type. This type received its name more than a hundred years ago from the Iranian city of the same name, located on the southern coast of the Caspian Sea. The name persists, although there is no evidence for the production of such tableware in Sari. New archaeological evidence—the open production complexes—show that the likely centers of production of this type of tableware were the workshops of the city of Gurgan in the southeast of the Caspian coast (Catalog 2007) and Nishapur, the capital of Khorasan (Rante 2012).

Despite the small size of the Bilyar find, it has features typical for this group of ceramic. Typically, such vessels on a small hollow base have a conical wide-open shape with straight diverging walls (Curatola 2007), and the find shows an even continuation of the straight walls. The Bilyar fragment also possesses traditional decorative elements: a concentric rosette or a brick-red flower in a dark brown frame and a matching core are applied on a white background along the inner edge and the front side of the vessel; the dark color is accented with a chain of white dots.

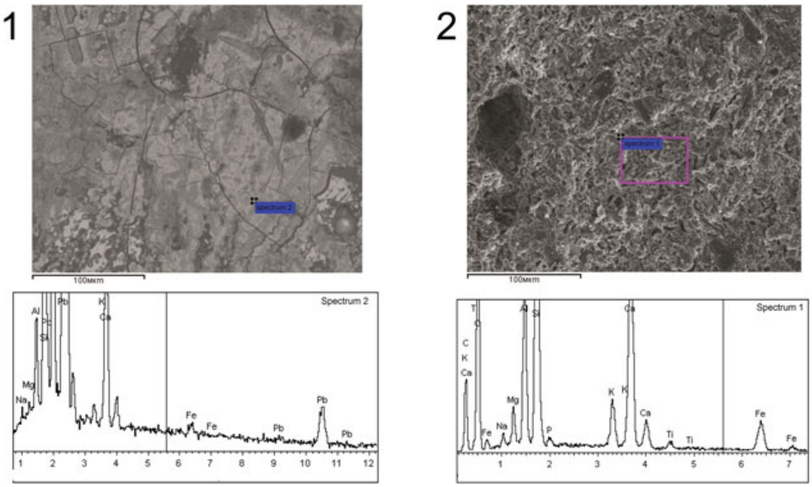
The central element of the ornamental composition of the classic "Sari" bowl was the image of a large ornate bird (Feherwari 2000; Watson 2004). Also, in other versions of the composition, round flowers with shoots or "lollipops" were complemented by stylized palm leaves, fans, and calligraphy (Watson 2004; Porter 2014). The sophisticated color scheme of the combination of dark brown, terracotta red, and white could include olive green elements (Fig. 4, *5*). The colorless transparent glaze inside did not cover the outer surface, slightly going over the outside of the edge.

For a complete characterization and reliable attribution, the chemical composition of glaze (Fig. 5, *1*) and the clay base (Fig. 5, *2*) of the fragment from Bilyar were recorded by scanning electron microscopy. The analysis showed the use of lead-silica transparent colorless glaze where lead oxide is almost 54%; the high percentages are Ca and Al compounds, with 12.13% and 3.10%, respectively; their concentration, like that of 1% iron compounds, is most likely due to the nature of sand and the result of the close location of engobe and clay base under a thin layer of glaze.

Fig. 4 Ceramic fragments of the “sari” type: 1, 4—Bilyar (BXXIII 75/2920; AKU 262/476); 2, 3—Bilyar II settlement (AKU 321/77, 78)

However, it is obvious that in the future, a representative analytical series will allow for a more accurate explanation of the result. At present, more than 30 fragments of such items have been recorded in pre-Mongolian Bilyar.

For example, a small but vivid fragment from the alchemical workshop of the late 12th-early thirteenth century in Bilyar represents a wide-open vessel: a dish made of light red clay with polychrome painting on white engobe under colorless transparent glaze (AKU262/476; Fig. 4, *3*). The contour of the drawing is made with the sgraffito technique, palmette, or a fan-shaped figure painted in terracotta brown tones on a milky white background. On the outside, the vessel had no painting and was covered with glaze only on top under the edge. By the nature of clay, the plot of the painting, and the color scale, the fragment resembles early Iranian products (tenth-eleventh centuries) (Watson 2004; Pancaroglu 2007; Porter 2014).



Element	Weight %	Atomic %	Comp. %	Formula
Na K	0.34	0.57	0.45	Na2O
Mg K	0.29	0.46	0.48	MgO
Al K	1.64	2.36	3.10	Al2O3
Si K	13.16	18.22	28.15	SiO2
K K	0.66	0.65	0.79	K2O
Ca K	8.67	8.41	12.13	CaO
Fe K	0.77	0.54	1.00	FeO
Pb M	50.04	9.39	53.90	PbO
O	24.44	59.40		
Total	100.00			

Element	Weight %	Atomic %	Comp. %	Formula
Na K	0.85	0.84	1.14	Na2O
Mg K	1.81	1.69	3.00	MgO
Al K	7.73	6.51	14.60	Al2O3
Si K	20.77	16.82	44.43	SiO2
P K	0.54	0.40	1.24	P2O5
K K	3.12	1.81	3.75	K2O
Ca K	16.39	9.30	22.94	CaO
Ti K	0.76	0.36	1.26	TiO2
Fe K	5.93	2.42	7.63	FeO
O	42.11	59.85		
Total	100.00			

Fig. 5 The chemical compositions of a ceramic fragment of "Sari" tipy from Bilyar: 1—glaze (BXXIII 75/2920), 2—clay matrix (BXXIII 75/2920) according to SEM analysis, analyst A.A. Trifonov

This item does not correspond to the time of the workshop's functioning and should probably be regarded as an accidental find due to digging and disturbance of an earlier stratigraphic layer.

At least two fragments (Fig. 4, *4*, *5*) of the "Sari" type ceramics and derived types are included in the collection of materials from the Bilyar II settlement (AKU321/77–78), located northwest of the fortifications of the pre-Mongolian Bilyar settlement (Valiulina 2016).

The settlement is reliably dated by the rich numismatic and all archaeological material between the tenth and eleventh centuries and the middle of the eleventh century (Valiulina 2019). Among other things, the collection includes two glass lamps—the examples of early Islamic pendant lamps, marked by numerous analogies from the 10th to eleventh centuries (Kröger 1995; Carboni 2001).

Iranian dishes of the "Sari" type were found in other cities of Volga Bulgaria, besides Bilyar and its surrounding areas. includingMuromski gorodok and Suvar (BGIAMZ 505–1169/228).

4 Conclusions

The considered finds of the Early Islamic glazed ceramics are interesting objects to compare with the Middle Eastern glass products (but not beads) of the tenth-eleventh century from the Bulgar cities. The earliest Middle Eastern glassworks—miniature bottles for incense, medicines, perfumes with carved and applied decor, standard weights, inkwells—are known primarily in Bolgar and, also, in Suvar.

The small quantities of produces do not allow to consider them as imports, but rather as personal items or gifts of foreign merchants or ambassadors (Valiulina 2015). The whole sparse but eloquent set of early glass products has a wide list of analogies in the materials of excavations of the Middle Eastern cities and museum collections. This opens up great opportunities in their attribution, allowing for the establishment of their origin and dating. The time of existence of these glass objects is mainly the tenth century. It is important to note that there are no synchronous imported ceramic vessels in the Middle Volga region at this time.

This fact, in the context of other Eastern imports of the tenth century to the Middle Volga region (coin silver, mainly Samanid dirhams, Middle Eastern glass beads), allows us to conclude that during the tenth century in Volga Bulgaria, the urban Muslim culture has not yet developed, and the aristocracy that would have had the need and opportunity to order and purchase expensive and fragile products far from the first necessity did not exist. One of the indicators of the development of the culture of the Muslim city is the dynamic arrival of the Eastern imports—crockery glass, lamps, and glazed ceramics in the eleventh century.

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Chemical and Technological Characteristics of Glazed Vessels from the Pottery Workshop of the Tsarevskoye Medieval City

Svetlana I. Valiulina and Sergei G. Bocharov

Abstract Glazed pottery is a vivid symbol of the Golden Horde culture. The production of glazed dishes, mosaic architectural tiles, and toys was established almost everywhere in the Golden Horde cities. The products of these workshops are currently well studied from the standpoint of the morphology of products, stylistics of decor, but practically without taking into account the data of chemical and technological analyses. Based on the results of the analysis of glaze and clay matrix of the vessels obtained by scanning electron microscopy in combination with energy dispersive spectral analysis (SEM–EDS), this article presents the results of the chemical and technological analyses of Golden Horde glazed ceramics. The materials came from the pottery workshop in the eastern suburb of Saray al-Jedid of the Tsarevskoye medieval city. The pottery workshop on Estate III worked exclusively with a lead transparent glaze of the $PbO\text{-}SiO_2$ type. The entire manufacturing process represents sustainable craft specialization and standardization of all stages of the production cycle from the selection and processing of reliable and limited raw materials and fixtures to finished products.

Keywords Golden horde · Fourteenth century · Glazed ceramics · Chemical composition · Technological characteristics · Scanning electron microscopy · Energy dispersive spectral analysis

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1 Introduction

The collections of the Archaeological Museum of the Kazan Federal University contain materials obtained during the study of the Tsarevskoye medieval city (the Volgograd region, Russia), carried out by the Volga Region Archaeological Expedition (under the leadership of G. Fedorov-Davydov) (Bocharov 2020). A team of the Kazan State University (headed by I. Vayner) excavated the site from 1963 to 1968, studying the eastern suburbs of the medieval city. The total studied urban area is about 3000 m^2. It received the provisional name "The Three Estates" (Fedorov-Davydov et al. 1974). The materials of the consolidated excavation "The Three Estates" on the territory of the eastern suburb made up the collection of the Tsarevskoye medieval city, deposited in the Kazan Federal University Museum. During the study of Estate III, two kilns for firing glazed red clay bowls and stamped (muld) ceramics were found in the adjacent territory. Kiln 1 was located 18 m south of the buildings of Estate III. The lower part of the firing chamber was preserved. The kiln was rectangular, 120 × 220 m, made of bricks. Kiln 2 was located 0.5 m from the outer side of the eastern wall of Estate III. It was built of bricks; the firing chamber retained the foundations of the three arches of the vault. The kiln had a rectangular shape; 1.20 × 3.00 m in dimensions. Disposed products from the pottery workshop were thrown into an abandoned reservoir on a neighboring estate, into irrigation ditches and utility pits. During the excavation, a large number of stove supplies, fragments of bowls with sgraffito ornaments (not covered with glaze), and kalyps (molds for pottery making) were found (Fig. 1). The authors of the excavations attributed the beginning of the functioning of the pottery workshop on Estate III to period IIIb with the date of the mid-70 s of the fourteenth century. In their opinion, the estate survived until 1395 in a state of neglect (Fedorov-Davydov et al. 1974).

This study aims to establish the recipe and chemical composition of glaze and raw clay matrix materials and to recover the mechanism of the pottery emergence.

2 Material and Methods

The analytical sample of our research was made up of workshop products, including 8 fragments of vessels and stove supplies (stands, a kalyp-matrix form), smudges, and drops of glaze. Glazed bowls made by local potters are shaped by pulling from a lump of clay (RFK-6–7). Bowl ring bases are molded and made separately. Clay is brown–red, it has medium plasticity and sand inclusions. For all samples, both glaze and clay matrix were analyzed (Table 1). A chemical-technological study of glazed glassware was carried out using scanning electron microscopy combined with energy-dispersive spectral analysis (SEM–EDS), samples were analyzed directly. The study of the samples in back-scattered electrons was carried out on a scanning electron microscope Carl Zeiss EVO 50 inconjunction with the energy dispersive X-ray spectral analysis (SEM–EDS). Samples were sprayed with a thin layer of carbon,

Fig. 1 Fragments of glazed pottery from a workshop of the Tsarevskoye medieval city

Table 1 Results of the chemical composition analysis of the glaze, engobe and clay matrix, SEM–EDS (wt%)

№/description	SiO_2	Na_2O	CaO	FeO	K_2O	Al_2O_3	MgO	SnO_2	PbO	TiO_2	Sb_2O_5	MnO	CuO
1. Stand, 64/1157, a drop of green glaze	35.18	1.35	2.05	2.95	0.66	6.54	1.67	0	47.62	0.2	0	0.02	1.14
2. Stand, 64/1157, clay matrix	50.64	3.3	6.71	8.34	3.73	17.84	4.15	0	4.28	0.83	0	0.08	0.1
3. Bowl, 68/107, green glaze	34.97	1.36	1.82	2.61	0.93	6.24	1.26	0	49.02	0.26	0.1	0.03	0.77
4. Bowl, 68/107, engobe	12.13	1.41	6.95	22.87	1.66	6.25	1.58	0.02	29.75	0.52	0.3	0.81	0.15
5. Bowl, 68/107, clay matrix	35.28	2.39	8.95	8.69	3.49	15.98	3.61	0	12.91	0.77	0	2.52	0.5
6. Bowl, 68/10, green glaze	42.73	1.37	1.41	3.72	0.82	5.92	1.27	0	41.03	0.31	0	0.03	0.83
7. Bowl, 68/10, clay matrix	55.98	3.16	8.26	6.16	3.83	17.92	3.41	0	0	0.81	0	0.11	0
8. Bowl, 68/14,engobe	38.39	1.09	6.21	8.94	1.61	9.27	1.16	0.01	27.66	0.47	0.37	0.04	0.11
9. Bowl, 68/14,yellow glaze	35.58	1.51	1.22	2.65	1.12	6.38	0.9	0	49.67	0.14	0	0.02	0.12
10. Bowl, 8/14 clay	47.48	3.38	10.68	9.24	2.93	18.11	4.78	0	1.95	0.8	0	0.15	0
11. Bowl, 86/16 green glaze	39.61	1.33	0.78	2.5	1.05	7.39	1.01	0	44.86	0.3	0	0.02	0.47
12. Bowl, 86/16, clay matrix	52.98	3.28	8.42	6.13	4.18	18.23	3.07	0	2.51	0.54	0	0.08	0
13. Bowl, 354/694, green glaze	31.27	1.08	1.27	1.26	0.21	5.1	1.21	0	56.66	0.05	0	0.03	1.2
14. Bowl, 354/694, clay matrix	48.35	2.51	10.37	9.55	2.45	16.86	4.34	0	3.5	0.9	0	0.08	0
15. Stand, 354/660, a drop of yellow glaze	33.6	0.67	0.91	3.89	0.14	3.71	0.57	0	53.56	0.11	0.02	0.01	0.25
16. Stand, 354/660, clay matrix	48.6	2.25	11.58	8.46	3.14	17.76	4.12	0	2.79	0.81	0	0.14	0
17. Kalyp-matrix form, ЦК/30, a drop of brown glaze	27.79	0.73	1.38	3.15	0.07	6.78	0.96	0	58	0.3	0	0	0.08
18. Kalyp-matrix form, ЦК/30, clay matrix	47.99	1.83	11.63	10.13	3.02	20.23	3.64	0	0	0.82	0	0.06	0

which was not taken into account in quantitative and qualitative analysis, to ensure the drainage of the charge from their surfaces. The samples were taken at a beam current of 800–1200 pA, an accelerating voltage of 20 kV, and a working distance of 20 mmfrom the front lens to the sample's surface; the signal accumulation time was 120 s. The X-ray spectral analysis was performed using the Esprit Bruker software. Correction of the readings of the energy dispersive spectrometer was carried out using the ZAF-correction program module. Each sample was analyzed by 5 spectrums, which were collected from several regions. This method ensures high accuracy for detecting major and minor (for example, dyes) elements and the elimination of point analysis brings the loss in the determination of alkali metals to the minimum. For statistical processing, the data from at least three measurements of each sample with similar indicators were taken into account. The analysis average results are presented in oxides in the maximum oxidation states, oxygen was calculated by stoichiometry (Table 1). The detection limit was 0.1–0.5%. The entire "stratigraphy" of the sherd's profile was differentiated and studied separately, with each layer analyzed by five spectra followed by the calculation of average values (see Table 1).

3 Results and Discussion

The analysis established that the pottery workshop of Estate III in the southeastern suburb of Saray al-Jedid (the Tsarevskoye medieval city) produced red clay dishes and bowls with or without engobe-engraved decor, coated with transparent, green or yellow, and brown glaze. In all spectrum, the analysis finds only one recipe for high-lead glaze double glass batch, which consisted of two glass-forming components: lead oxide varying from 41.03 to 58% with the average value is 50%, and silicon dioxide (quartz or quartz sand) varying from 27.79 to 42.73%, on average −35.09% (see Table 1). As the main source of raw materials in both glass and glazes of the $PbO\text{-}SiO_2$ type, galena (monometallic lead ore) and lead sulfide (PbS) were typically used. The pyrometallurgical technology was used to obtain the pure lead. In the process of ore roasting (oxidative roasting), lead was oxidized, sulfur was removed, and lead litharge (PbO) was formed. Further, the resulting product was crushed into powder, mixed with crushed quartz or sand, and sintered in the oven to achieve the homogeneous substance (Tite et al. 1998). It is much easier to establish what was used as a siliceous raw material in high-lead glass—quartz pebbles or sand. This is because all impurities, expressed in units of percent, got into the charge together with sand, and if their concentration was noted at the level of trace impurities, then sufficiently pure quartz was added to pure lead.

It is difficult to resolve this issue unambiguously for glaze; on the one hand, lead glaze usually has a thin covering layer. On the other hand, it has a layer of interaction between glaze and clay matrix. The nature of this diffusion layer is a reflection of almost all heat engineering processes during firing: the atmosphere and physicochemical processes in the firing chamber, temperature, firing time and cooling time, the composition of clay matrix and engobe, the presence or absence of glazeless firing, etc. In this regard, the visual-microscopic and analytical study of the vertical cleavage of the sample is important (Fig. 2, *1*).

Macro photographs of the cross-section of the sherd provide information on the interaction between the ceramic base and the overlying glaze layer (Fig. 2, *2*).

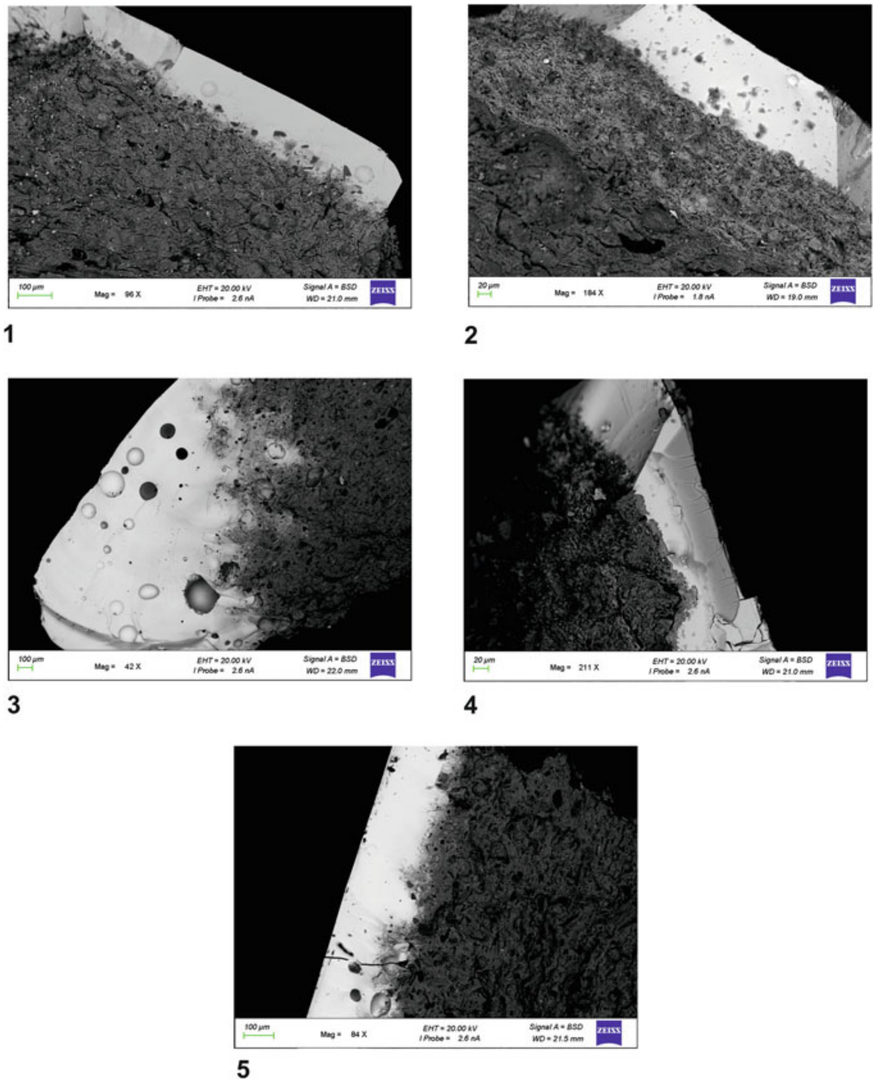

Fig. 2 Macro photos of the SEM–EDS analysis: 1—sample C 64/1157; 2—sample C 64/354–660; 3—sample C 68/10–2; 4—sample C 64/14–2; 5—sample C 68/ 16–2

The processes of diffusion between the layers are reflected in the chemical composition of the interaction zone; this process is most clearly illustrated by the samples Nos 68/107 and 354/660 (see Table 1, 3–5; 15–17; Fig. 2, *3–5*).

The width of the interaction zone in the samples of our analytical sample varies from 40 to 160 μm. At the same time, the narrowest diffusion zone was noted on the support for the firing of the vessels No. 68/10 (Table, 6–7) and on the wall of the matrix-form No. TsK/30 (Table 1, 17–18), on which random drops of glaze were recorded. The width of the lead glaze interfaces in the Tsarevskoye settlement workshop corresponds to the established parameters of the transition zones of lead glazes from other collections. It differs from the wider zones of interaction between alkaline glazes (Rehren and Yin 2012). The narrow interaction zones (usually 40–130 μm in the lead glaze samples) indicate a high melting rate of lead glass in a smaller temperature range (Rehren and Yin 2012).

The microstructure of the samples' profiles reflects the physicochemical processes during firing, including movement—the penetration of the glaze into the body. The first firing of products (without glaze) ensured the maximum removal of gases from the clay matrix, but residual gas exchange processes took place during the second firing. Macro photographs show the concentration of bubbles in the clay matrix at the border with glaze and, to a lesser extent, on the boundary layer of glaze. Closer to the surface of the glaze layer there are practically no bubbles, as well as other defects (Fig. 2, *3*, *5*). We see two opposite movements: gases from clay go into the glaze, and how glaze fills the resulting gaps. In a thin and low-melting layer of high-lead glaze, gases find a free outlet without disturbing (damaging) the smooth and even surface. Since lead glaze has a low melting point with a coefficient of thermal expansion similar to that of ceramic, cracking and flaking of this glaze is much less common than alkaline glazes (Henshaw et al. 2005). This is the situation in which we can observe o- + n our samples (see Fig. 1).

High-lead glasses are characterized by a small amount of alkali metal compounds. In our sample, there is 1.8% on average, as well as calcium oxides—1.35% and magnesium—1.10% (see Table 1). These elements, like aluminum, are primarily natural inclusions in silicon dioxide. At the same time, the glaze of all samples is distinguished by a rather high Al concentration, ranging from 3.71 to 7.39%, with the average value being 6%. The source of aluminum oxide in glaze could be the deliberate addition of clay to the batch to increase the viscosity (Tite et al. 1998; al-Saad 2002; Henshaw 2010). Saiko (1963) admits this option, relying on ethnographic data and the practice of handicraft ceramists in Central Asia. It should be borne i mind that the diffusion process also could cause the entry of these elements into glaze from the clay matrix of vessels, and calcites from engobe (Henshaw 2010).

The concentration of lead in the glass of the PbO-SiO2 type defines it as a glass-forming element, but in combination with copper oxide, it could also function as a dye in green glazes, and, being a strong flux, lowering the melting point of Si. The main dye is iron compounds (Table 1), on average 2.84%. At the same time, a lower concentration of iron compounds was sufficient to achieve the coloring effect as silicate raw materials—the sand of the Lower Volga region—contains a significant amount of iron (Kuznetsov et al. 1981).

In five samples, in addition to iron, copper average 0.88% are active dyes producing different shades of green (Table 1, 1, 3, 6, 11, 13). A high percentage of iron, especially with a low concentration of copper (0.08–0.25%), gives the glaze a yellow (Table 1, 9, 15) or brown (Table 1, 17). Copper in glaze provided color and additionally also greatly lowered the melting point (Saiko 1963).

The glaze of all eight samples is transparent: the results of the analysis show the absence of tin and antimony oxides. Neither antimony nor manganese was used as bleaching agents-clarifiers in the recipe. The analysis shows an almost uniform glaze composition, which is caused by a stable and standard technology as well as the raw materials of the narrow region of the Lower Volga region.

The results of the clay matrix analysis also demonstrate a narrow localization of values (Table 1), reflecting the general source of raw materials. The unity of the raw material base is also confirmed by the fact that there are also technical ceramics in addition to dishes in the analytical sample – stands for firing (Table 1, 1,2) and a kalyp-matrix form for making a relief ornament (Table 1: 17). Most of the clay matrix samples were taken from the area of active diffusion of the glaze and the clay matrix itself, so the analysis showed the presence of the glaze lead (on average 4.65%); this impurity is especially significant in the clay matrix of the green dish 12.91% (Table 1: 5). In this regard, a high percentage of lead oxide in two samples of engobe 29.75% and 27.66% looks natural; engobe is an interface between the glaze and the clay matrix (Table 1: 4,8). Two more samples were taken from the crock edge opposite to the glaze coating; this area did not experience the glaze diffusion process and there is no lead oxide at all (Table 1: 7, 17).

In this study, the determination of the temperature regime of glaze firing was not an original task, but we have an opportunity to assume this matter, relying on the publication of the results of studies of Islamic ceramics in other regions, which should be considered as the starting point for the beginning of the Golden Horde tradition of pottery. The melting points for Iranian alkaline glazes were determined at 800–900 °C and for Iranian lead glazes at about 650 °C (Hill 2004). In Central Asian lead glazes, the lowest calculated firing temperatures were 700–760 °C. The Tsarevskoye samples must also have similar values. During the excavation of the Tsarevskoye workshop, Guseva (1974) drew attention to the fact that the bulk of the scrap and broken products belonged to fragments of vessels without glaze, i.e. blanks that have failed the first firing, while there were incomparably fewer defective glazed items. This fact was explained by the lower temperature of the second firing (Guseva 1974). Microscopic examination of clay of the vessels showed the presence of glassy neoplasms,[1] reflecting the initial stage of the polymorphic transformation of silica into tridymite, which occurs at temperatures above 870 °C (Valiulina 2005). At the same time, there are rare carbonate grains with signs of temperature transformations, but not destroyed. Carbonates are destroyed at a temperature of 950 °C, i.e. it can be concluded that the temperature of the first firing was not higher than 900 °C.

[1] Apparently, N. Bulatov considered these formations in the clay matrix of the glazed vessels of the Selitrennoye and Tsarevskoye medieval cites to be an additive of crushed glass (Bulatov 1976).

4 Conclusion

The pottery workshop on Estate III in the eastern suburb of the Tsarevskoye medieval city worked exclusively with a lead transparent glaze of the $PbO\text{-}SiO_2$ type. The entire manufacturing process represents sustainable craft specialization and standardization of all stages of the production cycle from the selection and processing of reliable and limited raw materials and fixtures to finished products.

Based on materials from the pottery workshop, the technological characterization and expediency of the formulation of high-lead glazes of a double charge ($PbO\text{-}SiO_2$) have been described. Currently, the technological advantages of lead raw materials have been proven: such raw materials are easier to process, they are more predictable in production, glaze covers the surface with a smooth, even layer; it has a shiny surface and a clear color. All these qualities have provided a wide chronological and geographical range of the existence of high-lead glaze. The chemical and technological characteristics of the Tsarevskoye glazed pottery confirmed the affinity of the production of glazed dishes with the craft tradition of lead glazes of Central Asia. But if the formation of the technological tradition of using lead glaze in Akhsiket, Sughd, Shash, and other cities of Central Asia, was formed over 6–7 generations (Henshaw 2010), then there was no "period of apprenticeship" in the craft of the Golden Horde. Instead, it appropriated ready-made cultural and technical achievements of the conquered peoples.

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Asbestos Ceramics from Archaeological Sites of Southern Fennoscandia (Karelia): Mineralogical and Geochemical Aspects

Marianna A. Kulkova, Dmitry V. Gerasimov, Alexander M. Kulkov, Alexander M. Zhulnikov, Gleb K. Danilov, and Mikhail A. Streltsov

Abstract Pottery with asbestos fiber appeared in Eastern Finland about 4700 BC and widely spread to the North of Fennoscandia and North-Western Russia in the Late Neolithic—Eneolithic periods. In this study, we analyze the asbestos pottery sherds from Eneolithic archaeological sites of Fofanovo and Derevyannoe (ca. 3340–2935 cal BC), located on the shores of the Onega Lake (Karelia), the asbestos pieces from cultural layers and the samples of asbestos rocks from natural outcrops. Ceramic and asbestos samples were studied by pXRF and thin section analyses. The results allowe us to establish that asbestos (serpentine and chlorite) from local metamorphic outcrops (Chevzhavara) was used in the pottery from the named sites. At the Ileksa site located in the southern part of the Onega Lake, different asbestos minerals used in manufacture of the pottery were exploited from the north-western Onega Lake (the Chevzhavara outcrop) and the sources of the north-eastern Karelia. Various technological traditions relying on the use feather and plant temper coexisted at the sites located on the Eastern European Plain (e.g., Volosovo).

Keywords Asbestos pottery · pXRF analysis · Thin section analysis of ceramics · Karelia · Pottery technology · Minerals of Asbestos · Asbestos outcrops · Eneolithic sites

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1 Introduction

A tradition of using asbestos fiber as a temper for the clay appeared in Eastern Finland about 4700 BC and spread after 3600 BC, during the Late Neolithic period (the Eneolithic in the Karelian periodization), from Norway to the Archangelsk region in Russia (Carpelan 1978; Lavento and Hornytzkyj 1996; Pesonen 1996; Børslid Hop 2016; Zhulnikov et al. 2012). Asbestos ceramics were mostly found together with other types of ceramics at the settlements suggesting some special (non-technological) functions of the asbestos temper (KholkIna et al. 2020). According to the investigations of some scholars (Colomban and Kremenovic 2020), the best fracture resistance is obtained by reinforcing a ceramic matrix with long mineral fibers like asbestos. Some interesting research was published about the archaeological excavations in Corsica (Colomban and Kremenovic 2020). They have shown that asbestos-reinforced artefacts have been produced since the Middle Ages in the north-east part of the island, where there are numerous ophiolite and serpentine outcrops. Other evidence (Kakoulli et al. 2014) suggests that asbestos, a fibrous form of serpentine or amphibole was discovered and used in Cyprussince ancient times. It is also reported that asbestos fibers were added to plaster during the Middle Ages or before in Cyprus. On data of Hulthén (1991), the Early Metal Age—Medieval Age clay vessels could be used for metal production (crucibles and molds) in the regions of Finland and North Scandinavia. Both the closed porosity and the fiber reinforcement improve the mechanical properties of the pottery. But there remain questions about using asbestos in ceramics manufacture.

In Northwest Russia the occurrence of asbestos ceramics was limited by the geographic boundary stretching from the mouth of the Neva River and towards the south-eastern direction. This boundary existed since the Early Neolithic period (5000 BC). Other typologically similar elements of material culture were spread at different times on both sides from the border (Gerasimov and Kholkina 2017; Gerasimov et al. 2019).

Technological characteristics of pottery with asbestos temper were studied since the end of the 19th c. AD. Several types of asbestos pottery that belonged to the Neolithic—Bronze Age were already identified at the beginning of the twentieth century (Pälsi 1915). Early general studies of asbestos pottery, including results produced using mineralogical and geochemical analyses, allowed to define two main sources of asbestos that were used as a temper in the Finnish Neolithic Asbestos Ware (Carpelan 1978; Lavento and Hornytzkyj 1996). The analysis of the mineral composition of asbestos from the earliest pottery in the Saima Lake area in Eastern Finland showed the exploitation of anthophyllite asbestos from the Savolaks metamorphic rocks of Middle Finland. However, the more proximate sources, such as the outcrops of chrysotile asbestos (serpentine) from ultramafic serpentine rocks located near the settlements of Eastern Finland were not exploited.

The typology of Eneolithic pottery for the territory of Karelia (Fig. 1) was developed at the end of the twentieth century by Zhulnikov (1999). Three main types,

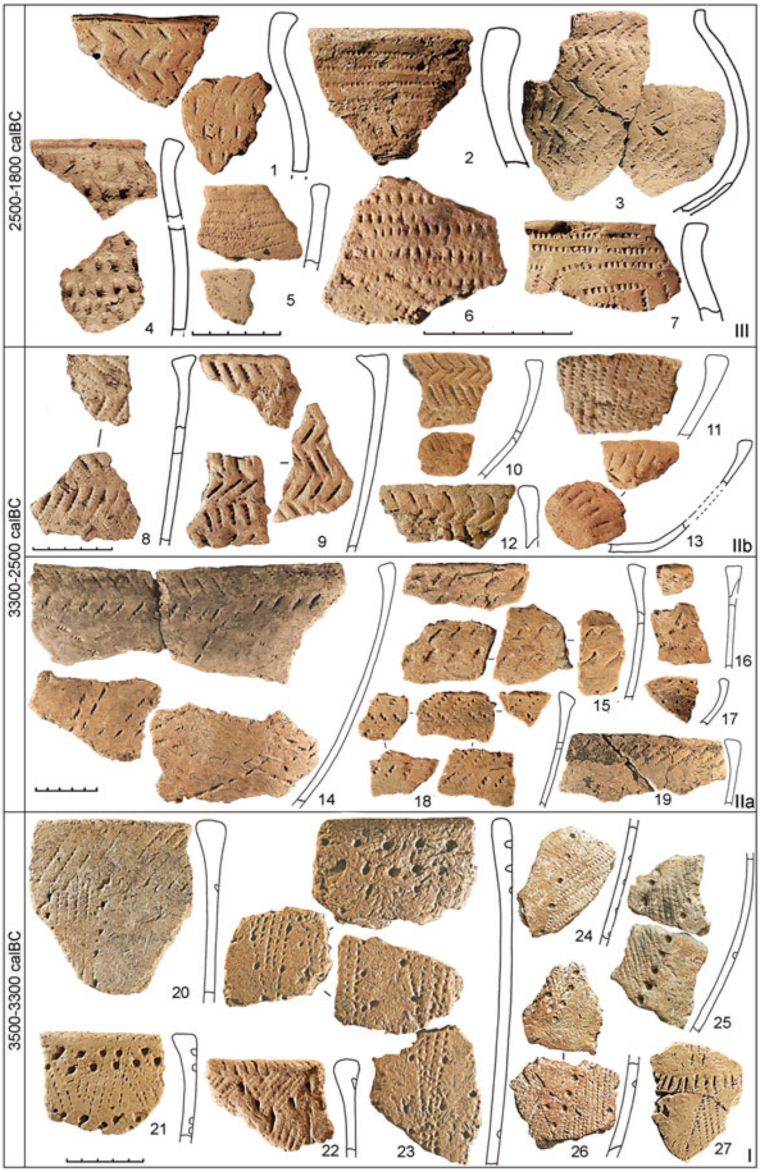

Fig. 1 The main types of pottery with asbestos in the Late Neolithic (Eneolithic) sites in the Onega and Ladoga Lakes catchments. **I**: Voynavolok type, **IIa**–**IIb**: Orovnavolok type (early and late stages), III: Palayguba type; **1**–**4** and **7**: Rozmega-2, **5** and **27**: Ileksa at the Lake Kushtozero, **6**: Derevyannoye-21, **8**, **9** and **13**: Derevyannoye-12, **10**, **11**: Derevyannoy-14, **13**: Derevyannoye-11, **14**–**26** Fofanovo-13

named according to eponymous sites—Vojnavolok, Orovnavolok, and Palayguba—were defined based on the extensive study of materials from excavations of "closed" dwelling contexts.

Voynavolok type pottery (3500–3100 BC) was made using asbestos and down/fuzz temper. Vessels are of half-egg shape with round bottoms. The main feature of the type is the ornamentation—zig-zag figures, triangles, and other geometric patterns made by comb stamps and surrounded by small dimples and two–three punch stamps (Fig. 1, *20–27*).

Orovnavolok type pottery (3300–2500 cal. BC) can be divided into the early and the late stages. The shell was used together with asbestos and feather/fuzz temper during the early phase, and disappeared during the later phase. Vessels are ornamented by: (1) oblique, sometimes intersecting rows of comb (or other) stamps, separated by empty areas; and also by (2) vertical zig-zag patterns of comb stamps (Fig. 1, *14–19*). The later pattern became dominant in the late phase (Fig. 1, *8–13*), when vessels with flat bottoms have also appeared.

The Palayguba pottery type (2500–1800 cal. BC) emerged under the influence of the Finnish Corded Ware and Upper Volga Fatyanovo cultures. Palayguba ornamentation includes rows of comb stamps of cord imitations and "cord-on-stik" or tiny comb stamps under the rim (Fig. 1, *2, 5–7*). Body of a vessel is usually ornamented by vertical or horizontal zig-zag patterns created by long comb stamps, and rows of oval dimples created by short comb stamps (Fig. 1, *1, 3–4, 6*). The vessels mainly have flat bottoms, although few miniature vessels with round bottoms were also found.

The typology of asbestos ceramics developed for the Karelian region differs from the typology of Finland, although there are some similarities and a chronological correlation between some pottery types (Zhulnikov et al. 2012; Nordqvist 2018). The typology of pottery from the Kola Peninsula was based on the typology developed for Karelia, Finland, and Northern Norway. Thin section analysis of pottery from the Kola Peninsula showed the use of actinolite asbestos as a temper (Murashkin and Carpelan 2013). For Sweden and Norway, the typology of asbestos pottery is the same as in Northern Finland, although the asbestos tradition appeared later, at the end of the Neolithic period, and existed for a longer time, until the 4th–5th c. AD (Carpelan 1978). Based on the thin section analysis, the pottery from Swedish archaeological settlements was divided into the "Asbestos pottery" type characterized by the amount of asbestos up to 50–60% and the "Asbestos Ware" type characterized by the amount of asbestos of about 90% (Stilborg 2017).

Easternmost Neolithic pottery with asbestos inclusions was found at the site of the Modlona culture in the Vologda and Arkhangelsk regions of Russia (Nedomolkina 2007). The mixture of feather, fuzz/down, and asbestos were used as a temper in the pottery of Modlona type, that has analogies with pottery of Volosovo type in the Upper Volga region. According to some authors (Krainov 1987), pottery of the Volosovo type can also contain asbestos, which is a marker of contacts with the people of Karelia and Finland.

In the final phase of the use of asbestos pottery (1st–5th c. AD), clay with asbestos temper was used for the manufacture of molds for copper metallurgy (Carpelan 1978). However, for the earlier periods, the technological advantages of vessels with asbestos temper were not obvious. There is some evidence that admixing asbestos in clay was done with a non-utilitarian purpose, especially in the early phase of this tradition (Kholkina et al. 2020).

The purpose of this study is to develop models for procurement of asbestos by prehistoric societies in the areas with and without natural asbestos outcrops, and for pottery manufacture based on mineralogical and geochemical criteria. Analyzing pottery fabrics and defining different mineral types of asbestos used as a temper allow for: (1) the identification of the natural outcrops exploited for the asbestos procurement, (2) the characterization of technological peculiarities of ancient asbestos pottery; and (3) the understanding of transformations of ancient communication networks that served for transmission of ideas and goods between remote territories of Northwest Russia and contiguous regions in different prehistoric periods.

2 Materials and Methods

Sherds of Eneolithic asbestos ceramics and pieces of asbestos rocks from cultural layers of archaeological sites were sampled for the analytical investigation (Fig. 2). Samples of Vojnavolok and Orovnavolok pottery were selected from the assemblages of the sites of Derevjannoy-12, 19, 20, from the western shore of the Lake Onega, and the site of Fofanovo-13, in the mouth of the Shuya River near Petrozavodsk. Fofanovo 13 is a famous workshop for the production of cutting tools of the

Fig. 2 The location of sampled materials. Archaeological sites: 1—Vojnavolok-7; 2—Fofanovo-7, 13; 3—Derevyannoy-7, 16, 19; 20; 4—Ileksa-on-Kushtozero; 5—Chevzhavara asbestos outcrop

Russian-Karelian type, made of local metamorphosed tuffs (Tarasov and Zobkov 2015). The archaeological context at this site is extremely rich in the products of manufacture of tools from metamorphosed tuffs and also contains a lot of asbestos pottery of the Vojnavolok and Orovnavolok types, as well as other materials like amber, copper artifacts and asbestos rocks. This context can be considered as an evidence of complex social-cultural processes associated with the development of a specific cultural union that is attested by the pottery of the Orovnavolok type. We also sampled two pieces of natural asbestos from cultural layers of the sites of Fofanovo-6 and Derevyannoe-16. Two sherds of Orovnavolok pottery were sampled from a collection of the site of Voynavolok-7 from the north-western shore of the Lake Onega. Furthermore, Voynavolok type pottery was sampled from the assemblages of the Ileksa archaeological site at the Lake Kushtozero in the Vologda region, located 100 km away from the natural asbestos outcrop.

Asbestos samples were also taken from the natural outcrop of Chevzhavara, the quarry located 3.2 km to south-west from the Padozero station (Fig. 2). The total area of the quarry is 230 m^2. The main mineral resource is gabbro diabase. The gabbro dolerites form a sloping sill (PR1 ld) which intrudes the carbonate strata of the tulomzerskaya series (PR1 jt) (Lavrov and Kuleshevich 2020). Ten samples of asbestos minerals were sampled from the veins of this outcrop.

The analyses of ceramics and asbestos minerals were performed by pXRF and thin section microscopy. The use of pXRF to analyze the composition of ancient ceramic is described elsewhere (Daszkiewicz et al. 2020). For the pXRF analysis, ceramic samples were powdered in an agate mortar and prepared using hydraulic press and boric acid into tablets. The chemical composition was determined by Olympus Vanta pXRF in mode GeohimExtra with three measurements for each sample. The average of three measurements for major elements and minor elements is provided in Table 1.

During the analysis of thin sections, we determined various characteristics of the ceramic matrix including: nature and features of aplastic inclusions (mineral composition, their percentage, content, size, shape, distribution, and orientation of different particles); textural and optical characteristics of clay matrix (birefringence, color); shape, amount and orientation of pores. The study of mineral composition of pottery fabrics (i.e., thermal transition of different mineral phases) can allow the assessment of relative firing temperature and firing condition of pottery.

Information obtained from the petrographic analysis of pottery allows to understand the choices of potters for selection and preparation of clay, moulding, firing condition, and final treatment of vessels. These data permits to understand the use of raw materials by the past communities, spatial distribution of social communications, specialization, and development of technological processes.

Thin section analysis of pottery and asbestos samples was performed using polarized microscope Leica DM4500 P with the digital camera Leica DFC 495.

Table 1 The chemical composition of ceramic samples and asbestos samples on the base of pXRF analysis (%)

Cermics and asbestos	Index	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe
Ileksa (Kushtozero)	K24	4.47	5.65	23.80	0.978	0.0000	1.47	3.14	0.33	0.018	0.000	0.134	7.52
Ileksa (Kushtozero)	K25	4.71	5.31	18.59	1.744	0.0000	1.04	2.61	0.43	0.000	0.008	0.040	4.64
Ileksa (Kushtozero)	K26	2.09	6.39	18.96	2.143	0.0000	1.81	1.72	0.58	0.000	0.000	0.055	4.72
Ileksa (Kushtozero)	K27	3.17	7.09	20.50	2.061	0.0113	1.53	1.90	0.61	0.000	0.000	0.055	4.29
Ileksa (Kushtozero)	K28	1.88	9.04	13.00	3.822	0.0071	1.65	1.91	0.58	0.000	0.000	0.089	6.29
Ileksa (Kushtozero)	K29	2.73	7.36	24.58	0.946	0.0000	2.24	1.44	0.59	0.000	0.018	0.040	4.82
Ileksa (Kushtozero)	K30	0.00	8.12	12.34	1.043	0.0922	1.43	1.13	0.47	0.008	0.000	0.061	8.12
Ileksa (Kushtozero)	K31	3.49	5.55	14.95	2.127	0.0000	1.16	1.60	0.31	0.000	0.000	0.075	6.44
Ileksa (Kushtozero)	K32	3.50	7.79	22.85	2.255	0.0000	1.81	2.38	0.55	0.000	0.000	0.077	4.82
Ileksa (Kushtozero)	K33	1.40	5.93	16.50	1.162	0.0000	1.51	0.73	0.57	0.015	0.010	0.076	5.22
Ileksa (Kushtozero)	K34	2.54	7.59	15.73	3.262	0.0000	2.20	2.32	0.47	0.019	0.000	0.084	5.14
Derevjannoe XII	K61	1.15	11.36	10.69	1.069	0.1101	0.76	0.61	0.43	0.017	0.010	0.070	7.83
Derevjannoe XII	K62	1.05	9.35	15.91	0.793	0.0476	0.87	1.03	0.39	0.007	0.018	0.064	8.25
Derevjannoe XII	K63	2.14	5.67	18.84	0.553	0.0071	1.47	0.87	0.49	0.000	0.000	0.042	6.41
Derevjannoe XX	K65	3.80	6.18	17.75	0.312	0.0000	0.98	1.65	0.36	0.018	0.009	0.079	6.26
Derevjannoe XX	K65	5.63	4.95	23.51	0.325	0.0000	0.91	1.95	0.29	0.007	0.000	0.089	5.95
Derevjannoe XIX	K66	3.30	1.35	27.50	0.093	0.0374	0.21	2.23	0.10	0.006	0.000	0.067	2.90
Derevjannoe XIX	K67	3.48	6.73	23.95	0.247	0.0283	2.62	1.50	0.38	0.000	0.007	0.074	4.69
Voinavolok VII	K68	0.00	7.85	17.04	1.469	0.0202	0.93	1.18	0.36	0.000	0.008	0.049	5.96
Voinavolok VII	K69	0.44	9.06	17.69	1.017	0.0079	1.14	1.20	0.42	0.011	0.008	0.078	7.32
Fofanovo XIII	K70	2.39	6.41	27.82	0.991	0.0000	1.62	2.62	0.48	0.014	0.000	0.107	5.94

(continued)

Table 1 (continued)

Cermics and asbestos	Index	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe
Fofanovo XIII	K71	3.50	7.52	18.45	1.467	0.0062	1.27	2.12	0.55	0.000	0.009	0.158	8.86
Fofanovo XIII	K72	4.25	5.66	18.21	1.960	0.0000	1.62	2.04	0.55	0.013	0.021	0.101	8.19
Fofanovo XIII	K73	2.41	6.63	23.84	0.819	0.0000	1.61	1.93	0.54	0.012	0.008	0.110	8.15
Fofanovo XIII	K74	3.98	4.78	18.03	2.678	0.0000	1.06	3.37	0.41	0.012	0.006	0.186	7.83
Fofanovo XIII	K75	2.79	7.41	17.88	2.913	0.0000	1.86	2.15	0.45	0.000	0.025	0.121	7.92
Fofanovo XIII	K76	2.72	6.19	25.51	0.790	0.0091	1.46	2.17	0.42	0.014	0.020	0.100	8.67
Fofanovo XIII	K77	4.60	3.90	15.80	1.588	0.0000	0.68	2.59	0.23	0.018	0.000	0.974	4.78
Fofanovo XIII	K78	1.87	4.83	15.85	2.632	0.0000	0.95	1.75	0.31	0.007	0.004	1.335	7.43
Fofanovo XIII	K79	4.33	5.22	22.99	0.328	0.0000	1.43	2.38	0.40	0.011	0.005	0.121	7.05
Chevzhavara outcrop	A01	9.06	1.90	21.95	0.23	0.00	0.021	7.63	0.021	0.00	0.0000	0.09	5.84
Chevzhavara outcrop	A02	7.02	0.59	19.05	0.00	0.02	0.000	6.23	0.027	0.02	0.0000	0.20	18.41
Chevzhavara outcrop	A03	0.60	4.69	18.38	0.13	0.00	0.078	8.27	0.183	0.01	0.0000	0.09	0.23
Chevzhavara outcrop	A04	5.66	0.08	13.06	0.00	0.00	0.000	18.82	0.164	0.01	0.0000	0.18	4.02
Chevzhavara outcrop	A05	10.74	0.89	18.18	0.11	0.00	0.000	17.64	0.081	0.01	0.0000	0.22	1.76
Fofanovo 6	A06	4.70	0.24	14.45	0.22	0.01	0.060	5.42	0.102	0.02	0.0000	0.09	6.28

(continued)

Table 1 (continued)

Cermics and asbestos	Index	Mg	Al	Si	P	S	K	Ca	Ti	V	Cr	Mn	Fe
Derevjannoe 16	A07	8.35	0.89	20.29	0.15	0.00	0.000	6.83	0.131	0.01	0.0000	0.10	8.04

Cermics and asbestos	Index	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr
Ileksa 22/90	K24	0.134	7.52	0.038	0.024	0.009	0.048	0.0000	0.000	0.010	0.030
Ileksa 20/88	K25	0.040	4.64	0.009	0.021	0.018	0.017	0.0005	0.000	0.003	0.009
Ileksa 16/84	K26	0.055	4.72	0.011	0.016	0.015	0.037	0.0009	0.000	0.008	0.014
Ileksa 21/89	K27	0.055	4.29	0.027	0.011	0.008	0.017	0.0000	0.000	0.007	0.019
Ileksa 23/91	K28	0.089	6.29	0.017	0.020	0.006	0.073	0.0003	0.001	0.008	0.017
Ileksa 15/87	K29	0.040	4.82	0.032	0.019	0.007	0.026	0.0000	0.001	0.012	0.014
Ileksa 18/86	K30	0.061	8.12	0.087	0.017	0.011	0.019	0.0028	0.000	0.009	0.016
Ileksa 19/87	K31	0.075	6.44	0.011	0.024	0.011	0.014	0.0000	0.000	0.005	0.013
Ileksa 17/85	K32	0.077	4.82	0.012	0.022	0.011	0.029	0.0005	0.001	0.009	0.020
Ileksa 24/92	K33	0.076	5.22	0.006	0.024	0.009	0.028	0.0016	0.001	0.012	0.011
Ileksa 25/93	K34	0.084	5.14	0.010	0.029	0.008	0.015	0.0004	0.001	0.007	0.018
Derevjannoe XII	K61	0.070	7.83	0.009	0.022	0.006	0.021	0.0000	0.001	0.008	0.011
Derevjannoe XII	K62	0.064	8.25	0.029	0.013	0.013	0.015	0.0000	0.001	0.010	0.011
Derevjannoe XII	K63	0.042	6.41	0.000	0.016	0.007	0.009	0.0000	0.000	0.009	0.011
Derevjannoe XX	K65	0.079	6.26	0.023	0.028	0.006	0.013	0.0003	0.000	0.005	0.007
Derevjannoe XX	K65	0.089	5.95	0.013	0.037	0.006	0.021	0.0000	0.000	0.007	0.012
Derevjannoe XIX	K66	0.067	2.90	0.007	0.032	0.002	0.006	0.0000	0.001	0.002	0.002
Derevjannoe XIX	K67	0.074	4.69	0.012	0.031	0.007	0.011	0.0000	0.001	0.018	0.014
Voinavolok VII	K68	0.049	5.96	0.026	0.007	0.011	0.015	0.0000	0.000	0.010	0.020
Voinavolok VII	K69	0.078	7.32	0.018	0.013	0.013	0.017	0.0005	0.001	0.009	0.016

(continued)

Table 1 (continued)

Cermics and asbestos	Index	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr
Fofanovo XIII	K70	0.107	5.94	0.069	0.012	0.008	0.025	0.0007	0.001	0.010	0.045
Fofanovo XIII	K71	0.158	8.86	0.008	0.024	0.014	0.051	0.0016	0.001	0.004	0.027
Fofanovo XIII	K72	0.101	8.19	0.031	0.042	0.011	0.046	0.0004	0.001	0.005	0.034
Fofanovo XIII	K73	0.110	8.15	0.061	0.019	0.013	0.016	0.0004	0.001	0.010	0.040
Fofanovo XIII	K74	0.186	7.83	0.012	0.045	0.016	0.029	0.0007	0.000	0.006	0.043
Fofanovo XIII	K75	0.121	7.92	0.029	0.020	0.013	0.047	0.0000	0.001	0.006	0.039
Fofanovo XIII	K76	0.100	8.67	0.057	0.020	0.015	0.018	0.0012	0.001	0.010	0.037
Fofanovo XIII	K77	0.974	4.78	0.000	0.027	0.013	0.032	0.0009	0.000	0.003	0.024
Fofanovo XIII	K78	1.335	7.43	0.000	0.027	0.012	0.039	0.0004	0.001	0.007	0.048
Fofanovo XIII	K79	0.121	7.05	0.042	0.026	0.041	0.034	0.0004	0.001	0.011	0.027
Chevzhavara outcrop	A01	0.09	5.84	0.013	0.020	0.002	0.015	0.0000	0.000	0.000	0.001
Chevzhavara outcrop	A02	0.20	18.41	0.000	0.028	0.010	0.022	0.0011	0.001	0.001	0.003
Chevzhavara outcrop	A03	0.09	0.23	0.008	0.006	0.004	0.006	0.1750	0.001	0.001	0.020
Chevzhavara outcrop	A04	0.18	4.02	0.013	0.007	0.006	0.011	0.0000	0.000	0.001	0.006
Chevzhavara outcrop	A05	0.22	1.76	0.000	0.005	0.021	0.015	0.0006	0.001	0.001	0.007
Fofanovo 6	A06	0.09	6.28	0.064	0.063	0.058	0.030	0.0000	0.000	0.002	0.008
Derevjannoe 16	A07	0.10	8.04	0.000	0.023	0.003	0.027	0.0000	0.001	0.001	0.002

Cermics and asbestos	Index	Y	Zr	Mo	Ag	Sn	Sb	Ba	Pb	Bi	Other elements
Ileksa 22/90	K24	0.004	0.014	0.005	0.007	0.024	0.026	0.161	0.005	0.005	53.39
Ileksa 20/88	K25	0.004	0.013	0.003	0.005	0.015	0.009	0.137	0.003	0.004	61.41
Ileksa 16/84	K26	0.004	0.020	0.003	0.006	0.014	0.016	0.375	0.003	0.000	61.80
Ileksa 21/89	K27	0.004	0.023	0.004	0.004	0.017	0.026	0.235	0.004	0.004	59.11

(continued)

Table 1 (continued)

Cermics and asbestos	Index	Y	Zr	Mo	Ag	Sn	Sb	Ba	Pb	Bi	Other elements
Ileksa 23/91	K28	0.003	0.022	0.005	0.009	0.019	0.028	0.268	0.004	0.010	62.32
Ileksa 15/87	K29	0.003	0.022	0.003	0.003	0.014	0.019	0.227	0.004	0.002	55.68
Ileksa 18/86	K30	0.004	0.016	0.004	0.006	0.019	0.026	0.278	0.003	0.002	68.08
Ileksa 19/87	K31	0.003	0.016	0.002	0.002	0.017	0.012	0.256	0.004	0.006	65.02
Ileksa 17/85	K32	0.003	0.021	0.003	0.010	0.011	0.016	0.295	0.003	0.003	54.32
Ileksa 24/92	K33	0.004	0.022	0.005	0.006	0.018	0.021	0.171	0.003	0.005	67.42
Ileksa 25/93	K34	0.003	0.016	0.003	0.005	0.022	0.018	0.203	0.002	0.005	61.18
Cermics and asbestos	Index	Y	Zr	Mo	Ag	Sn	Sb	Ba	Pb	Bi	Other elements
Ileksa 17/85	K32	0.003	0.013	0.002	0.008	0.020	0.018	0.195	0.003	0.005	66.91
Ileksa 24/92	K33	0.003	0.015	0.003	0.006	0.017	0.016	0.153	0.004	0.004	63.33
Ileksa 25/93	K34	0.002	0.012	0.002	0.003	0.008	0.014	0.142	0.003	0.008	64.38
Derevjannoe XII	K61	0.003	0.013	0.002	0.007	0.017	0.019	0.130	0.002	0.003	63.42
Derevjannoe XII	K62	0.002	0.012	0.002	0.002	0.011	0.010	0.308	0.003	0.006	56.97
Derevjannoe XII	K63	0.001	0.005	0.003	0.004	0.013	0.016	0.141	0.003	0.007	62.47
Derevjannoe XX	K65	0.003	0.015	0.003	0.006	0.009	0.019	0.080	0.004	0.005	56.87
Derevjannoe XX	K65	0.003	0.019	0.004	0.006	0.017	0.020	0.185	0.005	0.005	65.81
Derevjannoe XIX	K66	0.003	0.020	0.004	0.006	0.015	0.024	0.238	0.003	0.002	62.48
Derevjannoe XIX	K67	0.003	0.017	0.003	0.007	0.025	0.020	0.169	0.003	0.002	52.21
Voinavolok VII	K68	0.005	0.017	0.004	0.012	0.012	0.026	0.309	0.003	0.002	57.11
Voinavolok VII	K69	0.003	0.016	0.003	0.008	0.019	0.021	0.146	0.002	0.002	58.41
Fofanovo XIII	K70	0.003	0.016	0.004	0.005	0.016	0.028	0.302	0.003	0.006	54.81
Fofanovo XIII	K71	0.003	0.012	0.003	0.003	0.019	0.018	0.313	0.002	0.003	58.48

(continued)

Table 1 (continued)

Cermics and asbestos	Index	Y	Zr	Mo	Ag	Sn	Sb	Ba	Pb	Bi	Other elements
Fofanovo XIII	K72	0.004	0.018	0.003	0.005	0.012	0.017	0.374	0.003	0.004	57.26
Fofanovo XIII	K73	0.003	0.011	0.003	0.008	0.014	0.019	0.354	0.002	0.006	52.86
Fofanovo XIII	K74	0.001	0.009	0.003	0.006	0.011	0.017	0.182	0.001	0.007	65.34
Fofanovo XIII	K75	0.004	0.015	0.003	0.003	0.016	0.019	0.225	0.002	0.006	63.90
Fofanovo XIII	K76	0.002	0.011	0.003	0.003	0.019	0.023	0.106	0.003	0.003	56.60
Fofanovo XIII	K77	0.003	0.013	0.002	0.008	0.020	0.018	0.195	0.003	0.005	66.91
Fofanovo XIII	K78	0.003	0.015	0.003	0.006	0.017	0.016	0.153	0.004	0.004	63.33
Fofanovo XIII	K79	0.002	0.012	0.002	0.003	0.008	0.014	0.142	0.003	0.008	64.38
Chevzhavara outcrop	A01	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.001	0.000	54.22
Chevzhavara outcrop	A02	0.003	0.004	0.006	0.014	0.013	0.023	0.176	0.002	0.006	51.31
Chevzhavara outcrop	A03	0.003	0.006	0.003	0.010	0.010	0.025	0.154	0.008	0.003	66.93
Chevzhavara outcrop	A04	0.004	0.004	0.005	0.009	0.027	0.024	0.045	0.004	0.000	58.52
Chevzhavara outcrop	A05	0.003	0.003	0.003	0.005	0.017	0.012	0.249	0.001	0.007	50.31
Fofanovo 6	A06	0.004	0.005	0.005	0.011	0.030	0.042	0.198	0.005	0.000	68.97
Derevjannoe 16	A07	0.003	0.004	0.004	0.006	0.014	0.013	0.151	0.003	0.005	56.35

3 Results and Discussion

The chemical composition of 37 samples of ceramics and asbestos is provided in Table 1. A visualization of the compositional characteristics in the ternary Si- (Al + Mg)—(K + Ca + P) diagram is presented in Fig. 3. It is necessary to note that the firing temperatures were low therefore any groups based on ceramic properties like sintering cannot be determined.

The chemical compositional data for pottery was subject to statistical processing using Statistica 10 software. The correlation analysis allows determining the correlations between chemical elements which reflects the mineral composition. Using PCA, some groups of ceramic samples having similar chemical and mineral composition can be identified. The results of PCA are provided in Fig. 5.

The correlation analysis of asbestos allows to differentiate various asbestos minerals based on their chemical composition. Three groups of samples were distinguished (Fig. 5).

Group 1—includes the samples from the Chevzhavara quarry (A01, A02, A04, A05) and Derevjannoe-16 (A07). These samples are enriched in Mg, Se, Zn, Fe, S.

Group 2—the sample from the Chevzhavara quarry (A03). It is characterized by high concentrations of Al, As, Ti, K, Sb, Pb.

Group 3—the sample from Fofanovo-6 (A06). This sample is characterized by high concentrations of K, Co, Zr, Zn, Fe, S.

The sample of asbestos (A07) from Derevyannoe-16 is represented by ferruginous serpentine, as identified by the thin section analysis. The asbestos samples from the Chevzhavara quarry has varying mineral composition. Most of the samples (A01, A02, A04, A05) consist of serpentine with tiny inclusions of olivine or sillimanite, and carbonates. An exception is sample A03 which consists of chlorite phyllite and carbonates. Thin section analysis of sample (A06) from Fofanovo shows that asbestos consists of serpentine (Fig. 4).

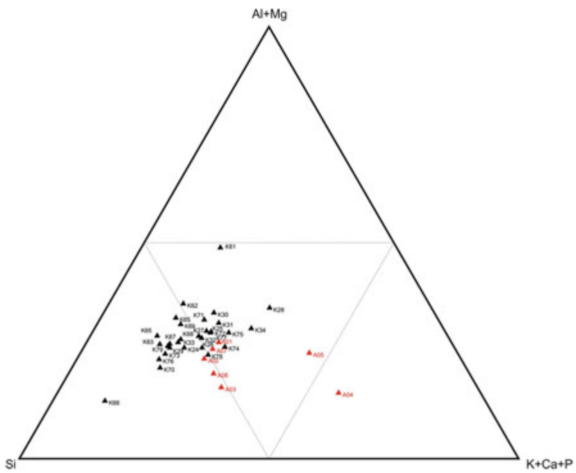

Fig. 3 The distribution of samples on the base of the ternary Si- (Al + Mg)—(K + Ca + P)

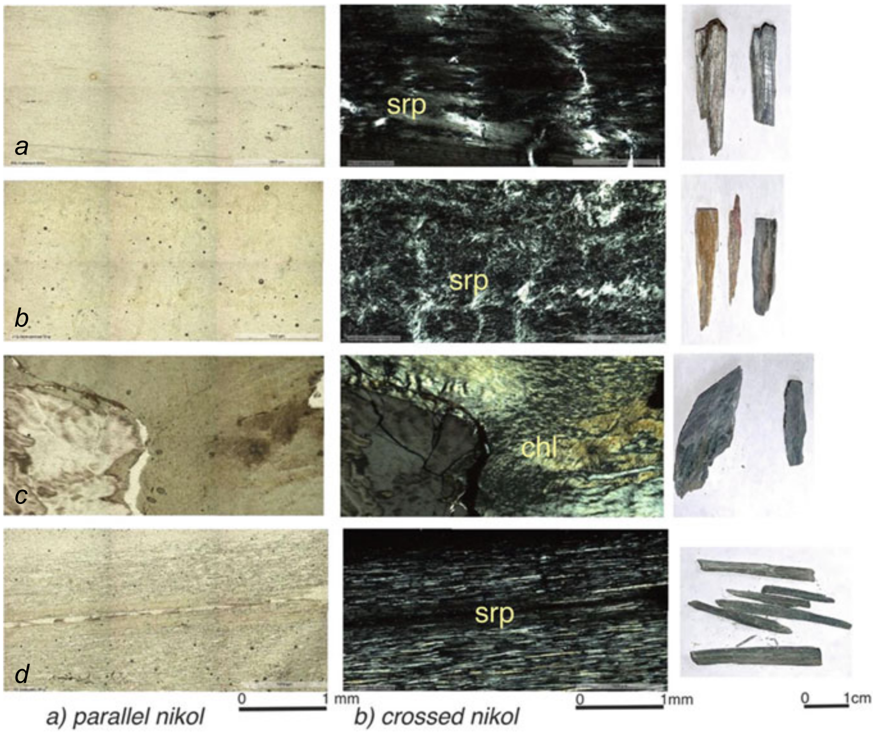

Fig. 4 Thin section microstructures of asbestos: **a** Fofanovo-6 site (A06); **b** Derevjannoe-16 site (A07); **c** sample from the Chevzhavara quarry (A03); **d** sample from the Chevzhavara quarry (A02)

The correlation and PC analyses (Fig. 5) allow dividing the collection of asbestos ceramics by the site, into several groups (Fig. 5). The first factor (F1) shows the anticorrelation between the groups of elements (Al, Ti, Zr, Y), and (Mg, Ni, Ca). This is also evidenced from chlorite and serpentine being the main mineral components of the samples. The formula of the second factor (F2) is (Ca, Sr, P, Mg)/(S, Pb, Rb, Sb, Zn). This formula shows the ratio of elements associated with carbonate minerals to elements associated with sulfide minerals. According to Factor 2, ceramic groups attesting to particular sites can be identified.

Group I—ceramics from Fofanovo. These ceramics is characterized by high contents of Ca, Sr, P, Mg.

Group II—ceramics from the sites of Derevyannoe and Voinavolok. This ceramics is characterized by high content of S, Rb, Pb, Sb, Zn.

Group III—ceramics from the Ileksa 1 site plots between samples from the sites of Fofanovo and Darevjanoe. This pottery is enriched in Al, Ti, Zr, Mg, Rb, S, Ca, Zn.

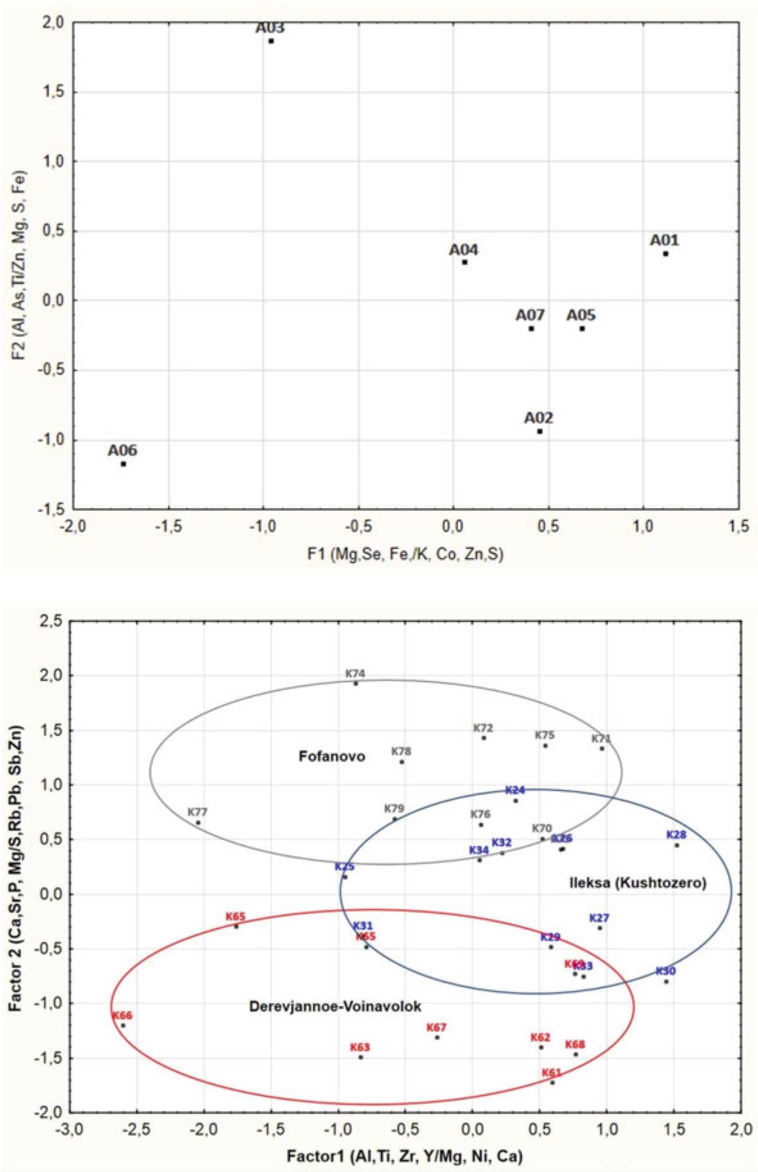

Fig. 5 Factor analysis based on the chemical composition of asbestos (**a**) and ceramic (**b**) samples

Thin section analysis of ceramics

Several groups were determined based on the composition of ceramic matrix and temper (Fig. 6).

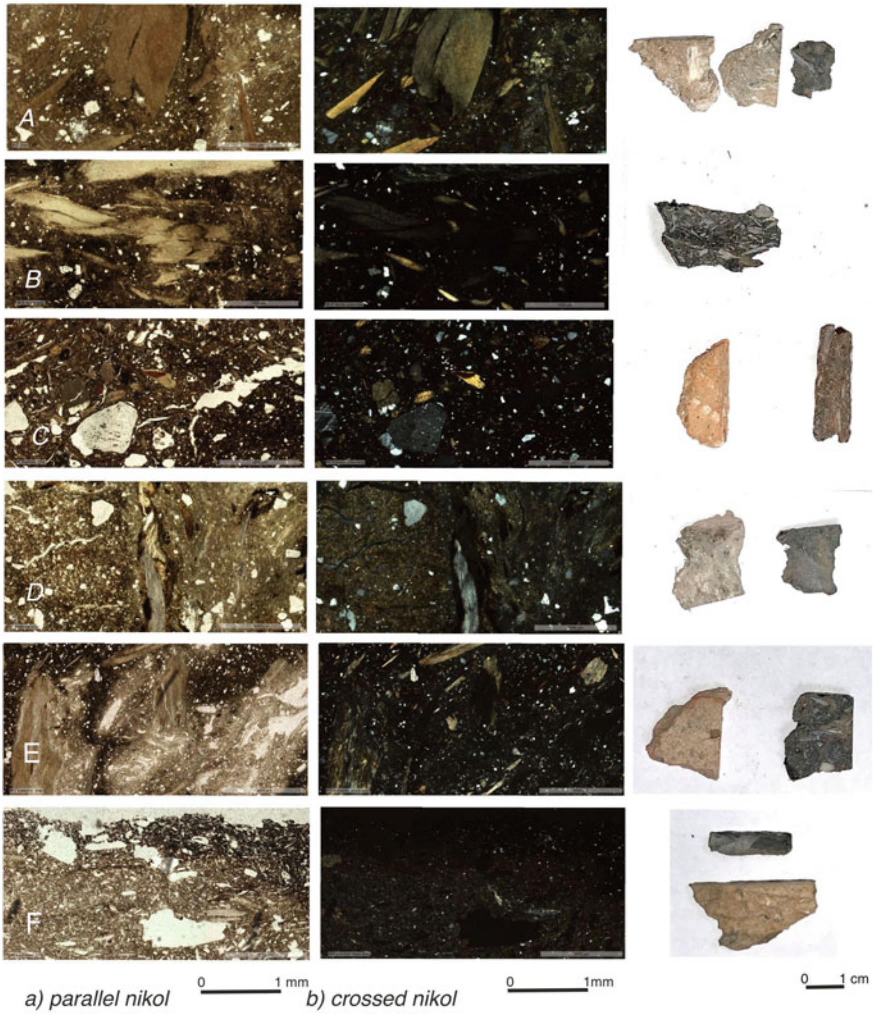

Fig. 6 Ceramics groups based on thin section analysis: **A** Group 1. Temper consists of crushed metamorphic rocks and sand (Fofanovo-13, the Voinavolok type); **B** Group 2. Temper consists of crushed metamorphic rocks (Fofanovo-13, the Voinavolok type; **C** Group 3. Temper consists of crushed metamorphic rocks and crushed intrusive rocks (Fofanovo-13, the Voinavolok type); **D** Group 4. Temper consists of crushed metamorphic rocks, sand and grog (Fofanovo-13, the Voinavolok type); **E** Group 5.1. Temper consists of crushed metamorphic rocks and feather (Ileksa, the Voinavolok type); **F** Group 6. Temper consists of crushed metamorphic rocks and cut plant (Ileksa, the Voinavolok type)

Group 1. Temper consists of crushed metamorphic rocks and sand [the ceramics from the site of Fofanovo-13, the Voinavolok style (5 samples), the Derevyannoe site, the Palayguba style (2 samples), the Orovnavolok style (5 samples), the Ileksa 1 site, the Voinavolok style (3 samples), the Voinavolok site (1 sample)].

Ceramic samples were produced from chlorite-hydromica clay. Clastic material comprises about 25%. The mineral composition of clastic material is plagioclase, feldspar, mica. Temper consists of: (1) crushed metamorphic rocks, serpentine and chlorite (25%) characterized by fragment size 1.5–5 mm; (2) sand (7%) consisting of plagioclase, feldspar, mica of grain size 0.28–0.5 mm. Porosity is 15–20%. The firing temperature is about 600–650 °C.

Group 2. Temper consists of crushed metamorphic rocks [the ceramics from Fofanovo-13, V the oinavolok style (2 samples)].

Ceramic samples were produced from smectite clay. Clastic material comprises about 45%. The mineral composition of clastic material is plagioclase and feldspar. Temper consists of: (1) crushed metamorphic rocks, serpentine, wollastonite and gneiss (20%) characterized by fragment size 1.5–5 mm. Porosity is 15–20%. The firing temperature is about 600–700 °C.

Ceramic samples from Ileksa-1, the Voinavolok style (2 samples) were produced from the chlorite clay. Clastic material is about 5%. The mineral composition of clastic material is plagioclase, feldspar, mica. Temper consists of: (1) crushed metamorphic rocks, anthophyllite-gedrite, chlorite, gneiss, quartzite (25%) characterized by fragment size 1.5–5 mm. Porosity is 15–20%. The firing temperature is about 650–750 °C.

Group 3. Temper consists of crushed metamorphic rocks and crushed intrusive rocks [ceramics from Fofanovo-13, the Voinavolok style (2 samples)]. Ceramic samples were was produced from the kaolinite clay; the clastic material comprises ca. 45%. The mineral composition of clastic material is plagioclase, feldspar, mica. Temper consists of: 1) crushed metamorphic rocks (serpentine, wollastonite, gneiss), crushed intrusive rocks (gabbro) (30%) characterized by fragment size of 1.5–5 mm. Porosity is 15–20%. The firing temperature is about 600–700 °C.

Group 4. Temper consists of crushed metamorphic rocks, sand and grog [ceramics from Fofanovo-13, the Voinavolok style (1 sample); the Derevyannoe site, the Orovnavolok style (1 sample)]. Ceramic samples were was produced from smectite-hydromica clay; the clastic material constitutes 25%. The mineral composition of clastic material is plagioclase, feldspar, mica. The pores are filled with isinglass. Temper consists of: (1) crushed metamorphic rocks, serpentine, chlorite, anthophyllite (25%) characterized by fragment size of 1.5–5 mm; (2) sand (7%) characterized by grain size of 0.28–0.5 mm, and consisting of plagioclase, feldspar and quartzite; (3) grog (7%) (i.e., crushed pottery of different composition) characterized by fragment size from 0.5 to 1 mm. Porosity is 15–20%. The firing temperature is about 600–650 °C.

Group 5. Temper is presented by crushed metamorphic rocks, sand and feather [the ceramics from Ileksa-1, the Voinavolok style (1 sample)]. Ceramic samples were produced from kaolinite-smectite clay; clastic material is about 35%. The mineral composition of clastic material is plagioclase, feldspar, mica, and chlorite. Temper additions: (1) crushed metamorphic rocks—serpentine, anthophyllite (25%) characterized by fragment size of 1.5–5 mm; (2) sand (7%), characterized by grain size of 0.28–0.5 mm, consisting of plagioclase, feldspar and quartzite; (3) feather (25%), characterized by pore size of 3–5 mm. Porosity is 15–25%. The firing temperature is about 600–650 °C.

Group 5–1. Temper is presented by crushed metamorphic rocks and feather [ceramics from Ileksa-1, the Voinavolok style (1 sample)]. Ceramic samples were produced from chlorite-hydromica clay, the clastic material is about 25%. The mineral composition of clastic material is plagioclase, feldspar, mica, chlorite. Temper consists of: (1) crushed metamorphic rocks—chlorite, anthophyllite (25%), characterized by fragment size 1.5–5 mm; (2) feather (15%), characterized by pore size 3–5 mm. Porosity is 15–25%. The firing temperature is about 700–750 °C.

Group 5–2. Temper is presented by crushed metamorphic rocks, feather, sand and grog [ceramics from the Voinavolok site, the Orovnavolok style (1 sample)]. Ceramic samples were produced from hydromica clay; the clastic material comprises ca. 25%. The mineral composition of clastic material is plagioclase, feldspar, mica, and chlorite. Temper consists of: (1) crushed metamorphic rocks—serpentine (25%), characterized by fragment size of 1.5–5 mm; (2) feather (15%), sizes characterized by pore size of 3–5 mm and porosity of 15–25%; (3) sand (12%), characterized by grain size of 0.28–0.5 mm, consisting of plagioclase and feldspar; (4) grog (5%), characterized by fragment size 0.5–0.8 mm. The firing temperature is about 600–650 °C.

Group 6. Temper consists of crushed metamorphic rocks and cut plant [ceramics from Ileksa-1, Voinavolok style (1 sample)]. Ceramic samples were produced from hydromica clay; the clastic material is about 45%. The mineral composition of clastic material is plagioclase, feldspar, mica, and chlorite. Temper additions consists of: (1) crushed metamorphic rocks—serpentine, actinolite (20%) characterized by fragment size 1.5–3 mm; (2) cut plant (23%) characterized by pore size of 1–2 mm. Porosity is 20–30%. The firing temperature is about 600–650 °C.

The geochemical and mineralogical analyses allowed to determine that asbestos from the Chevzhavara quarry (A01, A02, A04, A05) and Derevyannoe-26 (A07) consists of serpentine. This suggests that serpentine asbestos from these outcrops was used as a temper in production of pottery at the sites of Fofanovo-13 (4 samples), Derevjannoe, Voinavolok, and Ileksa-1 (3 samples).

Another type of temper was chlorite asbestos. It was extensively used for ceramic manufacture at Fofanovo-13 (6 samples), Derevjannoe (8 samples), Ileksa-1 (5 samples), and Voinavolok (1 sample). In Fig. 5, Factor 1 (F1) shows the portion of chlorite and serpentine components in ceramics samples. The increase of contents of Al, Ti, Zr and Y in the samples is a marker of increased amount of chlorite (Klimovskaya and Ivanov 2018), while high concentration of Mg, Ni and Ca indicates serpentine enrichment. The fact that most of ceramics samples plot within the field of positive values of Factor 1 on the scatter plot in Fig. 5 supports the hypothesis that chlorite asbestos from the Chevzhavara quarry (A03) was used in ceramics production. There are also samples in which both serpentine and chlorite from Chevzhavara quarry were identified.

The chemical composition of ceramics from the Fofanovo, Derevjannoe, and Ileksa sites varies by the second factor (F2) of the PCA. Group I, ceramics from the Fofanovo site, is characterized by the high concentrationы of Ca, Sr, P, Mg, which is also evidenced from the presence of carbonate-phosphate minerals in the ceramics matrix. Carbonates were also identified in asbestos rocks from the Chevzhavara quarry. The group II—ceramics with high contents of S, Rb, Pb, Sb, Zn was found at Derevjannoe and Voinavolok sites. This composition can reflect presence of sulfide phases in the matrix. It is possible, that some pottery from the site of Derevaynnoe were produced using asbestos with high sulfide content. Furthermore, sample of serpentine (A06) enriched in sulfide elements (K, Co, Zr, Zn, Fe, and S) was found at the Fofanovo 6 site. Based on Factor 2, ceramics samples from the Ileksa site plot between ceramics from Fofanovo and Dervyannoe—Voinavolok sites. Various asbestos types were probably added into the clay, which is also supported from the results of thin section analysis of ceramics.

Certain technological differences were identified between the pottery from Fofanovo, Derevjannoe, Voinavolok and Ileksa sites. The main types of temper used in production of pottery from Fofanovo and Dervjannoe were crushed metamorphic rocks and a mixture of crushed metamorphic rocks and sand. In some cases, pottery was manufactured using a mixture of crushed metamorphic rocks, sand, grog, crushed metamorphic rocks and crushed intrusive rocks. At the Ileksa-1 site, temper mostly consisted of crushed metamorphic rocks, sand and feather/cut plant. At the Voinavolok site, temper consisted of crushed metamorphic rocks, feather, sand, grog and crushed metamorphic rocks.

It is important to note that Fofanovo and Derevjannoe ceramics was produced using mainly local asbestos materials (serpentine and chlorite) from the proximate Chevzhavara outcrop. Pottery recipes were rather simple relying on the use of crushed metamorphic rocks or crushed metamorphic rocks mixed with sand. Ceramics from the Vojnavolok site located in the NE part of the Onega Lake was produced following a more complex recipe incorporating the use of metamorphic rocks, sand and also feather and grog. The site of Ileksa-1 located in the southern part of the Onega Lake, in the vicinity from the Baltic crystal shield, features a higher variety of ceramics recipes relying on the use of feathers and plant. The asbestos minerals used for pottery manufacture at this site were supplied from the Chevzhavara outcrop (NW of Onega Lake) and from the sources in the NE part of Onega Lake. Several different pottery-making traditions coexisted at the Ileksa site. The feather and plant temper were added into the clay during manufacture of pottery from Volosovo sites located on the Eastern European Plain.

4 Conclusions

Investigation of Neolithic pottery from the Onega Lake basin showed that a single local natural source of asbestos was used to obtain a temper for the pottery from the sites nearby the asbestos outcrops. This is particularly seen from the analysis of samples from the Derevjannoe and Fofanovo sites where the asbestos (serpentine and chlorite) from local metamorphic Chevzhavara outcrop was exploited. This practice was typical for the early pottery-making traditions of Finland where anthophyllite asbestos from a single outcrop was used for the making of pottery over several hundreds of years. Although fragments of other mineralogical/geochemical types of asbestos were also found at those sites, the use of these materials was generally much less common.

The use of mixed clay recipes for ceramics production reflects the interaction of different cultural traditions. An example of such a technological process can be traced at the site of Ileksa-1 where complex clay recipes, including tempters produced from a mixture of feather, grog, plant and asbestos were used. Such technologies reflect the influence of other cultures, such as the Volosovskaya. Various mineral types of asbestos were used at Ileksa-1, which suggests well-established connections between people from different regions.

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Lithic Tools and Materials

Diversity of Lithic Raw Material Types Used by the Population of the Mountain-Forest Trans-Urals (3rd–2nd Millennium BC)

Olga N. Korochkova, Ivan A. Spiridonov, Irina V. Usacheva, and Evgeny S. Shagalov

Abstract The paper considers various raw material strategies of the population of the mountain-forest Trans-Urals during the Eneolithic and Bronze Age based on the study of the artifacts from the Shaitanskoe 4–6 multilevel archaeological site. The typological, contextual, and geological analyses provide sufficient data for the confident identification of several typical lithic industry complexes attributed to various periods. One of the characteristics of the Eneolithic is a wide range of tools, including numerous knives, scrapers, woodworking tools, and arrowheads. The local craftsmen were well aware of the advantages of the local materials: coal shale, chert, greenstone, quartzite, and granite-gneiss. Stone tools assortment shrunk significantly in the Bronze Age. Most of the Bronze Age tools were made from jasper, ice quartz (silicon dioxide), quartzite, porphyry, and chert. The local people possessed extensive knowledge of local rocks and resources suitable for the production of various tools, knew the signs associated with raw materials deposits and mastered a variety of stone flaking techniques.

Keywords Ural · Archaeology · Geology · Eneolithic · Bronze age · Lithic industry · Typology

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1 Introduction

The third-second millennia BC in the mountain-forest Trans-Urals was the time of dynamic changes, high population density, the building of complicated patterns of relationships, the adoption of new adaptation and symbolic practices (interments, sacred sites, rock art). The local population's craftsmanship and woodworking skills are well known; evidence of this can be found in the numerous implements, boats, oars, skis, various types of flooring, platforms, and sculptured images discovered during the Urals peat bogs excavations (Chairkina 2005; Korochkova 2019). All those items were made exclusively with stone tools. The technological repertoire was largely shaped by the available material. In this article, we attempt to demonstrate the variety and mixed composition of the lithic industry raw material base employing an assemblage of stone tools as a case study. The study provided evidence of the high competence of the local craftsmen, as well as their skills in finding various raw materials.

The Shaitanskoe 4–6 site is located on the eastern coast of the same-name lake in the Kirovgradskii district of the Sverdlovsk region, 70 km north of the City of Ekaterinburg (Fig. 1).

The place was best known for the discovery of the ancient Bronze Age sacred site Shaitanskoe Ozero II and the religious sites of the Eneolithic on the opposite coast of the lake (Serikov 2013; Korochkova et al. 2020). The 2020 excavations season revealed a complex multilevel structure of the site. The 0.7–1 m thick cultural level contained finds of the Neolithic, Eneolithic, Bronze, and Iron ages. The longest periods of occupation occurred during the third millennium BC (the Ayat, Lipchinka, Shapkul, Shuvakish cultural type complexes) and the second millennium BC (Cherkaskul). Within the excavation pit, we discovered an Eneolithic interment with non-typical grave goods set. The interment was made in an oval pit, 1.6 × 0.56 m, oriented along the NW–SE direction and buried only 7–8 cm deep into the sterile soil. The human remains were represented by fragments of teeth in the southeastern part of the pit. The deceased was laid with his or her head pointing to the lake. The accompanying grave goods included 3 massive knives, 19 arrowheads, 1 dart, 1 adze, 8 beads, and an abrasive block.

The artifacts assemblage consisted of over 9000 items, 34% of which were made from ceramic. The stone items assemblage consisted of about 6000 items. Of that number, there were about 300 tools, and the rest consisted of production debris in the form of flakes, micro flakes, and semi-finished products. A special note should be made on the discovery of a chert zoomorphic figurine.

Fig. 1 Archaeological site Shaitanskoe 4–6 on the map of Eurasia

2 Materials and Methods

For the study of the assemblage, we are employing the means of contextual, typological, and cultural-chronological analyses, as well as the tentative geological age determination data. Our chronological complexes determination relied on the analogies with the known closed-type or single-level complexes. The raw material was identified macroscopically by the mineral composition and texture-structural characteristics of the samples. The definitions were carried out at the Ural State Mining University. Reference collections of minerals and tools that are stored in the Ural Mineralogical Museum and the Archaeological Museum of the Ural Federal University were used for comparative analysis.

3 Results and Discussion

The tentative analysis of the raw materials composition and the typology of the artifacts indicated that the assemblage consisted of roughly two major complexes that correlated with the two main stages of the site's functioning, namely, the Eneolithic and the Bronze Age.

The *Eneolithic complex* (Figs. 2 and 3) consisted of about 250 artifacts including scrapers (24), planer knives (7), push-planes (3), burins (5), reamers, axes, chisels, knives, polishers, a crowbar, borer tips, and saws. Arrowheads were represented by several types. The arrowhead assemblage (17 whole and 23 broken) mostly consists of the miniature willow-leaf or triangular points with straight, rounded, or concave base. The assemblage also contained some original items, e.g. an arrowhead with a wide short stem, and a pentagonal arrowhead with a straight base. One-third of the arrowheads were made from coal shale and the remaining ones from multicolored chert.

A special set from the interment consisted of the long, narrow willow-leaf points with a straight base (Fig. 2, *8, 10, 11*). Only one arrowhead of that type was found outside of the internment (Fig. 2, *9*).

The raw materials composition of the offering complex was completely different from the rest of the assemblage. The arrowheads, dart points, and the insert tool microliths were made from the typical local coal shale, while a massive blade tool and the original arrowhead with a lengthwise crest and edge retouch were fashioned from rhyolite.

The material of three massive knives (17–20 cm long) was light brown siliceous schist from a thin silicified rock vein (Fig. 3, *6, 7*). This material is not typical for the territory. The specific type of the knives, together with the material originating, probably, came from the southern Urals region, suggesting possible ways for the reconstruction of a personal history of the deceased.

The same siliceous schist served as the material for an elegant zoomorphic figurine (Fig. 2, *13*). It is important to note, that within the cultural level we did not see any evidence of on-site manufacturing (raw material blanks, flakes) of light-brown siliceous schist items.

Based on the known analogies, a garnet disk debris (Fig. 2, *59*) and a thin quartz-peach-sericitic shale plate with engraved signs (Fig. 2, *29*) could also, with some caution, be attributed to the Eneolithic complex.

Fig. 2 Shaitanskoe 4–6. Typical tools of the Eneolithic complex

The most commonly used raw materials of the local origin were coal shale, multi-colored chert, and apovolcanic green rock. Coal shale was the preferred material for making arrowheads, knives, and reamers. Chert was used for scrapers, push-planes, and carvers. The green rock was good for high-performing chopping and wood-working tools (axes, chisels, adzes, knives, and crowbars) (Fig. 3, *1, 2, 3, 9, 13*). The local craftsmen were quite familiar with the properties of the local rhyolites, aplites, and shales that served as the material for scrapers, knives, and push-planes. For the

Fig. 3 Shaitanskoe 4–6. Peculiar tools of the Eneolithic complex

production of saws and large tools (hammers, polishers, pestles) they used granite-gneiss, gabbro, quartzite, and pegmatite (see Fig. 3). The abrasive block material was quartz-sericitic shale. The level contained a significant amount of production debris, blanks, and a few cores. The lithic debris contained numerous siliceous concretions covered with white loose weathered crust (Fig. 2, *45, 46, 48, 55, 56, 57, 61, 62, 63*). This type of concretions is typically found in redeposited placers or loose layers of the alluvial-deluvial sediments. The characteristic surface of the concretions served as an indication of the presence of siliceous rocks, the material widely used in the lithic industry of the local population.

Direct analogies to the Eneolithic tool complex can be found in the Eneolithic burial sites of the Ural and Western Siberia (Matveev et al. 2015; Chairkina 2011; Zakh et al. 1991; 2005).

Fig. 4 Shaitanskoe 4–6. Specific tools of the Bronze Age complex

The Bronze Age complex (Fig. 4) was represented by scrapers (13), knives (16), push-planes (16), a borer, and arrowheads (8). The material of triangular arrowheads with a straight or slightly concave base was gray-green jasper (Fig. 4, *4–11*). Similar items were typical for the Trans-Ural Seima-Turbino and Andronovo horizon complexes (Kosinskaya 2011; Korochkova et al. 2020; Matveev 1998). The knives and push-planes on flakes, the material for which was also mainly gray-green or red jasper, belonged to the same group of analogies. The specifics of the material provide reasons for isolating this group into an original set within the assemblage, the closest analogies to which may be found in the Bronze Age complexes. The set lacked the signs of the characteristic flaking techniques typical for the Eneolithic group. The morphogenetic pressure retouch technique was also lost. The artifacts were made mostly from jasper, ice quartz (silicon dioxide), quartzite, porphyry, and low-quality chert. The level contained numerous talcum debris, more than ten quartzite, and fine-grain aplite hones. Stratification data suggested that they belonged mostly to the Bronze Age complex.

The Bronze Age period of the site's functioning was represented with the Cherkaskul culture ceramic; thus, it would be logical to correlate the aforementioned lithic complex with that Bronze Age period. It was difficult to make more accurate attributions since there are few known examples of the lithic industry of the Cherkaskul culture. We believe that the complex will become one of the main benchmarks for the understanding of the lithic industry traditions of the Middle Trans-Ural population in the Bronze Age.

4 Conclusions

The diversity of the material types was a result of the richness of raw material sources in the mountain-forest Trans-Ural. The geological addresses of the finds mainly corresponded to rock outcrops located near the lake (within a radius of 5–50 km). At the same time, the complex contained items, the material of which was not of the local origin (250–400 km away). This correlated with the archaeological context of the internment, the items from which had no analogies in the local Eneolithic complexes.

The Eneolithic complex demonstrated a great variety of stone tools, a high level of flaking technique, and a wide range of raw materials. The items represented in the assemblage reflected various aspects of the economy related to hunting, skin dressing, butchering, and wooden and bone tools manufacturing. The mix of the raw material suggested that the local population possessed extensive knowledge of the local rock resources suitable for the production of various tools, knew the signs associated with the raw materials deposits, and mastered a variety of stone flaking techniques.

The grave goods complex may be considered evidence of the existence of a rather extensive network of information exchange contacts between various groups of the mountain-forest Trans-Ural population.

The Bronze Age complex demonstrated the use of some entirely different lithic industry strategies. The amount and the quality of stone tolls decreased noticeably. The Bronze Age stone tolls assemblage was 5 times smaller than the Eneolithic one. Coal shale and greenstone, the main raw material types for making arrowheads, knives, and massive tools, disappeared completely from the raw material assemblage. Low manufacturing quality and a visible decrease of woodworking tools number in the Bronze Age tool kit were a result of their substitution with the bronze items. The specific raw material mix (jasper, quartz, low-quality chert) may indicate poor knowledge of the available resources. Otherwise, it would be difficult to understand why the population did not use coal shale, high-quality chert, and various volcanic rocks, abundant deposits of which could be found near the Shaitanskoe Lake. The use of jasper and quartz as a preferred raw material may, with some caution, serve as an indication of the origin of the Cherkaskul culture population, which did not inherit, or lost the local Eneolithic industry traditions.

The obvious conservatism of some stone flaking traditions was evidence of the early development of the optimal lithic industry strategies and the existence of the established traditions of skills transfer in the most important fields of knowledge of the pre-written period.

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On the Issue of Consumer Settlements of Flint Products from the Tripolye Settlement-Workshop of the Bodaki in Phase BII

Vera V. Terekhina, Natalia N. Skakun, and Vyacheslav M. Bicbaev

Abstract The article is devoted to studying raw materials (including flint and quartzite rocks) from the sites of the Cucuteni-Tripolye culture from the Bug-Dniester and Prut-Dniester interfluve of their heyday. Based on the data from archaeological contexts, technical and morphological analysis, and geological and mineralogical sciences, the authors identify sites of the developed period of the Cucuteni-Tripolye culture, which were consumers of flint products from the Bodaki workshop. This is indicated by the similarity of Cucuteni-Tripolye tools with those from Bodaki and by the absence of traces of the Volhynian flint processing. Located in the Upper Prut, Middle Dniester, and Middle Bug, these sites are pretty far from the center of high-quality Volhynian flint processing. Nevertheless, their production complexes were based on sets of tools made of imported raw materials; local rocks were used to a lesser extent. The close resource-based contacts of the Cucuteni-Tripolye sites with Bodaki are also emphasized by the isolated finds of tools from the Middle Dniester raw material in its inventory. Adzes of South Bug ferruginous quartzite and blanks made of the Swieciechov flint indicate contacts with the Upper (Middle) Bug and Central Vistula territories. These findings highlight the high level of organization of flint processing, the presence of well-established links between the Tripolye communities in Phase BII, what provided their economy with high-quality tools.

Keywords Eneolithic · Cucuteni-Tripolye · Bug-Dniester and Prut-Dniester interfluve · Stone raw materials · Volhynian flint · Workshop settlement · Consumer settlement

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1 Introduction

The flourishing period of the Cucuteni-Tripolye culture [Phase BII according to the periodization by Passek (1949)] was marked by fundamental changes in such a strategically important branch of the economy as flint processing. At this time, the Trypolian communities living in the northwest of the area initiated the development of deposits of high-quality Turonian flint, widespread on the territory of South Volhyn and in the Upper Dniester region (modern Rovno, Ternopol, and Ivano-Frankovsk regions of Ukraine) (Geological map of the Ukrainian and Moldavian SSR 1957; Petrougne 1995: 193, Fig. 1; Petrun' 2004: 204, Fig. 1) (Fig. 1c).

This flint entered the literature under the name "Volhynian" flint. According to chemical and physical analysis, an attempt to divide it into West Volhynian and Podolsk flint failed since differences at the elemental level were insignificant (Konoplya 1998: 153–154).

In 1938, at the outcrops of Volhynian flint, a Polish archaeologist A. Cynkałowski discovered the Trypolian settlement of Bodaki (Cynkałowski 1961, 1969). It is located in the Buchina tract on the left bank of the Goryn River (the right tributary of the Pripyat River) in the Zbarazh district of the Ternopil region of Ukraine (Fig. 1, *1*). Stationary systematic work on this site began in 1987 under the leadership of N.N. Skakun (IHMC RAS) and continued until 2013 (Skakun 1996, 2004, 2007, 2012a, b; Skakun et al. 2012; Terekhina et al. 2014). Studies have shown that the site with an area of 1.3 hectaresdated to the end of Phase BII of the Cucuteni-Tripolye culture (IV millennium BC) was a specialized settlement workshop for the processing of large-noduled Volhynian flint and manufacturing of advanced macroblades (Skakun 1996, 2004, 2005) (Fig. 2).

According to their technical qualities, macroblades were universal blanks for tools, and therefore were in demand by people of the vast area of Cucuteni-Tripolye and beyond (Fig. 3) (Skakun 2004, 2007).

Many flint products found in Bodaki and the presence of specialized workshops in the settlement indicate that their products were intended for exchange.

Currently, Bodaki is the only excavated settlement workshop of the Tripolye in Phase BII specializing in the processing of high-quality Volhynian raw materials.

This study is devoted to the search for settlements-consumers of Bodaki's products based on flint and stone raw material characteristics.

2 Materials and Methods

In the course of the search for settlements-consumers of flint products from Bodaki, information was analyzed on the presence of products from Volhynian flint in archaeological collections originating from synchronous the Tripolian sites of the Upper Prut, Middle Dniester, and Middle Bug regions (Sorokin 1991; Husev 1995; Ryzhov

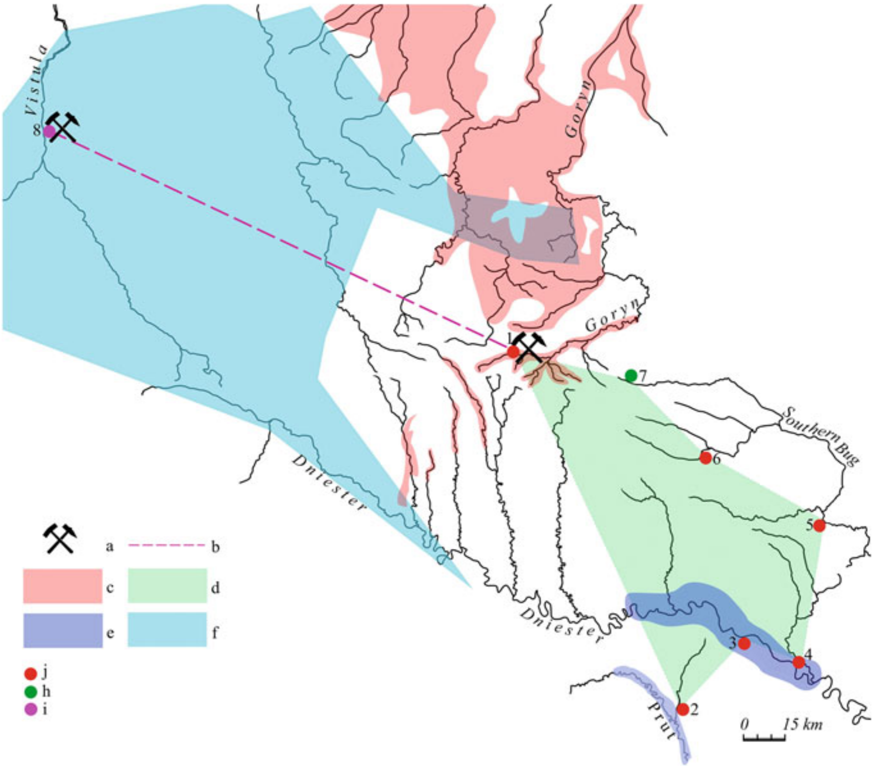

Fig. 1 A schematic map of connections for stone raw materials between the synchronous Tripolye sites in Phase BII: a—places of flint mining; b—the conditional distance between the Bodaki settlement and the places of Swieciechov flint mining near Annopol city; c—deposits of Volhynian flint; d—the area of circulation of Volhynian raw materials between the Tripolye settlements in Phase BII; e—deposits of the Prut and Dniester flint; f—the area of distribution of late Malice and Lublin-Volhynian cultures; j—Tripolye settlements in Phase BII, in the materials of which Volhynian flint items were found; h—Tripolye settlements in Phase BII, in the materials of which ferruginous quartzite items were found; i—the place of Swieciechov flint mining. 1—Bodaki; 2—Brînzeni VIII; 3—Mereşeuca-Cetăţuia; 4—Busha; 5—Voroshilovka; 6—Sosny; 7—Rusanovtsy; 8—Annopol

2007; Tkachuk 2002; Starkova 2011; Burdo 2012; Burdo and Videyko 2012; Rud' 2018). Among them are Brînzeni VIII in the Upper Prut region (Markevich 1980, 1981, 1985: 76, photos 65, 66, 68; Ţerna and Heghea 2017, 299–308); Mereşeuca-Cetăţuia III in the middle Dniester region (Sorokin 1983: 103–105, 1991: 134); and Busha (Kosakivskyy and Rud' 2009: 351, 2010: 183; Rud' 2018). These sites are about 300 km away from Bodaki in a straight line. Voroshilovka and Sosny are in the middle Bug region and located about 200 km straight from Bodaki (Zayets and Skakun 1990: 105; Husev 1995: 172, 2005: 62) (see Fig. 1). The key visually identifiable varieties of raw materials were defined in the collections of stone products from the Bodaki workshop settlement and the alleged consumer sites. First of all, their color

Fig. 2 Tools and blanks from Volhynian flint in the Bodaki settlement materials: 1—semi-crest macroblade; 2—retouched macroblade; 3—crest macroblade; 4—core with macroblade removal negative

and texture were taken into account. The selected samples were analyzed with an MBS-10 stereomicroscope at a 16-fold magnification; the rock hardness was checked with a steel needle. The presence of CO_2 was checked with 10% hydrochloric acid (HCl) solution. The place of origin of the extracted raw materials was determined by field observations and in accordance with the specialized literature on geology of this and adjacent regions (Polansky 1936; Geologicheskaya…1957; Geologiya…1958;

Fig. 3 Tools and blanks from Volhynian flint in the Bodaki settlement materials: 1—a dart; 2—a fragment of a macroblade with denticulated retouch; 3, 4, 13–17—fragments of macroblades with parallel retouch; 5–10—endscrapers on macroblades; 11, 12—fragments of middle blades

Polovinkina 1966: 140–143; Petrun' 1967, 1998, 2000, 2004, 2005; Pasternak et al. 1968, 1987; Geologiya SSSR…1969; Pryroda…1973; Senkovskyy 1973; Ivanova 1975, 1977; Nature…1975; Pryroda…1978, 1979, 1980; Geologicheskaya…1990; Ivannikov 2005; Mihailescu 1999). A technical and morphological classification of flint tool assemblages and gathering available data on raw materials were conducted for all studied archaeological materials. Next, a comparative analysis of items made of flint and stone was carried out.

3 Results and Discussion

Near the settlement of Bodaki, six outcrops of Volhynian flint were observed. The occurring layers are close to the surface in the Cretaceous sediments of the Turonian stage and in the redeposited state. The proximity to the surface made it possible to mine it with the open method in antiquity (Fig. 4, *1, 2*).

Two deposits are located near the settlement: one is 1 km from its eastern edge, and another one is only 100 m from the western edge. Nodules from these deposits have a flat-oval or irregularly amoeba-like shape; their sizes vary from 10 cm to 50–60 cm and more (Fig. 4, *3, 4*).

Flint concretions are composed of microcrystalline and fine aggregate, and spherulite chalcedony. They are black, dark, or expressive gray, sometimes with a blue tint, mostly covered with a cortex up to 1 mm in thickness. Flint is opaque or semi-transparent (with noticeable translucency at the edges of items), often with a specific pattern in the form of black or gray concentric circles, without cracks or inclusions (Skakun 2004).

Volhynian flint is characterized by ease of knapping and, accordingly, a high degree of suitability for processing (Skakun 1996; Girya 1997: 83–86; Skakun and Plisson 2014; Skakun et al. 2018, 2020; Zakostselna 2018: 262–264). Among the mass of the Volhynian flint products found at the settlement, few artifacts are from other raw materials. So, out of 36 arrowheads and darts, only 2 arrowheads were made of flint of a different type. An arrowhead (length—2.2 cm, width of the hafting element—1.5 cm) (Fig. 5, *1*) and two darts (length—6 and 8 cm, the width of the hafting element—3.7 and 3.5 cm, respectively) (Fig. 5, *2*,*3*) were made from semi-transparent (less translucent than Volhynian) raw material of cream-gray color, structurally with amorphous white large and small balls (whitish phantom puncture) and thin needle-like inclusions. In its structure, this raw material is similar to flint, which V.F. Petrun', who professionally dealt with the problems of geoarchaeology, described as a Middle Dniester flint of the Cenomanian age (Figs. 1e and 6, *1*) (Petrun' 2005, 130).

Analysis of the flint inventory of the site of Brînzeni VIII located on the Upper Prut (Markevich 1980, 1981, 1985: 76, photos 65, 66, 68; Ţerna and Heghea 2017: 299–308) and the Middle Dniester sites of Mereşeuca-Cetăţuia III (Sorokin 1983: 103–105, 1991: 134) and Busha (Kosakivskyy and Rud' 2009: 345, 2010: 189) shows that the bulk of the items were made of Volhynian flint.

Fig. 4 Volhynian flint from deposits near the settlement of Bodaki: 1, 2—flint outcrops to the surface; 3, 4—flint nodules

The Brînzeni VIII settlement is located in the Syeche tract on the promontory formed by the Racovăț and Dragishte rivers in the Edineț region of the Republic of Moldova (Fig. 1, *2*). The total area of the site is 15–18 hectares (Scholz et al. 2018: 82); excavations have uncovered 4 dwellings and 8 pits (Markevich 1981: 18). Flint inventory consists mainly of finished tools from Volhynian flint: medium and large blades with retouch, drills, end scrapers on medium and large blades; among the blanks, there are dart and arrowheads (Fig. 7).

There are no cores and wastes of Volhynian flint processing.

A similar situation is observed in the multilayer settlements of Mereşeuca-Cetăţuia (Fig. 8) and Busha.

The first one is located in the Ocnița region of the Republic of Moldova, in the Cetăţuia tract, on a high slate outlier (Fig. 1, *3*). Phase BII includes the third layer of the site (Mereşeuca-Cetăţuia III), where one semi-subterranean dwelling and three utility pits were excavated.

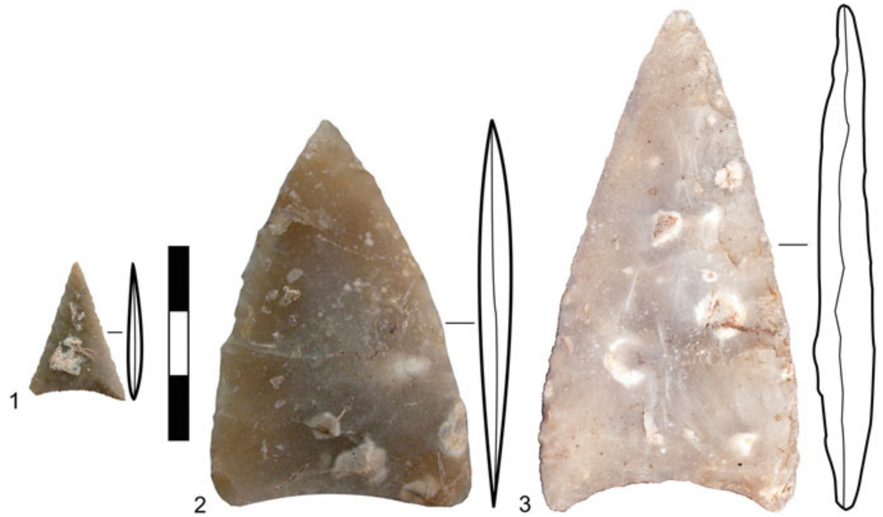

Fig. 5 Dniester flint hunting tools in the Bodaki settlement materials: 1—arrowhead; 2, 3—darts

Fig. 6 Sample of Dniester flint

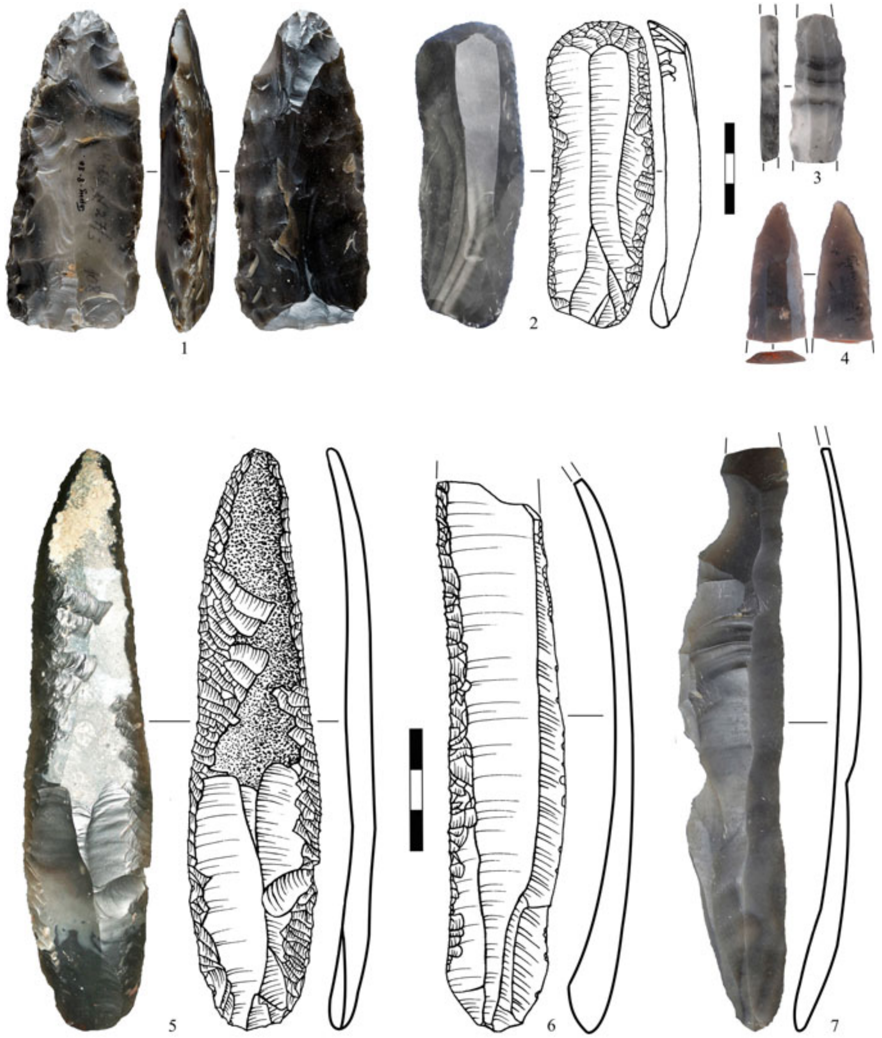

Fig. 7 Volhynian flint tools and blanks in the Brînzeni VIII settlement materials: 1—blanks for a dart; 2—an endscraper on a macroblade; 3—a fragment of the middle blade with retouch; 4—a fragment of a tool; 5—a "dagger" on a macroblade; 6—a retouched macroblade; 7—a semi-crest macroblade

The second settlement is located about 35 km from Mereşeuca-Cetăţuia III near the village of Busha in the Yampolsky district of the Vinnitsa region of Ukraine on a long cape formed by the confluence of the Bushanka and Murafa rivers (left tributaries of the Dniester) (Fig. 1, *4*) (Kosakivskyy and Rud' 2009, 2010). Among the excavated objects, the remains of a burnt house made of clay and belonging to

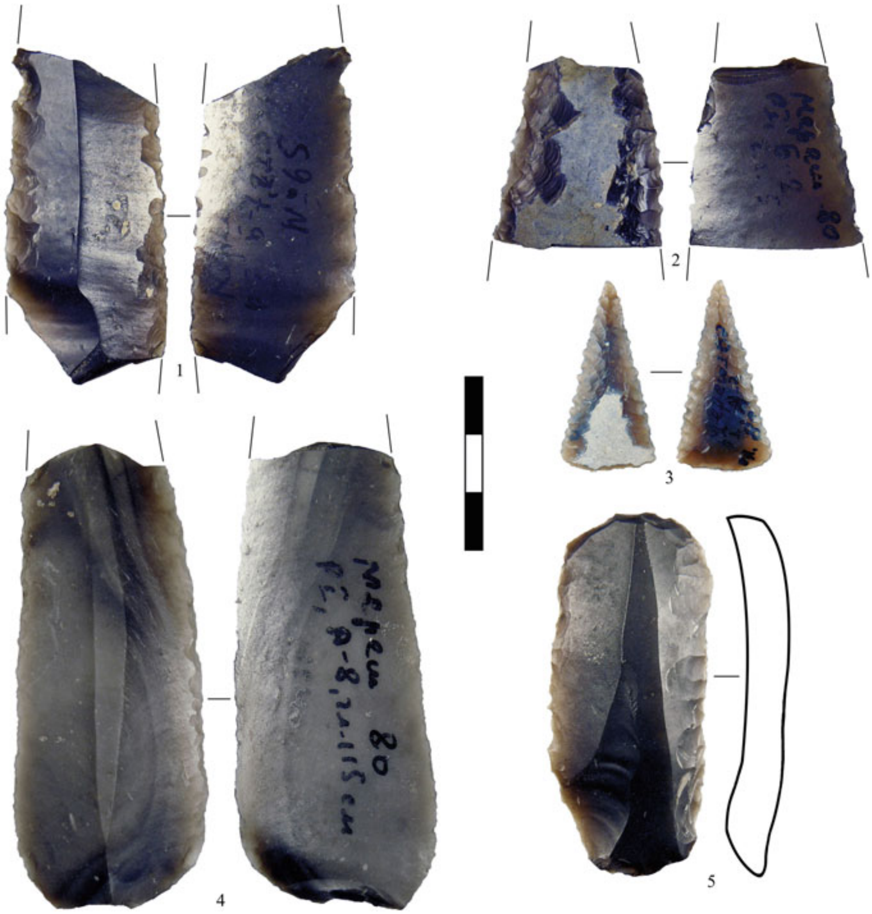

Fig. 8 Volhynian flint tools and blanks in the Mereşeuca-Cetăţuia III settlement materials: 1, 2—fragments of macroblades with parallel retouch; 3—an arrowhead; 4—a macroblade; 5—an endscraper on a macroblade

Phase BII. In addition to tools on blades of Volhynian flint, a precore from this raw material was also found here (Kosakivskyy and Rud' 2009: 345, 2010: 189).

It should be noted that in all three settlements, in addition to finds from Volhynian flint, a full cycle of processing of local, probably, Lower Cenomanian and Upper Cenomanian flint is recorded. Moreover, the primary blank for tools was the middle blade, the length of which was limited by the small size of flint concretions. V.F. Petrun' defined the Lower Cenomanian flint as "sedimentary diagenetic silcrete of the chert gas group in the basins of the Middle Dniester and Prut" (Petrun' 2004: 204). Its small concretions, rarely reaching 10 cm in diameter, have a strong lime cortex. Upper Cenomanian flint V.F. Petrun' has described as Middle Dniester flint occurring in marly limestones of the Upper Cenomanian (Petrun' 2004: 204). S.N.

Fig. 9 Dniester flint nodules (based on the results of exploration by V.M. Bicbaev)

Bibikov noted that such raw materials are found in the form of slab blocks, "placers" of redeposited flint, pebbles, or boulders (Fig. 9) (Bibikov 1953; 1965: 78–80).

Both types of Middle Dniester flint are found on both banks of the Dniester River and on the terraces of its tributaries. S.N. Bibikov, E.K. Chernysh, N.N. Gurina and other researchers described many places, from the city of Mogilev-Podolsky to the city of Kamenets-Podolsky, where the collection and extraction of raw materials could occur in antiquity (Bibikov 1965; 1966; Chernysh 1967; Gurina 1976). In the structure of this flint, amorphous white (light gray), large and small balls (whitish phantom puncture) (see Fig. 6), and thin needle-like inclusions are often traced. In the color range, flint is presented in white, gray, dark gray, and black. Iron oxides give this flint brownish and brown color. Often, flint is semi-transparent along the edges of chips but more opaque than Volhynian. Cataclastic quartz is very often the host rock of this flint. Caverns and cracks are filled with it. The black raw material is usually covered with a lime cortex, filling cavities and cracks in concretions. The quality of this raw material is in many ways inferior to Volhynian flint (Ginter and Kozłowski 1990: 29, Fig. 2; Balcer 1983: 47–48; Konoplya 1998: 142–146).

In Romanian archaeological literature, this type of flint is called "Moldavian flint" or "Prutho-Dniestrian flint". It occurs in the Cenomanian Stage on both banks of the Upper Pruth River and emerges as flint pebbles and cobbles in the alluvial sediments of the same river (Văscăuþanu 1923, 1925; Saulea et al. 1966), spreading across the Pruth River as far away as the Răut and Dniester Rivers (Macovei and Atanasiu 1934: 179–181; Chetraru 1995a, b; Chirica et al. 1996). Geologists refer to this material as Miorcani type flint is the type locality being the village of Miorcani (Botoşani county, Romania) situated on the bank of the Pruth River, where even today, a modern flint mine still exists (Văscăuþanu 1923; Chelărescu et al. 1961).

Outcrops of the same material can also be found at Products from Volhynian, and Middle Dniester flint were also found on the settlements of Voroshilovka and Sosny, located in the Middle Bug. Voroshilovka is situated on an elongated promontory on the right bank of the Southern Bug in the Tyvrov district of the Vinnitsa region of

Ukraine (Fig. 1, *5*), and the settlement of Sosny is 45 km away on a small remnant of the Zgar River in the Litinski district of the Vinnitsa region of Ukraine (Fig. 1, *6*). Moreover, a workshop was discovered in Voroshilovka to manufacture blanks or “repair’ of tools from “imported” raw materials (Husev 1995: 174).

Petrographic analysis of materials from these two sites conducted by V.F. Petrun’ showed that the overwhelming majority of items were made of Volhynian flint, and only a few items were made of Middle Dniester Cenomanian flint (Husev 1995: 172, 2005: 62). Deposits of both types of raw material are located about 200 and 60 km straight from the settlements. No artifacts from local Bug flint were found.

Particular attention should be drawn to the discovery in the Bodaki tool complex of partially polished chopping tools and their fragments (10 pieces in total), made of milky-white sedimentary rock, consisting of quartz (the structure of the rock under a microscope is granular; there are black point segregations of weathered pyrite). The surface of the products is covered with a thin crust of ferruginization, due to which they have a yellowish tint. In the material from which one of the finished adzes is made (length—10 cm, blade width—5.3 cm, height—2.3 cm, weight—136 g), there is an inclusion of cataclastic transparent vein quartz cemented with fine-grained quartz. Traces remain on the rock’s surface after scratching it with a steel needle; it does not react to hydrochloric acid and is light (Fig. 10, *1*).

Another finished tool is an axe made of the same material (length—9.3 cm, blade width—4.6 cm, height—3 cm, weight—72 g) (Fig. 10, *2*). By its structure, this rock can be classified as metamorphic, such as ferruginous quartzite. A similar product from the same raw material was found in the tool complex of the Tripolye settlement of Rusanovtsy 1 in the upper reaches of the Southern Bug. It is located 72 km straight from the village of Bodaki in the Letichevsky district of the Khmelnytskyi region of Ukraine (Ovchinnikov 2018: 19, 32, Fig. 12: 2), where the outcrops of

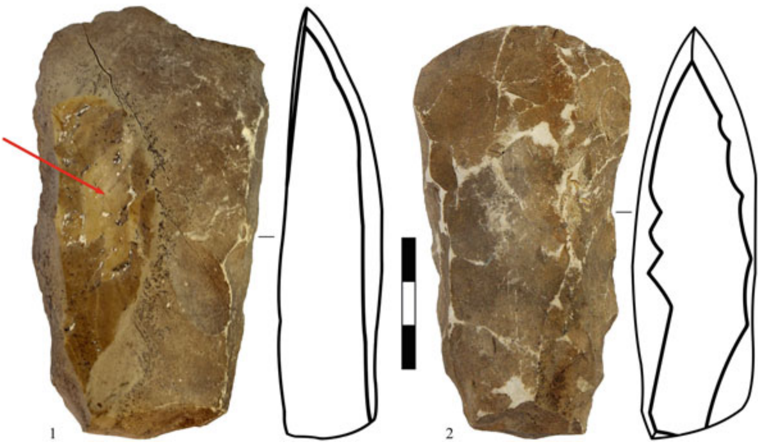

Fig. 10 Ferruginous quartzite chopping tools in the Bodaki settlement materials: 1—an adze; 2—an axe

this rock have also been recorded (Pryroda Chernivets'koyi oblasti 1980). Geologically, this region is represented by formations of the Archean group: highly altered metamorphic, igneous, and various hybrid rocks, including ferruginous quartzites, characteristic of the Ukrainian crystalline massif (Geologiya…1958: 86, Table 9; Geologicheskaya…1957). A thin crust of ferruginization on the studied adzes was formed in the process of oxidation of iron contained in the rock.

Among the few flint chopping tools in the tool complex of the Bodaki settlement, an adze was identified with a trapezoidal cross-section (length—7.4 cm, blade width—4.3 cm, height—1.7 cm, weight—76 g) (Fig. 11) which was made of opaque white heterogeneous ferruginous flint with inclusions of large amounts of pyrite. Such raw materials have not been found in the vicinity of the Bodaki settlement; perhaps its deposits are located in the Middle Dniester.

Of great interest is a single blank of adze (?) (length—9 cm; blade width—5.75 cm; height—1.75 cm) made of opaque spotted gray with a brownish shade flint (Fig. 12).

Such raw materials are widespread in the Cretaceous rocks of the Turonian age of the central Vistula (Poland), in the area of the Rakhov and Groyero anticlines, between Annopol, Swieciechov-Podukhovna (formerly Swieciechov-Lazek), Vymyslovo,

Fig. 11 A Dniester (?) flint adze in the Bodaki settlement materials

Fig. 12 A Swieciechov flint blank of tools in the Bodaki settlement materials

and Vulka-Radzeradovskaya plate (Balcer 1967) (Fig. 1, *8*). Swieciechov flint (krzemień świeciechowski) (or previously called Rakhovsky from the old name of Annopol) is presented in the form of flattened-convex concretions up to 50 cm in diameter. Usually, they do not possess a pebble cortex. White or light gray points and spots in the rock usually have a diameter of about 1 mm (Libera and Zakościelna 2002). The presence of flint in shallow water under the influence of the external environment made it available for extraction by ancient people to satisfy their economic needs.

It should be noted that this type of flint during the existence of the Tripolian settlement of Bodaki was used by the population of neighboring Eneolithic cultures, such as the late Malice and Lublin-Volhynian cultures, which metropolises were located in the area of its deposits. Still, it was less in demand than the chocolate and Volhynian flint (Zakościelna 1996: 21). At present, the lack of a sufficient factual base does not allow characterizing the connections of the Bodaki population with the territory of the Central Vistula. However, contacts with representatives of late Malice and Lublin-Volhynian cultures (Fig. 1f) are indicated by imitations of the forms of vessels in the ceramic complex of the workshop settlement (Starkova and Zakościelna 2018).

4 Conclusions

The research allows outlining the range of sites (Brînzeni VIII; Mereşeuca-Cetăţuia III; Busha; Voroshilovka and Sosny) of the developed period of the Cucuteni-Tripolye culture, which were consumers of flint products from the Bodaki workshop settlement (Fig. 1d). This is indicated by the absence of traces of processing of Volhynian flint in their materials and the similarity of their tools with those found in Bodaki. Located in the upper reaches of the Prut, Middle Dniester, and Middle Bug, they were distant from the center of the high-quality Volhynian flint processing. Despite this, the basis of their production complexes were sets of tools made of these very raw materials; local rocks were used to a lesser extent. The close resource-based contacts of Bodaki with consumer settlements are also emphasized by the discovery in its inventory of single tools made from Middle Dniester raw materials, which were partially used in consumer settlements. Polished chopping tools and their fragments from South Bug ferruginous quartzite and the blank made of the Swieciechov flint indicate contacts with the Upper (Middle) Bug and Central territory Vistula (Fig. 1, 7b). These observations suggest the high level of organization of the flint-processing industries, the presence of well-established links between the Tripolye sites of Phase BII, which provided their economy with high-quality tools.

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The Role of Stone Raw Materials (Not Flint) in Industrial Complexes of the Upper Paleolithic Sites (Based on Materials from the Cosauti Site, Republic of Moldova)

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Abstract In the multi-layered Upper Paleolithic site of Cosauti (the Republic of Moldova), which is unique in the richness and variety of finds, unmodified or slightly processed stones with use-wear traces were found, in addition to numerous flint implements. Among the various groups of tools were identified by applying the use-wear analysis: hammer stones, anvils, abrasives, palettes or pigment grinders, polishers, lower and upper grinding stones. These tools were used in various types of economic activities and served to process various materials: antler, bones, skins, ocher, flint, and other types of stone, as well as for crushing, kneading, and grinding plant materials. The obtained data points out the efficient and selective use of different stone raw materials to create the tools for various purposes.

Keywords Late Paleolithic · The Republic of Moldova · Cosauti · Stone raw materials · Use-wear analysis

1 Introduction

The materials of many Paleolithic sites in Eurasia contain large objects made of various types of stone; some are artificially processed, while others retain their natural shapes (Voevodsky 1952; Rogachev 1973; Chernysh 1961; Kuchugura 2003; de Beaune 2003, etc.). For this reason, it is difficult to distinguish between natural stones and tools. That is why these artifacts rarely become objects of special analysis. However, a present, comprehensive study of these finds is gaining significant importance. It includes classical use-wear analysis with the help of microscopes, a 3D

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visualization which is useful when studying the most worn-out areas, experiments for verifying the results of use-wear analysis, and study of organic residues, which can show what kinds of vegetation were processed (Semenov 1974; Shchelinsky 1994; Hamon and Plisson 2008; Revedin et al. 2010; Stepanova 2020; Pedergnana et al. 2016; Longo et al. 2018; Skakun and Plisson 2014; Skakun et al. 2020a, 2020b, Skakun et al. 2019). Our research is the result of studying a collection of stone objects (64 items) from the Upper Paleolithic site of Cosauti, Republic of Moldova.

2 Materials and Methods

The multi-layer Cosauti site was discovered in 1978 by I.A. Borziyak and M.V. Anikovich in the Soroca region of the Republic of Moldova (Fig. 1).

It is located on the right bank of the river Dniester, in the sediments of the first fluvial terrace (Borziac et al. 1998). All cultural layers of the Cosauti site fall into the general chronological interval from 20 to 16 BP (the stratigraphy of the site has been characterized in several publications, such as Haesaerts et al. 1998: 653, Fig. 2). All of them represent a single industrial complex, which is considered by most researchers as Epigravettian. In Cosauti this period is characterized by the flint blade producing technique, the predominance of borers, primarily retouched and side ones, the presence of end scrapers on the blades, the wide distribution of inserts—micro points and backed bladelets made with the help of vertical and steep retouch removing material over the entire thickness of the workpiece. At present, the data from the Cosauti site allow it to be included in the Epigravettian culture of the Molodova-Cosauti-Kotu-Mikulints type (Chirica and Borziac 2009: 29–31), the main territory of which covers the Middle Dniester and the Middle Prut.

During many years of excavation, a series of residential and household complexes was uncovered. Data were obtained to characterize various aspects of the life of the inhabitants of this site. Materials are uniquely preserved. It should also be noted that in layer 2B an infant burial was discovered near the fireplace with a concentration of bone fragments, animal teeth, reindeer antlers, flint products, ash, and coals (Kovalenko and Krojtor 2016).

In addition to numerous artifacts of flint, antler, and bone items, sandstone, quartzite, and slate artifacts were found in all layers of the site (STR).

These kinds of raw materials are often found on the coastal shoals and the eroded slopes of the Dniester valley. From the whole variety of stones, the inhabitants of the Cosauti site preferred to use rounded and elongated pebbles, large tiles, and their fragments (Kovalenko 2019). Unfortunately, there is no dedicated work on the mineralogical and petrographic features of these artifacts; however, there is general information on the lithology of stone raw materials in the Middle Dniester region (Peres 1963, 1968). The data on the geological structure of the Dniester river valley and the geomorphology of the vicinity of the site (Ivanova 1977), as well as data on the paleogeography of the area (Adamenko et al. 1996), are also significant. The geological and geomorphological description of the Dniester valley, which is the

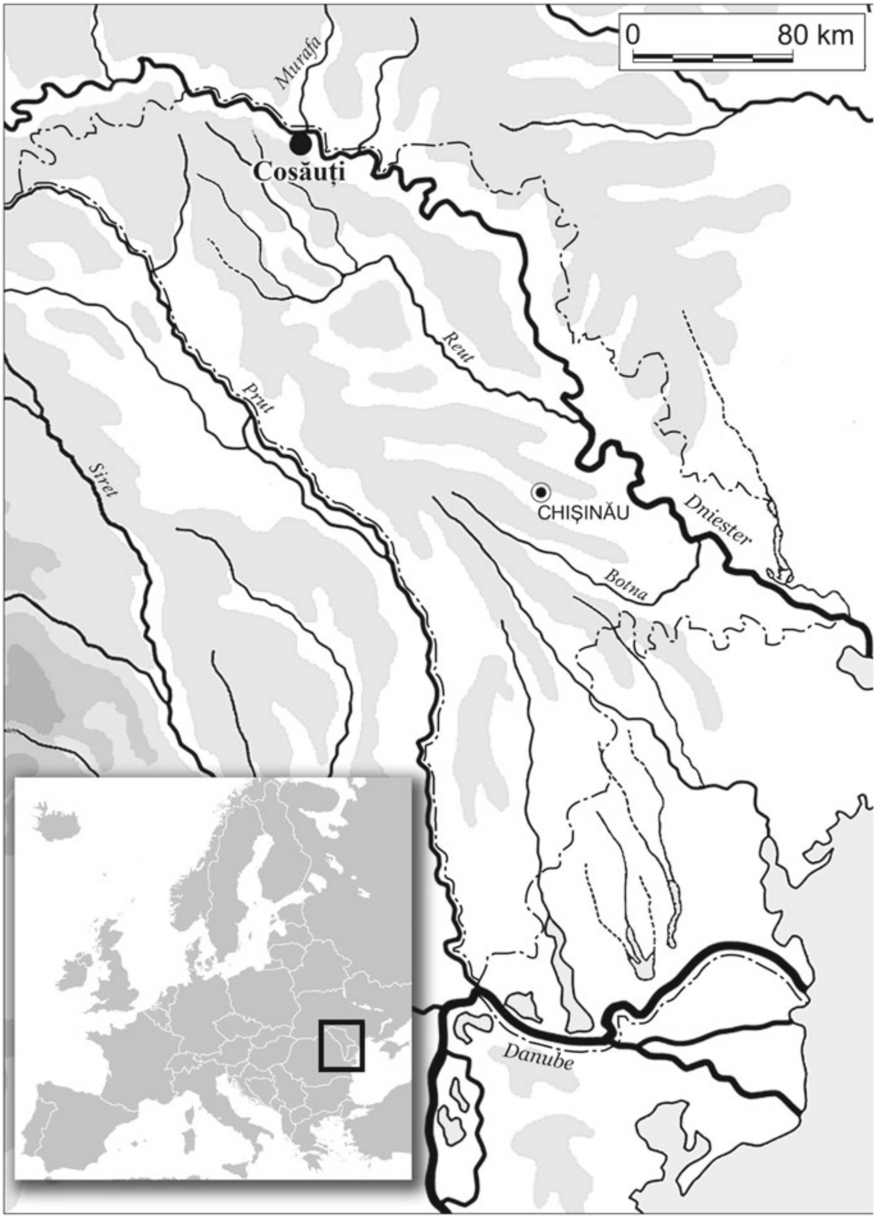

Fig. 1 The geographical position of the Upper Paleolithic site of Cosauti (the Republic of Moldova)

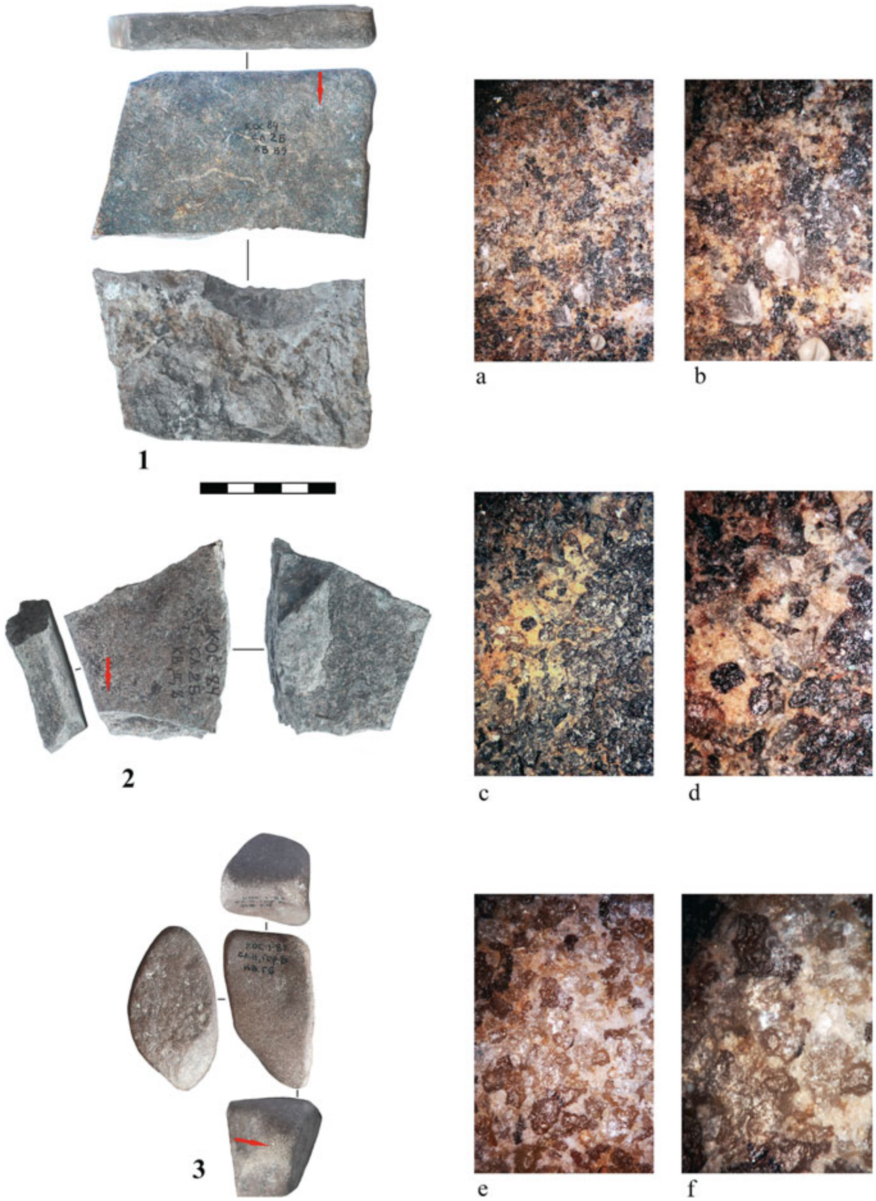

Fig. 2 The Cosauti site. 1—a fragment of the lower grinding stone; a, b—micro-photo of use-wear traces on tool 1 (a – × 100, b – × 200); 2—a fragment of a pigment grinder; c, d—micro-photo of use-wear traces on tool 2 (c – × 100, d – × 200); 3—mano; e, f—micro-photo of use-wear on tool 3 (e – × 100, f – × 200) (1–3—layer 2B)

most studied in its middle section (from the city of Mogilev-Podolsky to the town of Soroca), allows for the distinguishing sources of certain types of raw materials (cut by the river up to the crystalline bed). The most ancient rocks, opened by the river to a depth of 70 m, are represented by a stratum of mudstones and siltstones, interbedded by sandstones of the Upper Proterozoic that sometimes form steep slopes.

These dense rocky outcrops were also available in the Upper Paleolithic. In the collection of stone artifacts, the Upper Paleolithic materials are probably associated with fragments of slabs of siliceous sandstones and slate. They are distinguished by the density, roundness of the edges, and the presence of one or two naturally aligned surfaces. The color of these rocks ranges from brownish to grey. According to the mineralogical data, they can be associated with opal-glauconite-quartz silts of biogenic origin and fine-grained carbonate sandstones (Peres 1968), widespread in the adjacent territories of Ukraine and Romania.

The study of the collection of stone finds from the site, stored in the National Museum of the History of Moldova, revealed a series of objects from non-isotropic rocks in cultural layers 1, 2B, 3B, 3, 3A, 4, and 5, excavated over a relatively wide area. Objects for use-wear analysis were initially identified by authors using the macro use-wear analysis developed by the Experimental and Traceological Laboratory in St. Petersburg. This method is based on the characteristics of macro-traces: the visually distinguishable deformations and polishes (Korobkova and Shchelinsky 1996). Further micro use-wear studies of 64 items confirmed that most of them (45 items) were indeed tools used in various production processes. The use-wear analysis was carried out with an MBS-10 binocular microscope with the magnification from 8.4× to 98× and an Olympus BHMJ metallographic microscope with magnification from 50× to 500×. Microphotographs were taken on a Canon EOS 400D digital camera mounted on a metallographic microscope with a DIC (differential interference contrast) module; the photographs were taken with built-in illumination passing through the lens. The multiple photos of each tool, taken at different focus distances, were stacked together with the Helicon Focus software into the final images.

3 Results and Discussion

Firstly, it is necessary to pay attention to grinding stones for processing vegetation. The finds of this functional type are unique. Both components of these tools were found: the upper (movable) part—manos (6 items), and the lower stones (8 items), on which the vegetation was rubbed, kneaded, and fragmented. The working parts of the lower grinding stones have typical use-wear in the form of abrasion, flattening of the surface, spots of bright polish, and weak linear marks (Fig. 2a, b).

The two lower stones from layer 2B are represented by a tile fragment (Fig. 3, *4*) and a large subrectangular slab (30 × 16 × 3.5 cm) of high-quality fine-grained grey sandstone (Fig. 3, *6*).

In cultural layer 3, several slabs of dense quartzite sandstone and argillaceous sandstone were found. Their average size is 18 × 10 × 5 cm; the working surfaces

Fig. 3 The Cosauti site. Stone objects. 1, 2—pigment grinders; 3–6—lower grinding stones (1—layer 3B; 2—layer 3; 3, 5—layer 3A; 4, 6—layer 2B)

show slight wear. In layer 3B (Stepanova 2020) and layers 3–5, large sandstone slabs with flat surfaces and similar wear patterns were also found (Figs. 3, *5* and 5, *11*).

The rounded flattened pebbles were used as mano, and the working areas of some of them were processed with a light pecking tool with a narrow end for better adhesion with the processed material. On their working surfaces, the zones of smooth polishing and poorly discernible linear traces were revealed: shallow, short strokes, located parallel to each other in central parts and chaotically on peripheral parts (Figs. 2 and 3*e, f*). The most worked-out tools have intensive wear in the form of small pits, damage, and abrasion along with the entire or most of the circumference of these finds (Fig. 3, *4*).

The particular attention deserves two manos from layer 4 (Fig. 4, *4, 7*) as they possess strong wear and a mass of pits along their wide working edges, covering almost the entire perimeters of the tools. It was the wear that gave a specific look to these objects, and they are close to a cylindrical shape. The first of them is 4.5 cm in diameter, 4.4 cm in thickness, and the second is 4.8–5.5 and 5 cm in thickness. The larger pestles (Fig. 4, *5, 6, 8*) are found in almost every layer of the site, and they are also close to this group of artifacts. For them, flattened pebbles from light brown coarse-grained sandstone were selected; their diameters varied from 5.5 to 9.5 cm.

Quartzite, sandstone, and limestone pebbles of various shapes and sizes were used as hammerstones (4 items) for the knapping of flint nodules, as well as for the processing of stone tools with percussion and pecking (Fig. 5, *2*). Elliptical and angular pebbles were preferred; on their working parts, located, as a rule, on the protruding areas, the zones typical for these tools breakage in the form of cellular or star-shaped pits were formed during the work. In addition to pebbles, spherical spherosiderites were used as hammerstones (1 item), often with a concentration of wear traces on opposite areas (Fig. 5, *3*).

In the first cultural layer, an anvil was found. The tool was made of a large elliptical pebble of brown sandstone 19 cm in diameter and up to 6 cm in thickness (Fig. 5, *6*). On its flattened surfaces, separate small potholes are traced. A fragment of a dense, coarse-grained sandstone tile from layer 2B with typical wear in the form of cellular pits concentrated in the central part also served as an anvil (Fig. 5, *8*). A massive fragment of a brown slab from layer 3, rectangular in form, with a shape of 19.5 × 10 × 5 cm, was also used as an anvil that supported a flint core while knapping. Its edges are rounded, and on one of the flattened surfaces, there is an area with small fractures and pits. Finally, from layer 4 originates a fragment of an anvil tile with dimensions of 13.5 × 12 × 3 cm, on the surface of which the roughness from a mass of scratches and small pits localized in the central part is visible.

Judging by the nature and degree of wear, 5 items served as abrasives for processing bone and antler. Two fragments of slate tiles originate from layer 1. On the edges of one of them, 11 × 6 × 0.9 cm, longitudinal grooves and flat flake scars at the corners are seen (Fig. 5, *4*). On the second sample, 9.5 × 8.8 × 2.4 cm in size, numerous unidirectional small scratches can be seen on an even surface almost along its entire length; a total of 13 such linear depressions were found (Fig. 5, *5*). Three flat sandstone tiles were found in layer 2B. They were used as abrasives. One of these tools is the most worn out. On its surface, slightly concave wear from work, which

Fig. 4 Cosauti site. Pebble tools. 1–3—polishers; 4–8—manos (1—layer 3; 2, 4, 7—layer 4; 3—layer 3B; 5—layer 1; 6, 8—layer 2B)

exposed the stone structure, and deep linear traces located chaotically and parallel to each other, can be seen. At a magnification of 100 × , the stepped crumbling of sandstone grains, typical for abrasives, is visible. The boundaries of fine-meshed depressions formed from rock grains fallout are leveled, and the protruding tops are slightly rounded. No use-wear was found on the lower surface of this tool. The tool was painted brown, possibly as a result of contact with ocher substance. The dimensions of the other two fully preserved abrasives are 30 × 16 × 3.5 and 20.5 × 18 × 4 cm.

Fig. 5 The Cosauti site. Stone finds. 1—tool for processing soft material (scraper); 2, 3—hammerstones; 4—tile with abrasion; 5—abrasive; 7—engraved tile; 6, 8—anvils; 9–11—lower grinding stones (1–3, 7, 8—layer 2B; 4–6—layer 1; 9—layer 3A; 10, 11—layer 3B)

Two fragments of argillaceous sandstone tiles from layer 2B were the lower parts of pigment grinders, on which lumps of ocher were crushed and ground (Fig. 2, *2c, d*). The working surfaces are smooth, flattened during use, and painted with ocher. Their protruding areas are leveled and slightly polished with poorly discernible linear traces. Among tiles with smoothed surfaces, a fragment from layer 3B stands out. It has elongated proportions, the dimensions of 20 × 8 × 2.6–3.5 cm; one side of this item is uneven, naturally concave, and has dark red saturated ocher spots, occupying mainly protruding sections of the microrelief (Fig. 3, *1, 3*). A pigment grinder from layer 3 was made of a large sub-rectangular sandstone slab (22 × 16.5 × 7.4 cm). It is abundantly covered with red ocher along with one of the surfaces, and this coating has a pronounced linear orientation. In layer 3, six more tiles for grinding ocher were also found, and in two cases, linear traces are well seen on their surfaces (Fig. 3, *2*). In the same layer, tiles of brownish quartzite and red granite, similar in the character of wear, were found (Fig. 3, *3*).

There are several small sandstone pebbles in the collection, the identification of which is hypothetical. Slightly pronounced use-wear does not allow making an unambiguous classification. Still, the smoothed dark-colored surface with spotty polishing and randomly located linear traces, as well as similar wear on experimental tools, suggests that they were used as skin polishers. The following items were used in this way: a rounded 4 × 3.6 × 2.9 cm pebble with an intensely polished surface (Fig. 4, *3*) from layer 3B, a flattened pebble of 3.8 cm in diameter, and 1.2 cm in thickness from layer 3 (Fig. 4, *1*), and an elongated pebble 6.5 × 3.5 × 1.7 cm from layer 4, in which local surface polishing is combined with a rich dark (carbonaceous) coloration (Fig. 5, *2*).

A single specimen from layer 2B is a scraper with a retouched working edge (Fig. 5, *1*). Some parts of its blade show use-wear traces in the form of an edge rounding and leveling of sharp edges of retouch. Such traces are typical of tools associated with the processing of soft materials, possibly hides; experimental work is required to clarify their functions.

In addition to the stone tools described above, a subrectangular tile of coarse-grained greyish-yellow sandstone of 12 × 7 × 2.1 cm with deepened lines on one of the flat surfaces deserves attention (Fig. 5, *7*). On the surface of the tool, the deepened grooves form an image in the shape of the two "short stairs" and two parallel lines with a zigzag at their base, which resembles the so-called roof-like ("tectiform") symbols (Borziyak 1989). The appearance and location of grooves on the surface indicate intentional application. The small depth and the absence of typical abrasion wear allow us to assume their non-utilitarian origin.

4 Conclusions

Thus, the use-wear analysis has allowed identifying tools for processing stone, flint, bone, antler, hides, mineral pigment, and vegetation within the artifacts assemblage of stone raw materials from the Cosauti site. It should be emphasized that minerals with other physical qualities, including flint, could not be used for producing such functional groups as grinding stones, abrasives, pigment grinders. These data points out the utilization of various raw materials by the inhabitants of the site and their efficient use for production needs.

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The Use of Pebble Raw Materials in the Paleolithic and Mesolithic of the Urals

Yury B. Serikov

Abstract The paper discusses the nature and specificity of the use of local gravels and pebble raw materials has its own typical use of pebbles and pebble raw materials.

Keywords Pebbles · Urals · Paleolithic · Mesolithic ages necessary tools

1 Introduction

Pebbles are water-drenched rock fragments which have the diameter of up to 10 cm. It is always found in the form of open deposits (gravels) in riverbeds and on lake shores. Normally, there are pebbles of various sizes, shapes, composition and colors. Pebbles were the first mineral raw materials used by humans.

In the Urals, various types of mineral raw materials are presented in gravels, including jasper, quartzite, quartzitic sandstone, siltstone, shale, chalcedony and flint. There are also rare minerals such as carnelian, agate, hematite and crystal.

During the earliest periods, pebbles were often used without processing or with minimal processing. Untreated pebbles served as hammerstones, anvils, retouchers, hammers, pestles, abrasives, polishers, fishing sinkers (Serikov 2005: 44–46). Pebbles were also used as the initial mineral raw material for making necessary tools by knapping. Stone tools made from pebbles are enrountered at almost every Upper Paleolithic sites on the Urals. Their study allow us to characterize the role of pebble raw materials in the productive practices of Paleolithic and Mesolithic populations of the Urals.

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2 Results and Discussion

The earliest site that demonstrates the use of pebble raw materials for the tool manufacture is the early Paleolithic Yelniki II location (the Sylva River, the Middle Urals, the Perm Region of Russia). Based on the trogonterian elephant bones found on the site, it can be dated back to the Middle Pleistocene, or the Likhvinskiy interglacial period (about 300,000 years ago). Along with the elephant bones, a chopping made of rounded pebble quartz sandstone and a flake of quartzitic sandstone were found at the location.

There are other early Paleolithic sites with pebble tools that are dated slightly later than Yelniki II. They are the sites of Ganichata I, Ganichata II, Sludka, Tupitza, and Borisovo. All of them are located on the banks of the Kama reservior (the Middle Urals, Perm Region) and are currently being actively destroyed by the wave abrasion. The complex of finds at all locations is represented by choppers, choppings, nucleuses, scrapers, plates, and flakes. They are made of pebbles and boulders of quartz sandstone of different colors. Raw materials were taken from gravels recorded near the locations of Ganichata I and Ganichata II (Pavlov et al. 1995, 5–22).

The collection of finds at the Talitsky Late Paleolithic site (the Chusovaya River, the Middle Urals, the Perm Region) contains 4935 stone products. The population of the site used the rich gravel and pebble deposits of the Chusovaya River to obtain flint (62.5%), siliceous shale (25.3%), quartzite and quartz sandstones (5.2%), silicified limestone (2.7%), rock crystal (2.5%), and jaspers (1.8%). The preference was given to pebbles with the diameter of up to 7 cm. A full cycle of stone processing took place at the site, beginning with testing of raw materials followed by primary splitting, and making tools (Shcherbakova 1994, 22–25).

The Garinskaya site (the Sosva River, the Middle Trans-Urals, the Sverdlovsk Region of Russia) is located in the low-lying part of the Urals among swamps. There are no mountains there, and, consequently, there are no mineral resources. A small gravel deposit was recorded 2 km from the Garinskaya site near the Rychkova village. It should be emphasized that this is the only gravel deposit in the vicinity of the site since other gravel deposits have been identified in 50 km and in the different direction from the site. Since this deposit contains all types of mineral raw materials known at the site, this particular gravel could be used by the Paleolithic population of the Garinskaya site.

The collection of stone products of the Garinskaya site contains 690 items. Their analysis shows that 57.1% of products have a pebble crust (natural crust). Moreover, the percentage of products with the pebble crust is different for different categories. Among nucleuses the percentage with the pebble crust is 90.9%, among splinters—67.2%, among technical chips—58.8%, among plates without retouching—50.5%, among plates processed with retouching—38.2%. Pebbles with diameters of 2–6 cm were used for knapping.

More than a half of all products (56.15%) are made of different types of jasper (green—24.6%; dark gray—24.2%; brown—5.3%; red-green—1.6%; light gray—0.45%). The second place is occupied by a variety of color and structure siliceous shale—24.4% of products. 15.3% of products are made of black and brown flint of good quality. Products made of quartzite (2.5%), chalcedony (0.9%), aleurolite (0.6%) and milky quartz (0.15%) are presented in small quantaties (Serikov 2019: 5–19).

The original pebble complex of the Upper Paleolithic was found on the shore of the Bolshie Allaki Lake (the Southern Trans-Urals, Chelyabinsk Region of Russia) near the rock shelter site that overlapped the Paleolithic cultural layers. Of the 208 products of the Paleolithic layer, there are 164 (78.85%) that are made of rock crystal. The initial form of raw material was pebbles and druses of rock crystal (Zhilina and Petrin 1989; Petrin et al. 2012).

During the Mesolithic period, the local gravel deposits on the territory of the Northern and Middle Urals continued to be the primary sources of mineral raw materials. In the Mesolithic settlements of Parch 1, 2, and 3 (the Vychegda River, the Northern Urals, the Komi Republic of Russia), the composition of rocks in the collections reflects fully the composition of the local gravel deposit of the Vychegda river (Volokitin et al. 2003: 24–35).

The Ogurdino Mesolithic settlement (the Kama River, the Middle Urals, the Perm region) is confined to the layer of alluvial gravel. The settlement presents products from various types of flint—81.6%, chalcedony—7.2%, quartz—3.7%, siliceous shale—2.7%, siliceous limestone—3.2%, quartzite—0.9%, and jasper—0.7%. Many products still have the pebble crust. It is present on a half of splinters and chips that make up 64.6% of the entire complex of the site (Melnichuk 1989, 245).

In the Mesolithic of the Middle Trans-Urals, the local population had been increasingly using tiles of siliceous shale. The products made of pebbles became very few. Nevertheless, the Mesolithic sites are also known on the territory of the Middle Trans-Urals, and tools were made from pebble raw materials. The Uralskie Zori III Mesolithic settlement is located on the Tura River (the Sverdlovsk Region of Russia). The collection of finds contains 2819 stone products. The raw material features of the site's stone inventory are quite unusual. Almost a half of all products (46.58%) are made of jasper: brown—45.64%; red-green—0.69%; brown—0.25%. Such a significant number of jasper products are not found on any other site of the Middle Urals. Even at the nearby Uralskie Zori I settlement (3,676 stone products), there is no such amount of jasper, although the percentage of jasper products is 9.93%. The study of products made of brown jasper with the application method showed that part of them is chipped from the chunk of the pebble crust. The chipping of pebble crust to get better quality pebble cores or chunks and the division of these cores into nucleus blanks with their subsequent processing led to the appearance of such a significant jasper complex at the site. The study of the jasper complex as a whole has helped us to figure out that the 3–4 medium-sized jasper chunks (15–20 cm in diameter) were split and processed in the settlement. The abundance of colored raw materials (primarily jasper and chalcedony) on the site is evidence of its seasonal functioning during the spring time. In spring, floodwaters had washed away the river's banks and had exposed washed-out coastal graves, where the local population selected the most conspicuous colored raw materials—jasper (brown, red-green) and chalcedony (red, yellow, orange) (Serikov 2000: 160–162).

On the territory of the Southern Trans-Urals, the sources of raw materials were river and lake gravels. Regardless of the location of the sites on each of them, the raw materials were jasper and flint pebbles, as well as rolled tiles. Products from almost all types of mineral raw materials have a pebble crust. Striped (red-green) and grey jasper were most often used, then brown jasper and black siliceous rock. Other types of raw materials were used sporadically (Bezprozvannyj and Mosin 1996, 20, 30).

3 Conclusions

The analysis shows that in each region of the Urals during the Upper Paleolithic and Mesolithic, there are peculiarities of using the local raw material, but almost everywhere, products made of pebble raw materials are preserved. Moreover, there are typical features in the use of pebbles and pebble raw materials at each archaeological site.

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Obsidian as the Main Raw Material for the Production of Tools in the Early Agricultural Societies of Azerbaijan

Roza B. Arazova and Natalia N. Skakun

Abstract The paper discusses the results of interdisciplinary research on identifying deposits that served as the sources of raw material for the production of obsidian tools by farmers of the 6th–4th millennia BC in Azerbaijan. The data obtained indicate the widespread use of obsidian for the manufacturing of various tools; moreover, raw materials from different localities were often used by inhabitans of a single settlement. These facts allow us to suggest close ties between the ancient agricultural peoples of different regions of the South Caucasus.

Keywords Ancient farmers · Azerbaijan · Obsidian tools · Deposits of stone · Interdisciplinary research

1 Introduction

Obsidian has been known as a raw material for the manufacture of tools since the earliest periods of human history. Empirical knowledge about the physical properties of obsidian, such as the ability to easily split into thin blades with the formation of sharp cutting edges, allowed ancient people to skillfully use its natural feature. The widespread use of obsidian as a raw material and as an exchange commodity began in the 8th–4th millennia BC.

A large series of studies is devoted to the examination of obsidian from the Neolithic sites of the Near East and natural deposits by the method of optical spectrography (Cann and Renfrew 1964; Renfrew et al. 1966, 1969; Dixon et al. 1968; Wright 1969). The most frequent chemical elements in obsidian were detected (Fe, Na, Mn, Sr, Ba, Zn, etc.), and four different groups were identified by their presence, each corresponding to a specific deposit of raw material. However, there are also such cases when the group contains raw materials from several sources. When comparing

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obsidian groups from the Neolithic sites of the Middle East and the deposits known there (one of them is in Central Anatolia, and the other is in Eastern Anatolia, in the Van region), the exploited sources of raw materials were identified as well as the main directions of the "obsidian trade" (Renfrew et al. 1966; Dixon et al. 1968). The migration routes of the Neolithic people and the sources of obsidian in the Middle East have been suggested by Renfrew. His model considers the movement of obsidian depending on the distance. Accordingly, if a settlement located no more than 250–350 km from the deposit, more than 80% of raw material is obsidian. Outside this "supply zone" and up to 600 km, the percentage of consumed obsidian decreases because these settlements were located too far from the main obsidian sources and supply routes. This is the so-called "contact zone," where the proportion of obsidian products drops to 30–40%. Finally, at a distance of more than 600 km, the number of tools made of obsidian drops sharply up to 1% (Renfrew et al. 1966; Dixon et al. 1968).

The article discusses the use of obsidian in the settlements of ancient farmers of Azerbaijan and identifies the locations of this raw material according to petrographic analysis.

2 Materials and Methods

A number of archaeological and statistical studies show that during the Neolithic-Eneolithic period in the southern Caucasus region (including Azerbaijan), obsidian was a preferable raw material for tool-making (Arazova 1986: 29, Fig. 2; Arazova 2006, 2020; Arazova and Skakun 2017, 2019). Inserts of sickles and knives, scrapers, punches, chisels and other tools represent the instrumental complex used by agricultural and cattle-breeding societies in the Caucasian region (Figs. 1 and 2).

Volcanic glass—obsidian—is characterized by a wide variety of structural and textural features of the mineral composition (Kashkai and Mamedov 1961) due to the water content released at different temperatures. Several varieties of obsidian are known, such as homogeneous, banded, and brecciated. Homogeneous obsidian from black-shiny to black, without any luster, resembling resin, was a common raw material for tool-making at the settlements of the Ganja-Kazakh plain. Grey obsidian sometimes with a pearlescent tint can also be found there, especially at the site of Kultepe.

Banded obsidian, which is also quite common, is close to homogeneous black but differs in transparency and alternating black stripes (veins). Tools made of such obsidian are often found on the sites of the Mil-Garabakh steppe.

Brecciated obsidian is dark to reddish-brown with black spots. This type of obsidian is widespread in the Nakhchivan Kultepe.

Obsidian deposits are connected to volcanic centres. Most of the early agricultural settlements in the South Caucasus are located on the plains, adjacent mainly to the Lesser Caucasus Mountains, rich in volcanic formations and obsidian. There are two sources of obsidian in Azerbaijan. The first is located on the border of Nakhchivan and

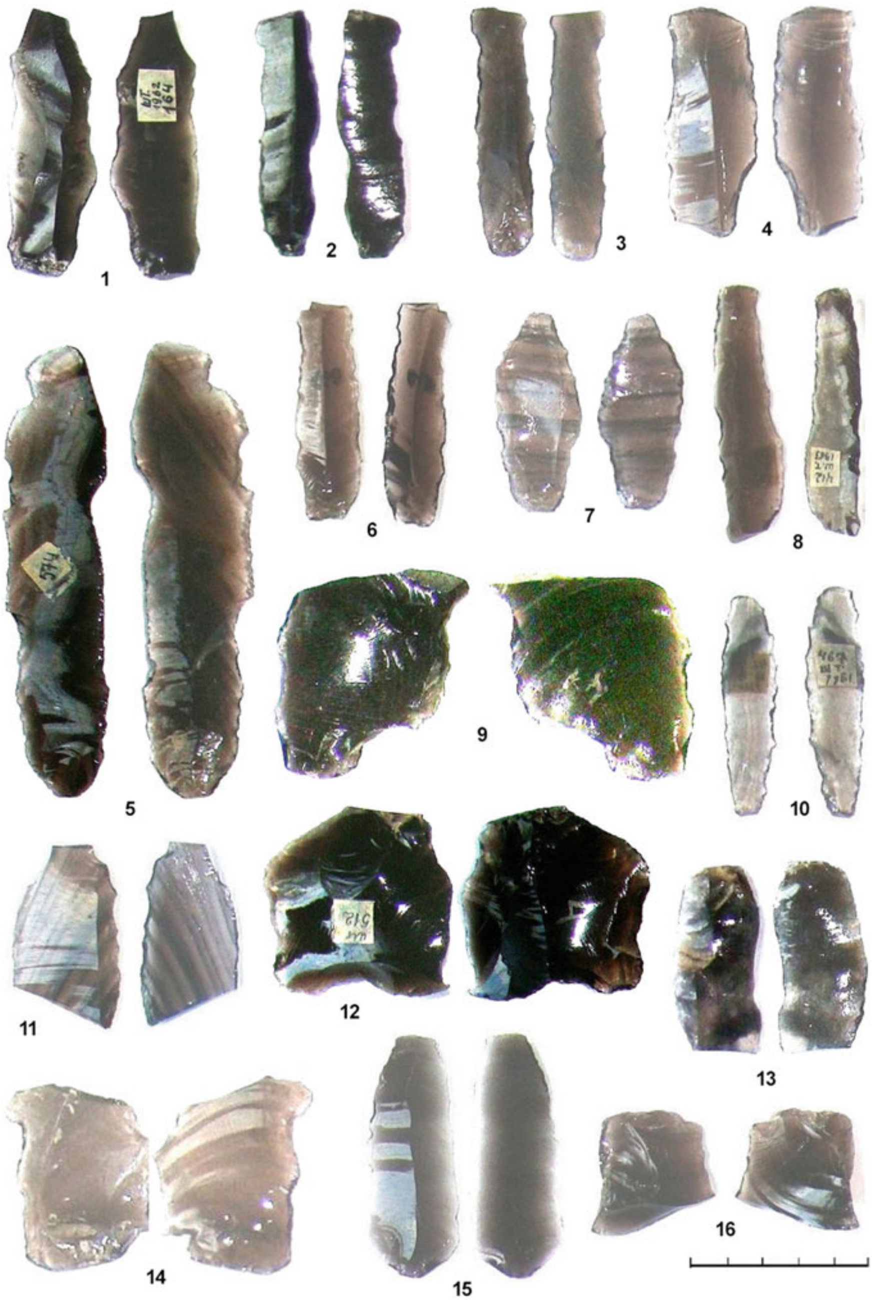

Fig. 1 Obsidian tools from the Shomutepe site (1–16)

Fig. 2 Obsidian tools from the Chalagantepe site (1–15)

Armenia, on the Guzgunlu, Gumargakh, Aghdaban, and Kochiberu mountains. The second, Kelbajar, has obsidian outcrops in four areas: Kechaldag, Deve-gezu (Small), Deve-gezu (Big), and at the source of the Bazarchay River (Mahmudov 1974). Of the a areas mentioned above, the most typical are Kechaldag and Deve-gezu (Small), located at an altitude of 3162 and 5171 m above sea level. Primary outcrops of raw materials are observed on the north-western and eastern slopes of Kechaldag, and the eastern side of Deve-gezu (Small). These sources are characterized by banded obsidian, from transparent to translucent with black streaks in the form of stripes (Mahmudov 1974: 18).

Two obsidian deposits are known on the territory of Georgia, in the Akhalsixi and Paravani regions (Kashkai and Mamedov 1961: 39–42, Fig. 2; Table 5; Esakia 1984; 2020; Esakia et al. 2017; Biagi and Gratuze 2016). The first is located 12 km north of the City of Akhalsixi, the second is north of the Trialeti Highlands, 15 km northeast of the Paravani Lake. Here homogeneous obsidian is common, i.e., those varying from dark gray to black-shiny color. Occasionally, dark brown stones with black spots can also be found.

There is a whole strip of volcanic manifestations in Armenia, including the Aragats, Geghama, Syunik, and other subzones (Geology of Armenia 1970: 105, Fig. 181). The main outcrops of obsidian are known in Arteni, Atis, Gutansar, Gokhasar, Spitaksar, etc. The following varieties represent obsidian from these sources: black, gray, banded, and brecciated (brown) obsidian, which is especially common.

As noted above, obsidian was widely used as a raw material in the early agricultural settlements of Azerbaijan and dominated over flint and other rocks. However, there are no obsidian outcrops near the sites, while flint, marl, mudstone, and other rocks are found there in abundance. It is a plaucible assumption that obsidian was delivered to settlements from the surrounding mountains. Back in the Soviet Era, obsidian from the sites of Krasnodar Territory and Checheno-Ingushetia and deposits of the North Caucasus was studied by the petrographic method. Based on the obtained indicators, the “obsidian paths” in the North Caucasus were identified (Nasedkin, Formozov 1965). To clarify this issue, petrographic analyses of obsidian from 6th to 4th millennia BC sites of Azerbaijan and deposits of the Lesser Caucasus were carried out by a geologist A.I. Mamedov at the Institute of Geology of the Academy of Sciences of Azerbaijan (in the 1970s). The study was based on the determination of the refractive index and other features (textural and structural). In total, 19 samples from archaeological complexes and 12 samples from deposits were studied (Arazova and Mamedov 1979).

3 Results and Discussion

The obtained data allow us to compare the parameters of the obsidian tools from the settlements with obsidian from natural deposits. As a result, it is possible to establish which deposits served as sources of raw materials for specific sites

Table 1 Results of petrographic analysis of obsidian samples from the archaeological sites of Azerbaijan

Sites	Petrographic features	
	Varieties	Refractive indices
1. Shomutepe (Western Azerbaijan)	Black shiny	1.484
2. Shomutepe (Western Azerbaijan)	Black shiny	1.484
3. Shomutepe (Western Azerbaijan)	Black muddy	1.485
4. Toyertepe (Western Azerbaijan)	Black shiny	1.484
5. Toyertepe (Western Azerbaijan)	Brown with black spots	1.485
6. Gargalartepe (Western Azerbaijan)	Brown with a dark red tint	1.485
7. Gargalartepe (Western Azerbaijan)	Black muddy	1.486
8. Rustepe (Western Azerbaijan)	Black shiny	1.484
9. Baba Dervish (Western Azerbaijan)	Black shiny	1.484
10. Baba Dervish (Western Azerbaijan)	Brown with black spots	1.485
11. Baba Dervish (Western Azerbaijan)	Brown with black spots	1.485
12. Baba Dervish (Western Azerbaijan)	Black muddy	1.486
13. Alikemektepe (Mughan)	Black shiny	1.484
14. Alikemektepe (Mughan)	Black shiny	1.484
15. Alikemektepe (Mughan)	Black shiny	1.484
16. Alikemektepe (Mughan)	Black muddy	1.485
17. Ilanlytepe (Garabakh)	Black shiny	1.484
18. Ilanlytepe (Garabakh)	Black muddy	1.485
19. Kultepe (Nakhchivan)	Black shiny	1.485

(Tables 1 and 2 show a correlation of the composition of obsidian used in settlements with the composition of obsidian from deposits).

For samples from the settlements of the Ganja-Gazakh plain in the western part of Azerbaijan, adjacent to Georgia, the following indicators were obtained: a low refractive index of 1.484 is typical for black-shiny and transparent obsidian (Shomutepe, Toyertepe, Rustepe, Baba Dervish), and 1.485 is typical for black-muddy sample (Shomutepe, Gargalartepe, Baba Dervish). The same parameters were established for obsidian samples from the nearby Paravani deposit (Esakia 1984; Biagi and Gratuze 2016). This indicates that the primary source of raw materials for these lowland settlements in Azerbaijan was Paravani obsidian (Fig. 3).

This conclusion becomes even more convincing if we consider the relatively close distance from the sites to the deposit: there is no more than 145 km in a straight line from the Lake Paravani region to the above settlements. Fields adjoining this deposit are strewn with obsidian debris; they stretch for tens of kilometres in the Khrami river valley. It is no coincidence that this river's valley was very favourable for settlement from the Paleolithic and later settled agriculture developed there (Berdzenishvili 1963: 5–16; Kushnaryova and Chubinishvili 1970).

Table 2 Results of petrographic analysis of obsidian samples from deposits of the South Caucasus

Deposits	Petrographic features	
	Varieties	Refractiveindices
1. Kechaldag (Azerbaijan)	Black shiny	1.484
2. Kechaldag (Azerbaijan)	Black muddy	1.485
3. Kechaldag (Azerbaijan)	Black muddy	1.485
4. Lake Parvani region (Georgia)	Black shiny	1.484
5. Lake Parvani region (Georgia)	Brown with black spots	1.485
6. Lake Parvani region (Georgia)	Black muddy	1.486
7. Bazenk (Armenia)	Black shiny	1.485
8. Gutansar	Black muddy	1.486
9. Gutansar	Brown with black stripes	1.487
10. Gokhasar	Black muddy	1.486
11. Hatis	Brown with black spots	1.486
12. Arteni	Brown with black spots	1.487

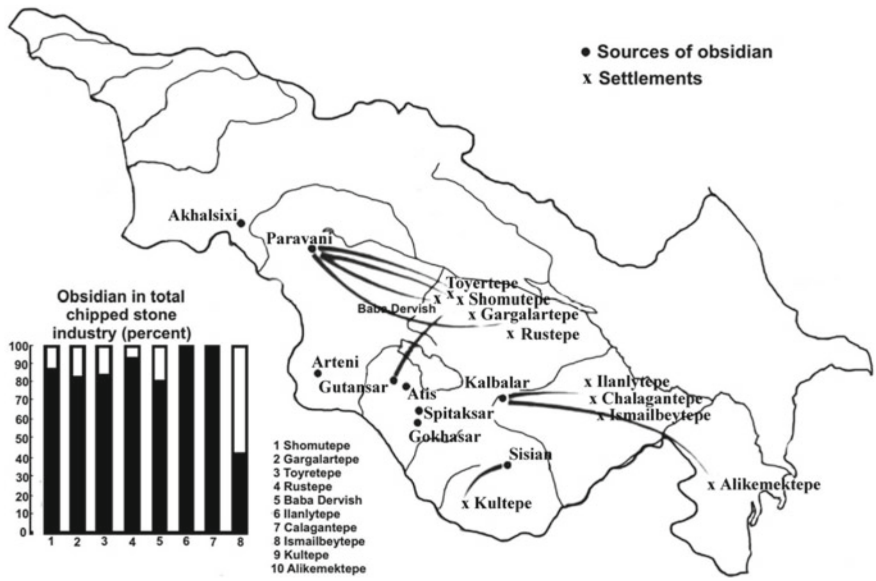

Fig. 3 Sources and transportation of obsidian (VI–IV mil B.C.)

Along with the exploitation of this source, the inhabitants of the settlements mentioned above used obsidian from other adjacent deposits, namely the volcanoes of the Armenian Highlands: the samples from Gutansar and Gokhasar give identical refractive indices with the samples from Gargalartepe and Baba Dervish, equal to 1.486.

Interesting indicators were obtained for samples from the Mil-Garabakh and Mughan steppe (Ilanlytepe and Alikemektepe), where obsidian with the refraction indices of 1.484 and 1.485 was used. Samples from the Kelbajar source yield the same indicators.

It should be noted that at Ilanlytepe, the tools are exlusively made of obsidian (Narimanov 1987: 103). This suggests that the ancient population of the site actively used the Kelbajar deposit, located within a radius of 96 km from the site. It can be assumed that other neighbouring settlements of Garabakh, such as Ismailbeytepe, Chalagantepe, Leylatepe, being near the Kelbajar outcrops, also preferred obsidian and widely used this raw material. However, it is also possible that the population of these settlements could have used other nearby outcrops of volcanic glass.

As for Alikemektepe on Mughan, where Kelbajar obsidian was also used for making tools, the significant remoteness of the settlement from the deposit (approximately 230 km) undoubtedly determines the predominance of flint products over obsidian in the industry.

For an obsidian sample from Nakhchivan Kultepe I a coefficient of 1.485 was obtained. The same coefficient has obsidian from the Bazenk volcano (Syunik subzone), located 78 km from the settlement. Therefore, we may assume, that Bazenk volcano zone could serve as a raw material source for tools from the Kultepe settlement site (Abibullaev 1982: 52–62). Other volcanoes from this subzone, especially rich in brown (or with black spots) obsidian, which is often found in the obsidian industry of Kultepe, could also serve as a source of obsidian import for the Nakhchivan Kultepe.

4 Conclusions

In sum, we can say that the study of obsidian from the Neolithic-Eneolithic sites of Azerbaijan and several deposits of the Lesser Caucasus allows establishing various sources of exploitation and transportation of raw materials. In Azerbaijan, the settlements are located at a distance no more than 300 km from the source, i.e., within the Renfrew's "supply zone". Obsidian tools constitute the basis of the stone industry with about 80% in the assemblage. Consequently, the early farmers of Azerbaijan preferred obsidian, with its physical properties superior to other rocks, especially since the outcrops were abundant near their sites. For example, the supply of raw materials to settlements, of the Ganja-Gazakh plain in the western part of Azerbaijan is explained by contacts and exchange links with neighboring early agricultural tribes of Kvemo-Kartli in the 6th-4th millennia BC. According to some researchers, the exchange among the early tribes arose out of vital necessity, and was based on the ecological diversity and, first of all, the raw material source (Masson 1976: 78).

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"Home, Sweet Home": Stones from the Bronze Age Settlement Hearths (South Trans-Urals, Russia)

Irina P. Alaeva, Maksim N. Ankushev, Egor O. Vasyuchkov, and Polina S. Ankusheva

Abstract The paper presents the results of the analysis of 200 stones from hearths, ash soil, and the inter-structure territory of the southern Trans-Urals Bronze Age settlements (21–16 centuries BC). Revealing of the stones' main parameters (size, weight, breed, presence/absence of fire impact, surface treatment) made it possible to characterize the gradation using different types of stones. Stones from the hearths filling have similar characteristics: homogeneous rock composition, similar size and weight, traces of deliberate crushing chips to obtain the desired size, traces of strong fire impact. Stones from the ash soil strata are diverse: some rocks were used to manufacture tools (talcochlorite, quartzite), metallurgy (magnetite ore), and rocks used in the hearths. On many of the stones from the ash soil, the impact of the fire was noted. Such a composition of the ash soil may indicate the nature of its formation as a result of burning out the garbage. A wide variety of raw materials also characterizes the stones collected in the inter-structure area. Still, unlike stones from the hearths, they do not have a standardized size, many chips, and there are no stones with traces of fire. Based on a comparative analysis of the parameters of stones from different structures, it can be concluded that the selection of stones for hearths was intentional. Besides, the hearths were not associated with metallurgy (copper was practically absent in the hearth soils). These facts indicate that the hearths with stones were used only for heating.

Keywords Bronze age · Late Bronze age · Hearths · Rocks · Sintashta culture · Alakul culture · Southern Trans-Urals

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1 Introduction

Stones in ancient hearths can be used for different purposes: as a part of a structure (lining the boundaries of the hearth, laying out /bottom of the hearth, house structure, a vault over the hearth) and as a functional element (using the properties of stones in heat accumulation, heat transfer). On Bronze Age settlements from the southern Trans-Urals (2nd millennium BC), stones in the construction of hearths are practically unknown. On the contrary, hearth depressions with a scattering of small rocks, which do not have traces of coating, processing, and occur chaotically, are massively presented.

Hearths with stones are among the varieties of furnace structures of Bronze Age settlements of the Ural-Kazakhstan region (Potemkina 1985; Koryakova and Epimakhov 2007). On the Sintashta and Petrovka cultures' fortified settlements, they are represented by elongated depressions filled with carbonized stones and grooves with stones leading to the sides of a pit well (settlements Arkaim, Ust'ye I). On unfortified settlements, in Alakul house structures, they are presented in the form of depressions with stones located near the walls of the house structure, sometimes at some distance from the pit wells (noted in the settlements of Mirny II, Mirny III, Kulevchi III). In the Final Bronze Age, they are represented by pits with horizontal chimneys lined with stones (found in the settlements of Malaya Berezovaya-4, Atamanovka V).

The main aim of the study is to determine the functional purpose of stones in hearth depressions in the southern Trans-Urals Bronze Age settlements. The following tasks were set in the work: characterization of morphological parameters of stones from various objects; determination of the rocks strength properties and resistance to fire impact stress; an analysis of the geological situation in the territories of localization of settlements to determine the local/ non-local nature of the raw material; a comparative study of stones from different types of objects (hearths with stones from the ash soil and inter-structure territory); a comparison of the petrology of stones from hearths and the tool complex.

2 Materials and Methods

For the study, hearths with stones were selected. They were found in the five Bronze Age settlements of the southern Trans-Urals, belonging to the two periods: the Sintashta-Petrovka period—21 to 18 centuries BC (Ust'ye I settlement) and the Alakul period, 18–16 centuries BC (Bolshaya Berezovaya-2, Malaya Berezovaya-4, Zvyagino-4, and Chebarkul III settlements).

From the materials of the five settlements, 200 specimens of stones were selected from objects and structures of various morphologies (Table 1):

- From the filling of hearths: depressions and grooves on the side of the well, filled with stones; depressions with stones near the walls of the house structure;

Table 1 Objects with stones in the Southern Trans-Urals Bronze Age settlements

Settlement	Number of samples	Localization	Number of rock types	Rocks	Traces of fire impact on stones
Ust'ye I	32	House structure No. 12: object 1 (hearth) object 5 (well)	2	Hematite-quartz, quartz pebbles	100%
Bolshaya Berezovaya-2	91	House structure No. 2: pit 1 (well), hearth 1	2	Quartz pebbles, granite	83%
Zvyagino-4	30	House structure No. 1: object 2 (hearth)	1	Quartz-carbonate metasomatite	100%
Malaya Berezovaya-4	28	Sector 12M, outside house structures	9	Vein quartz, silicite with quartz veins, chloritolite, quartzite, granite, talcochlorite	Absence
Chebarkul III	19	Excavation area B, house structure No. 2, yellow ash soil above object 1B	6	Quartz-carbonate metasomatite, granite gneiss, talcochlorite, silicite, vein quartz, magnetite ore	80%
Total	200				

- From the ash soil strata;
- From scatters in the inter-structure territory.

The sample from the fortified settlement Ust'ye I includes stones from object 1 (hearth) and object 5 (well) of house structure No. 12. The functioning of the hearth and well in house structure No. 12 is attributed to the period of the Petrovka culture, while a fragment of the Sintashta vessel was found at the bottom of the well.

Object 1 (hearth) is located on the high side of the well (object 5), 1 m from the edge of the well pit. It has an elongated oval shape, dimensions 1.1 × 0.4–0.5 m. The eastern part of the object was slightly deepened into the sterile soil by 2–5 cm; within the western depression (0.5 × 0.5 m, up to 15 cm deep), an accumulation of stones was localized (Fig. 1a, b). The sides of the recess were lined with flattened rectangular stone tiles measuring 30 × 15 cm and 20 × 30 cm, 5–7 cm thick, the central part was filled with small unprocessed stones measuring from 2 × 2.5 cm to 8 × 9 cm. The object's filling is gray humus soil. The finds within object 1 are insignificant: a fragment of a vessel's body, a flint chip, and three burnt animal bones.

Object 5 (well) is located in the southern part of house structure No. 12, at the buried soil level, the dimensions of the pit were 2.6 × 2.4 m, after one meter it

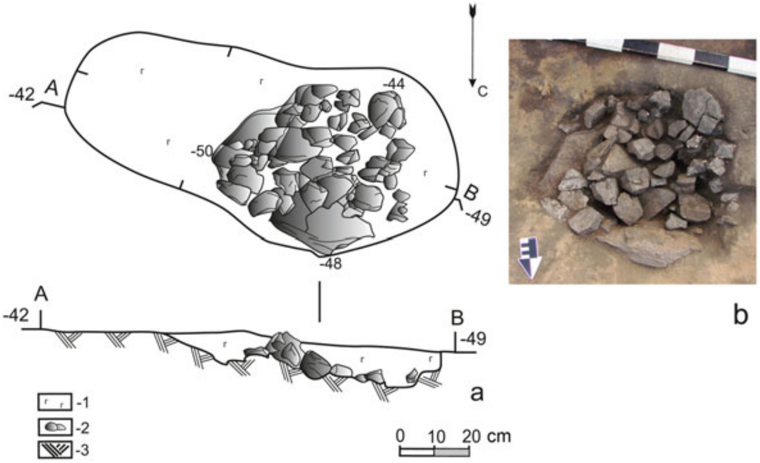

Fig. 1 Hearths with stones from the Southern Trans-Urals Bronze Age settlements. Ust'ye I fortified settlement: a—plan, profile of object 1, b—photo of stones from object 1. *Legend*: 1—humus soil, 2—stones, 3—sterile soil

was reduced to 1.6 × 1.6 m, in the bottom part, the diameter of the well shaft was 85 cm. The depth of the well from the floor level in the construction was 3.7 m. Around the well, an in-depth near-well zone with a complex system of ditches in the pit's sides was formed. On the northwestern and southeastern sides of the well pit, inclined grooves leading into the well were arranged diagonally from each other. In the grooves' filling, accumulations of small stone were found, measuring from 2 × 2.5 cm to 8 × 9 cm.

In the ***Ust'ye I fortified settlement's*** collection, a total of 32 samples were presented: from object 1 (the hearth), there are 15 specimens, and from the filling of the southwestern groove of object 5 (the well), there are 17 specimens. Half of the collection is very small in size, varying from 2.5 × 2 × 1.5 cm to 4 × 4.5 × 2 cm, weighing from 20 to 93 g; the second half has sizes from 5 × 3 × 2 cm to 8 × 3.5 × 3 cm, weighing from 42 to 365 g. On stones of a larger size, randomly located chips were recorded. The stones from the filling of the hearth and the groove on the well's side had similar parameters.

Most of the stones from the filling of object 1 (the hearth) and the groove onboard object 5 (the well) are hematite-quartz rocks, quartz pebbles. In rare cases, there are granites, chlorite schist, and siltstone. All samples showed traces of temperature effects of varying degrees (from strong on granites to weak on quartz pebbles) in the form of cracks, destroyed rock structure, the reddish shade of the surface.

The collection from ***the Bolshaya Berezovaya-2 settlement*** contains materials from house structure No. 2 (a hearth and a well) and the inter-structure territory. The functioning of the identified house structures and the entire settlement is associated with the Alakul culture.

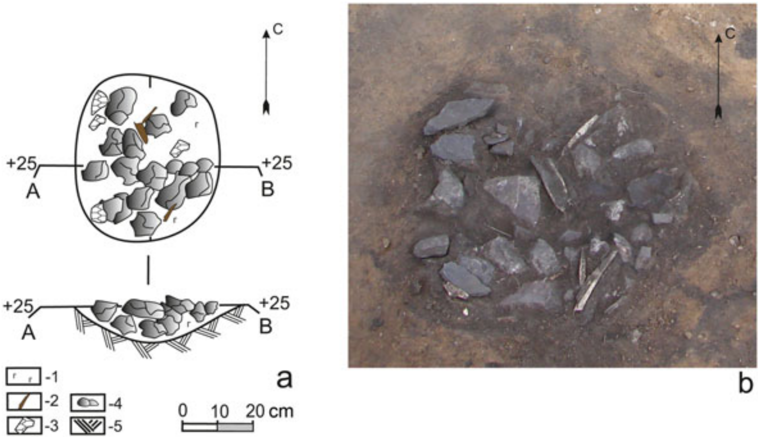

Fig. 2 Hearths with stones. Bolshaya Berezovaya-2 unfortified settlement: **a**—plan, profile of Hearths 1, **b**—photo of stones from Hearths 1. *Legend*: 1—humus soil, 2—bones, 3—fragments of ceramics, 4—stones, 6—sterile soil

Hearth 1 is located in the northern part of the house structure at the edge of the pit well, about five meters from the side of the well. The size of the furnace was 0.3 × 0.4 m, the depth reached 10 cm, and the depression was lenticular. The hearth is filled with small stones (several fragments of Alakul ceramic vessels and small animal bones are among them) (Fig. 2).

Pit 1 (the well) was located in the southern part of house structure No. 2 within a large near-well depression (7.5 × 6 m). At the sterile soil level, the pit dimensions were 2.5 × 1.8 m, one meter deeper, the pit parameters were 2.2 × 1.4 m. The depth of the pit was 2.8 m from the sterile soil. Within the near-well zone, on the descent to the pit well, areas of calcined soil were recorded, up to 5 cm thick. The areas of carbonization (0.7 × 0.45 m, 0.6 × 0.22 m, 0.4 × 0.2 m) were located 30–40 cm from each other in the southern and the eastern part of the near-well zone. Heaps of rough stones were localized at the edge of the pit well.

The collection from the Bolshaya Berezovaya-2 settlement includes 91 specimens. Twelve samples are coming from the filling of Hearth 1 in house structure No. 2. The parameters of the stones are varying from 2.5 × 3.2 to 9 × 7.5 cm in size, weighing from 15 to 189 g. Almost all stones from the filling of the hearth belonged to quartz pebbles. Chips were noted on the surface of half of the stones; traces of fire impact were recorded on most of the specimens. Seventeen specimens are coming from the near-well zone of pit well 1. The dimensions of stones are varying from 4 × 2 × 1.5 cm to 15 × 7.5 × 5 cm in size, weighing 27 to 494 g. Rocks are represented by quartz pebbles, hematite-quartz rocks, silicites, granites. Chips were noted on six stones, traces of fire impact on ten specimens. There are 62 pieces of stones collected from the inter-structure territory: 1 to 5 m around house structure No. 2 and the adjacent house structure No. 3. The parameters of the stones: half of the stones (32 samples) are very small in size (from 2.5 × 2 × 1 cm to 4.5 × 4.5 × 3 cm, weighing from 10 to 133 g); there are 17 samples of small stones, ranging in size from 5 × 4 × 3 cm to 7.5 × 6.5 cm, weighing from 56 to 282 g and there are 12 samples of a larger size: from 8 × 5 × 3 cm to 14 × 5 × 2.5 cm, weighing from 123 to 555 g. Fragments from the inter-structure territory are represented by a wide variety of rocks: quartz-silicite pebbles, hematite-quartz rock, quartzite, ferruginous quartzite, gabbro, granites, silicites, chloritolite, chlorite schist with pseudomorphs of limonite over pyrite. Chips were noted only on 14 stones; most of the stones have no traces of fire impact.

The collection from ***the Zvyagino-4 settlement*** contains materials from the filling of object 2 (the hearth) in house structure No. 1. The ceramic complex of the settlement belongs to the Alakul culture; several fragments of ceramics are attributed to the Fedorovo culture.

Object 2 (the hearth) is located 1.5 m from the longitudinal wall of the house structure in its northern corner. It was a hollow in the sterile clay, elongated-oval in shape, 80 × 55 cm in size, 32 cm deep (Fig. 3). The hearth was filled with many carbonized stones, at the bottom—a black carbonaceous layer, up to 14 cm thick. A fragment of an Alakul culture vessel was found in the filling of the hearth.

The collection from the Zvyagino-4 settlement contains 30 stones from the filling of object 2 (the hearth). The dimensions of the stones range from 5 × 2.5 × 2 cm to 11 × 7 × 5 cm, weighing from 30 to 582 g. Chips were noted on six specimens, traces of strong fire impact were recorded on all stones (Fig. 4a, b). All stones belonged to

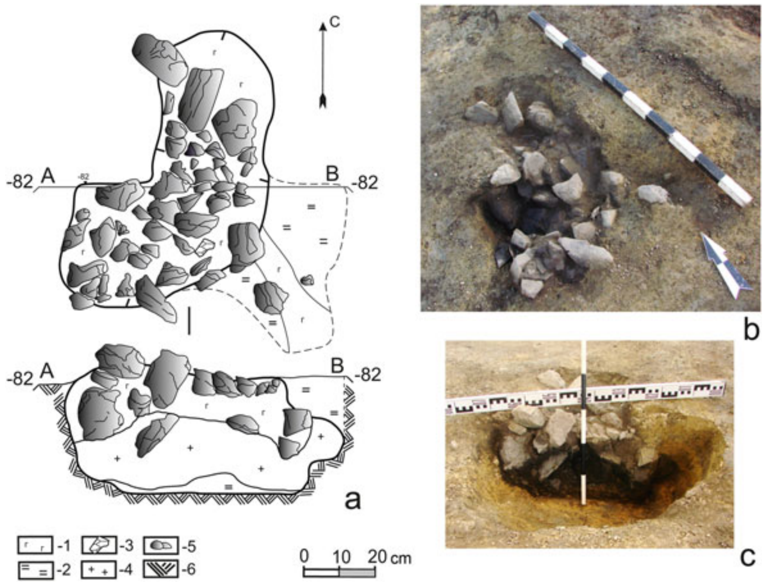

Fig. 3 Hearths with stones. Zvyagino-4 unfortified settlement: **a**—plan, profile of object 2, **b**—photo of stones from object 2. 1—humus soil, 2—clay, 3—fragments of ceramics, 4—coal, 5—stones, 6—sterile soil

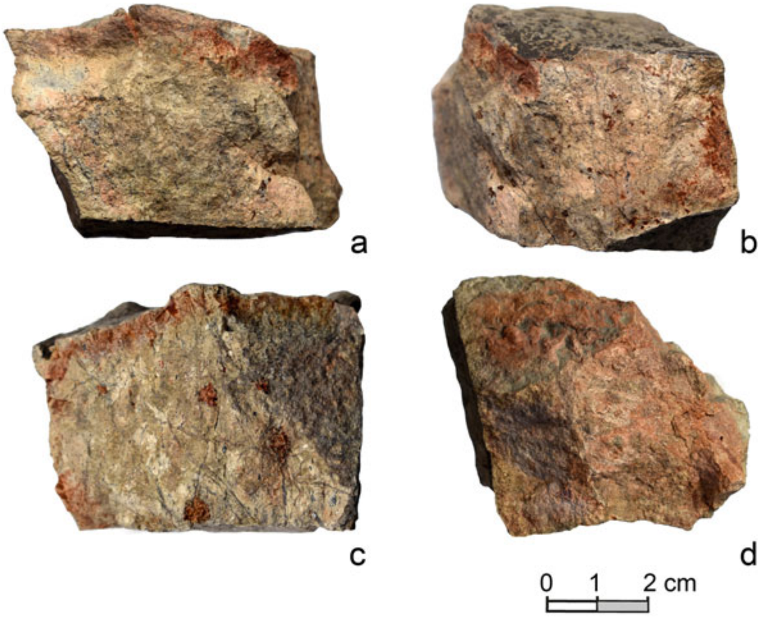

Fig. 4 Stones with fire impact traces from hearths. Zvyagino-4 unfortified settlement

the same rock – quartz-carbonate metasomatite.

The collection from ***the Malaya Berezovaya-4 settlement*** contains materials from the inter-structure territory; some stones were 3–10 m from the house structure. Along with the stones, the ceramics of the Alakul culture are presented in the cultural layer.

The collection contains 28 stones of different sizes. Parameters of stones: from 35 × 25 × 20 to 12.5 × 9 × 4 cm, weighing from 19 to 406 g. Chips were noted only on three specimens; traces of fire impact were not recorded. Among the rocks, the following are noted: quartz vein fragments, silicite with quartz veins, chloritolite, quartzite, granite, talcochlorite.

The ***Chebarkul III settlement*** has two stratigraphic horizons: the Alakul culture and the Cherkaskul-Mezhovka cultural complex. The collection includes stones from the ash soil strata, loose soil of yellow color with carbonized spots. The yellow ash soil lies over house structure No. 2. In the ash soil strata, artifacts belonging exclusively to the Alakul culture were presented. The functioning of house structure No. 2 was determined by the seventeenth century BC based on radiocarbon dating of animal bones from the bottom of the well.

The collection from the Chebarkul III settlement contains 19 samples. Most of the stones were small in size, from 3 × 3 × 1.5 cm to 7.5 × 4.5 × 2 cm, weighing from 30 to 151 g, two of them were represented by tiles measuring 23 × 16 × 3.5 cm, weighing 350–385 g. Chips were recorded on five stones, traces of fire impact were noted on most specimens (15 units). The stones belong to various rocks: quartz-carbonate metasomatite, granite gneiss, talcochlorite, silicite, quartz vein fragments, magnetite ore.

3 Results and Discussion

Based on the study of stones from the Bronze Age settlements objects of the Southern Trans-Urals, several conclusions can be drawn.

The rocks presented in the five settlements in the different landscape zones of the southern Trans-Urals demonstrate a great variety. Analysis of the geological situation in the zones of localization of monuments indicates the use of local rocks, and its diversity does not allow us to talk about any import in the supply of rocks, both for objects and the manufacture of a tool kit.

Near the unfortified settlements Bolshaya Berezovaya-2, Malaya Berezovaya-4, and the fortified settlement Ust'ye I, at least 25 types of rocks are recorded (Fig. 5).

In Zvyagino-4 and Chebarkul III unfortified settlements, at least 18 types of rocks are recorded (Fig. 6).

A clear gradation was recorded in the use of rocks for different purposes. The stones from fillings of hearths from various settlements were similar (quartz pebbles, quartz-bearing rocks, and quartz-carbonate metasomatite were most often used for these purposes). At the same time, for the creation of tools and stone products, a stable set of rocks was used for each type of tool and known in different Bronze Age settlements (Table 2).

The parameters of stones from different objects and structures are significantly different:

1. Stones from the filling of hearth depressions, grooves on the board of wells, and depressions with stones near the walls of house structure both Sintashta-Petrovka (Ust'ye I, object 1, object 5) and Alakul period (Bolshaya Berezovaya-2, pit 1, center 1; settlement Zvyagino-4, object 2) had similar characteristics. It is homogeneous in rock composition, size, and weight, with signs of chipping/deliberate crushing to obtain the desired size, all with traces of strong fire impact (Fig. 4).
2. Stones from the ash soil layer over house structure No. 2 in Chebarkul III have a great variety of types: both rocks that could be used for making tools (talcochlorite, quartzite), and rocks that were used in hearths with stones. Besides, fragments of metallurgical waste (magnetite ore) were also found in the ash soil layer. On many specimens from ash soil, traces of fire impact are noted. Such a composition of the ash soil may indicate the nature of its formation as a result of burning out the garbage.
3. Stones from the inter-structure area are also characterized by a wide variety of rocks (settlements Bolshaya Berezovaya-2 and Malaya Berezovaya-4). Unlike

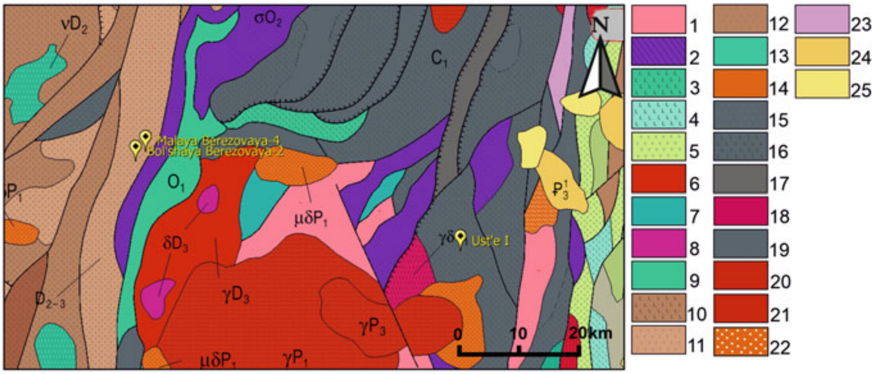

Fig. 5 Geological structures in the area of Bolshaya Berezovaya-2, Malaya Berezovaya-4, Ust’ye I settlements. 1—Middle Riphean amphibolite, quartzite, shale; 2—Early Ordovician serpentinites and metasomatites; 3—Early Ordovician basalt metatuffs, shales, metatuffites; 4—Middle Ordovician shale, siltstone, sandstone; 5—late Ordovician trachybasalts, basaltic trachyandesites, basalts, andesites, tuffs, siltstones; 6—Early Silurian diorites, granodiorites, plagiogranites; 7—Early Silurian diorites, granodiorites, tonalites, plagiogranites; 8—Silurian metagabbro, metagranodiorites, metagranites; 9—Silurian crystalline schists, metatuffs and metasilicites; 10—Middle Devonian basalts, tuffs, andesite, rhyodacite, rhyolite, jasper; 11—Middle Devonian andesites, basaltic andesites, rhyolites, tuffs, shales; 12—Middle Devonian basalts, basaltic andesites, tuffs, shales, jaspers, rhyodacites; 13—Middle Devonian hornblende diorites and gabbros; 14—Late Devonian monzodiorites, granosyenites, granites, granodiorites; 15—Early Carbon trachybasalts, basaltic trachyandesites, rhyodacites, tuffs, sandstones, siltstones; 16—Early Carbon sandstones, siltstones, shales, limestones, tuffs; 17—Early Carbon sandstones, siltstones, gravelstones, conglomerates, shales, limestones; 18—Early Carboniferous adamellites; 19—Early carbon limestone, shale, quartz sandstone, limestone, marble; 20—Early Permian granitoids and metasomatites; 21—Early Permian granitoids; 22—Early Permian monzodiorites, granosyenites, granitoids; 23—late Triassic conglomerates, gravelstones, sandstones, siltstones, shales; 24—Paleogene sands, silts; 25—Neogene clays with gypsum inclusions

stones from hearths, they are not standardized in size, do not have a large percentage of chips. Among them, there are no rocks with fire impact.

The revealed selectivity in the choice of rocks for hearths may indicate their special purpose for heating houses and peoples.

Several options for using stones in hearths to accumulate heat:

1. Using heated stones for heating sleeping places or as mobile hearths;
2. Using the steam (like in a sauna) for different purposes:

- Describing the life of the Slavs in the 9th age, Ibn Rustah noted that the hot stones used to generate steam and heat dwelling (Ibn-Dasta 1869, 33 p.);
- For hygiene purposes (steaming the skin cleansing);
- For medicinal purposes, steam inhalation (warming up the upper respiratory tract). Use steam as evidenced by the intense destruction of stones (Hot stones watered by cold water);

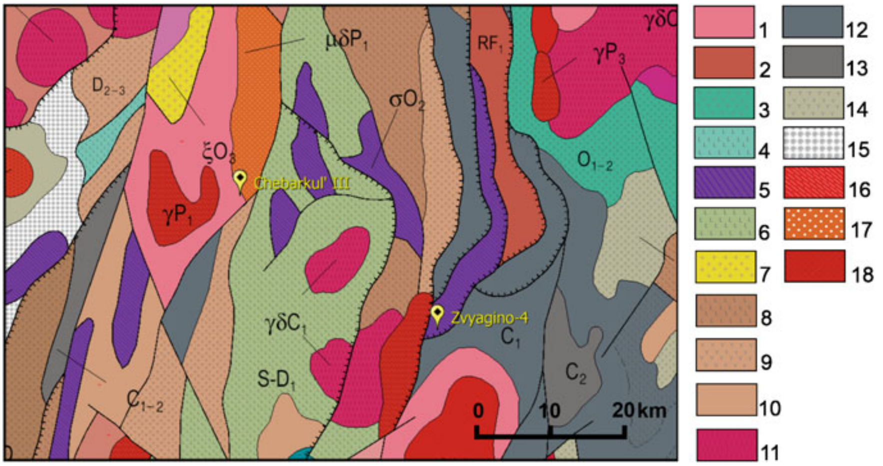

Fig. 6 Geological structure in the area of settlements Zvyagino-4, Chebarkul III. 1—Early Proterozoic biotite gneisses, quartzites; 2—Early Ordovician metasandstones, aleurolites, quartz sandstones, phyllites, metabasalts, shales; 3—Early Ordovician metabasalts, metatuffs, rhyolites, shales; 4—Early Ordovician metabasalts, schists, quartzites, metasandstones; 5—Middle Ordovician serpentinites, gabbro, dolerite dikes; 6—Silurian shales, quartzites, metabasalts and metatuffs; 7—Silurian miaskites, carbonatites, pegmatites; 8—Early Devonian basalts, sandstones, siltstones, shales; 9—Middle Devonian basalts, andesites, tuffs, jaspers, shales; 10—Middle Devonian metabasalts, shales, limestones; 11—Late Devonian diorites, granodiorite, granite; 12—Early Carbonian conglomerates, sandstones, schists, marbles; 13—Middle Carbonian limestones, mudstones, siltstones, sandstones; 14—Middle Carbonian granite–gneisses; 15—Late Carbonian melange serpentinites; 16—Early Permian granites; 17—Early Permian monzodiorites, granosyenites, granites; 18—Early Permian granites, leucogranites

- For drug purpose. Describing the life and customs of the Scythians, Herodotus noted that the Scythians cleansed the body in a steam bath: "The Scythians then take the seed of this hemp and, creeping under the rugs, they throw it on the red-hot; and, being so thrown, it smolders and sends forth so much steam that no Greek vapor-bath could surpass it" (Herodotus 1921–25, 273–275 p.). Considering the Iranian origin of the Scythians, one can assume the existence of this tradition for Indo-Iranian cultures of the Bronze Age.

4 Conclusions

The standardization of stone sizes and the use of specific rocks indicate the purpose of the hearths as heating. Also, it is indicated by the absence of metallurgical activity. Analysis of soil from the hearth on the Zvyagino-4 settlement showed a low quantity of copper (Alaeva et al. 2021). Stones were not used in the construction of the hearths. This is indicated by the absence of clay coating and the randomness in the

Table 2 Rocks in bronze age settlements

Settlement	Rocks in objects	Rocks of tools	Geological structure of the settlement area
Ust'ye I	Object 1 (hearth): hematite-quartz rock, quartz pebble	Pestle (syenite, basalt, tuff, quartz porphyry, sandstones, silicite, quartzite, carbonaceous shale); coasters (slate); casting mold (talc)	The settlement is confined to the Bredy suite (C_1bd), composed of sandstones, conglomerates, siltstones, gravel stones, limestones, shales, coal beds. In the west and east, these rocks are bordered by volcanic rocks of basic, intermediate, and felsic composition, volcanogenic-sedimentary rocks of the Bereznyakovo strata (D_3-C_1bz). In the north, phyllite schists of the Moscow strata (O_{1-2} ms) are found. Serpentinites of the Uspenovo gabbro-dunite-lherzolite-harzburgite complex (ιO?u) are manifested in the west. In the southwest, there is a large Dzhabyk-Sanarka granite complex ($\gamma P_1 ds_{1\text{-}2}$) represented by biotite and two-mica granites (Tevelev et al. 2018)
Zvyagino-4	Object 2 (hearth): quartz-carbonate metasomatite	No stone tools were found in the 2018 excavation	The settlement is confined to the serpentinites of the Kazbaevo massif (O_2čk). In the east, there are terrigenous and terrigenous-carbonate rocks of the Mayachnaya suite ($O_{1\text{-}2}$mč), Birgildy (C_1br), and Solnechnaya (C_1sl) sequences. In the west - sediments of siliceous-terrigenous strata (C_1jt) and basalts-andesites of the Kuluevo strata ($D_{1\text{-}2}$ kV). The Kalinovo (P_1st) and Zvyagino (P_1ds) granite massifs are located nearby (Petrov et al. 2015)
Bolshaya Berezovaya-2	Hearth 1: quartz pebble, granite	Hammer (silicite); Stands (sericite-quartz slate)	The settlements are confined to the contact of sericite-quartz schists, quartzites, radiolarites, and various volcanogenic rocks of the Arsi terrigenous strata (D_3an) and apogharzburgite, apodunite serpentinites of the Brient dunite-harzburgite complex (ΣD_1br), passing into talc rocks. In the west, the Arsi strata bordered with the Kiembaevo suite (D_1km) composed of basalts, rarely andesites, interlayers of marbleized limestones, and silicites. In the east, the Slyuda strata (O_1sl) is developed, composed of quartz-epidote-plagioclase-hornblende crystal schists and interlayers of graphite-muscovite-containing quartzites (Moseichuk et al. 2017)
Malaya Berezovaya-4	Inter-house structure area: vein quartz, silicite	Pestle, graters, abrasives (quartzite, sandstone, silicite; whetstones (silicite); sinker (talcochlorite); mace (serpentinite)	

(continued)

Table 2 (continued)

Settlement	Rocks in objects	Rocks of tools	Geological structure of the settlement area
Chebarkul III	Ash soil above house structure 2: Granite-gneiss, talcochlorite, magnetite ore, silicite, quartz-carbonate metasomatite	Pestles, abrasives (quartzite, sandstone,); grater (granite-gneiss); hammers (quartz pebbles, silicite); supports (carbonaceous shale); casting molds (chloritolite); sinker (quartzite)	The settlement is located in the contact zone of the Elanchik (PR_1el), Kyshtym strata (PR_1kš), the Verkhne-Saitovo suite (R_2vs) composed of amphibolites, quartzites, gneisses, schists and gravelites, metasandstones, metasiltstones of the Kundravy suite (Vkn). Metamorphic rocks border on granites of the Kisegach (P_1uk) and Elanchik (P_1e) massifs. In the southwest, there are volcanic rocks, siliceous and carbonaceous shales of Bulatovo (S_1-D_1bl) and Kopalovo strata ($D_{2\text{-}3}$kp), as well as conglomerates, gravel stones, sandstones, siltstones, clay shales, limestones of the Sosnovo strata (C_1ss). The area is complicated by bodies of apogarzburgite serpentinites and gabbroids of the Chebarkul massif (O_2čk), with which talc-carbonate rocks are associated (Petrov et al. 2015)

arrangement of stones. The strong impact of fire on stones indicates their function is keeping warm in the house.

Thus, we concluded that the special heating hearths with stones were used in the settlements of the Bronze Age. The hearths with stones were used only for heating purposes.

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Site Analyses and Geographic Information Systems (GIS) in Archaeology

Geoarchaeological Studies of Kurgans with Moustaches: Achievements and Prospects

Ivan V. Grudochko

Abstract The paper presents the results of geoarchaeological studies of kurgans with two stone ridges (referred to as moustaches) from the dual perspective of geology and radiocarbon dating. The first describes the survey of rocks in a monument and their sources, as a result of which we proposed the reconstruction of the construction process of the entire complex. We believe that the construction of one complex could be carried out within a fairly short period: a month or no more than one season. Radiocarbon data quite confidently date the kurgans with moustaches to the III/IV to mid-VII centuries.

Keywords Middle ages · Great migration of peoples · Steppe · Nomads · Kurgans with Moustache · Geology · Radiocarbon dating · Chronology

1 Introduction

The history of the Eurasian nomads is closely connected with the Ural-Kazakh region. It was in these steppes that the main migrations of the nomads of antiquity and the Middle Ages occurred. The history of the formation of the Scythian-Saka, Sarmatian, Hunnic, Turkic, and other cultures cannot be studied without archaeological materials of the South Ural region and Kazakhstan (Tairov 2017; Botalov 2008). One of the turning points in world history is the Migration Period, which can be traced here through the disappearance of the Hunno-Sarmatian (Late Sarmatian) archaeological culture and the emergence of a completely new historical and archaeological phenomenon called kurgans with moustaches. We believe that it is these complexes that testify to the initial stage of the Turkification of the Ural-Kazakh steppes.

Kurgans with moustaches were discovered in the first half of the XX century. This original archaeological complex is a burial mound from which two arched stone ridges (referred to as moustaches) 15 to 200 m or more in length extend. These monuments are mainly located in the Ural-Kazakhstan steppes (Fig. 1), although

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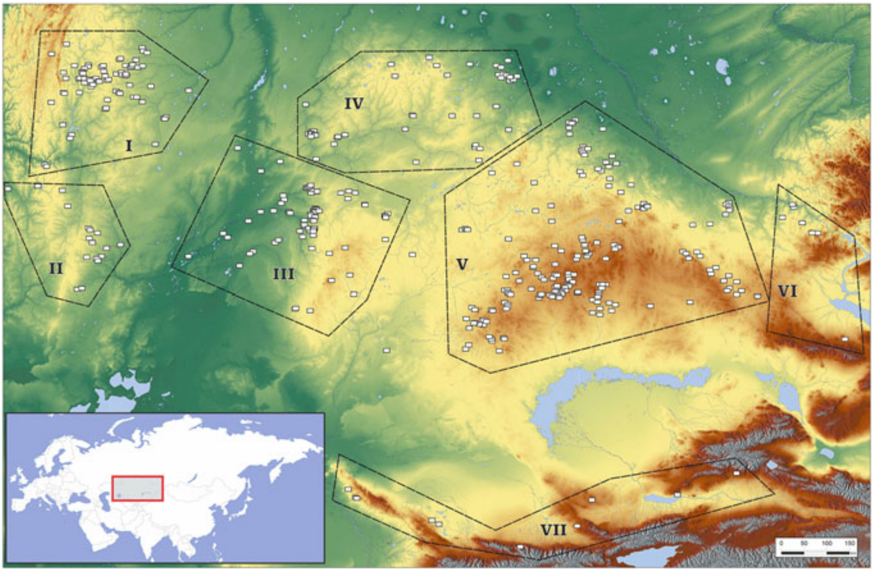


Fig. 1 The zonality of kurgans with moustaches. I—Southern Trans-Urals; II—ugodzhary; III—Ulytau and Turgay; IV—Northern Kazakhstan; V—Central Kazakhstan; VI—East Kazakhstan; VII—Southern Kazakhstan

there are isolated cases of their presence in Kalmykia, the Dnieper region, and in Crimea (Botalov et al. 2006; Tihomirov 2020; Tihomirov et al. 2020).s

Their cultural and chronological definitions are still being debated. They belong to the Early Saka period (Beisenov 1996; Habdulina 2007; Beisenov 2020[1]) or the Great Migration of Peoples Era and the Middle Ages (Botalov et al. 2006). We share the latter idea (Grudochko 2020). This ambiguous assessment results from the small number of found inventory and different opinions on its interpretation: some believe that the objects of the first millennium AD were placed into the kurgans with moustaches, and supporters of the late (early Medieval) interpretation believe that the kurgans with moustaches were built near and on top of early nomadic monuments.

In the last decade, geoarchaeological methods have been actively applied to the study of kurgans with moustaches. Let us describe the results of two approaches—geological and radiocarbon dating—which significantly expanded the knowledge on these complexes, and also allow us to determine their chronology.

The first approach was applied to two monuments from the Kamenny Ambar microdistrict (the Chelyabinsk region) and published in 2015 (Nikolski and Grudochko 2015). We assumed that a survey of the rocks from which kurgans were built, as well as searching for the source of raw materials, would help to reveal the construction process, labor costs, knowledge, and architectural and construction

[1] A. Z. Beysenov has recently expressed the need to review the chronology of kurgans with moustaches.

skills. In other words, this study is primarily aimed at studying the technological capabilities of the ancient population rather than the ritual or spiritual sphere of life. We are attempting to discover how long it would have taken to build these planned megastructures.

In our study, we completed a survey of the area, determined the raw materials used for the construction of the kurgans, and established the regularity of the raw materials' location in the kurgan with moustaches. We concluded that the workflow during the construction of the kurgans with a moustache in Sukhodol and Sarbulat-1 was as follows: (1) stone collection; (2) storing the stone in piles or immediately delivering them; (3) delivery of stone material to the site; (4) unloading, and possibly immediately laying out the structures; (5) returning for more stone materials. For both monuments, we have adopted the minimal values of labor resources to fulfill all labor costs. However, they also allow us to state with a high degree of probability that the construction of one kurgan with moustaches could be carried out within one season, and most likely—no more than a month.

The 16 radiocarbon dates (as of 2018) indicate the period from the III to the mid-VII centuries AD. A comparison with the inventory typology allows us to suggest the period of the IV–VII centuries as the most probable time of construction. It would seem that it is necessary to finally abandon the Scythian-Saka attribution of these monuments.

2 Materials and Methods

2.1 Geological Research

We examined two sites from the Kamenny Ambar microdistrict (Kartalinsky district, Chelyabinsk region): Sukhodol and Sarbulat-1. The tasks of our geological survey included: (1) identifying the stones used and establishing the regularity of their location as part of the structure; (2) survey of the surrounding area to detect possible sources of raw materials for construction; (3) calculating the mass and volume of raw materials used and attempting to restore the technological process, labor costs, and time of construction. The volume of the stone material was calculated by measuring the area and approximate volume, taking into account the volume weight of a particular type of rock. These data are listed in Tables 1 and 2.

The kurgan with moustaches of Sukhodol (Fig. 2, *2*) consisted of a central stone embankment, two arched stone ridges (moustaches) extending from the embankment in an easterly direction, and stone platforms at their beginnings and ends. The diameter of the central embankment is 12 m; the height is 0.15–0.2 m. It consisted of stones of different sizes, laid in 1–3 layers. The thickness of the rock layer increased from the periphery of the embankment to its center. The arc length of the northern moustache is 203 m, the southern moustache—85.5 m. In straight lines, they were measured at 194.5 and 172 m, respectively. The ridges vary in width from 1 to 2.5 m

Table 1 The composition and the parameters of the Sukhodol kurgan with a moustache

Size/diameter (m)	Square (for a circle of 3.14 × r^2)	Height (m)	Volume (m^3)	Volumetric weight (t/m^3)	Volume weight (t)	Stone type
The Central kurgan						
12 (d)	≈113:4 = 28.3	≈0.18	5.1	2.6	5.1 × 2.6 = 13.3	Granite
	≈113:4 = 28.3	≈0.18	5.1	3	5.1 × 3.0 = 15.3	Gabbro
	≈113:4 = 28.3	≈0.18	5.1	2.8	5.1 × 2.8 = 14.3	Basalt
	≈113:4 = 28.3	≈0.18	5.1	2.7	5.1 × 2.7 = 13.8	Quartz
	$\sum = 113.2$		$\sum = 20.4$		$\sum = 56.7$	
The western platform of the northern moustache						
4.3 × 5.8	≈25.0	0.18	≈4.5	2.6	11.7	Granite
The western platform of the southern moustache						
4(d)	12.6	0.18	≈2.3	≈2.8	6.4	Gabbro, Basalt, Quartz
The eastern platform of the northern moustache						
4.25 × 5.75	≈24.44	0.18	≈4.4	2.7	11.9	Quartz
The Eastern platform of the South moustache						
4.25 × 5.75	≈24.44	0.18	≈4.4	2.7	11.9	Quartz
Northern moustache						
82.5 × 1.8	148.5	0.18	27	2.7	73	Granite
29.7 × 1.8	53.46	0.18	8	3	24	Gabbro
24.5 × 1.8	44.1	0.18	14	2.8	39	Basalt
42.3 × 1.8	76.14	0.18	14	2.7	38	Quartz
					$\sum = 174$	
Southern moustache						
4 × 1.8	7.2	0.18	1.3	2.6	3	Granite
33.6 × 1.8	60.5	0.18	11	3	33	Gabbro
49.3 × 1.8	88.7	0.18	16	2.8	43	Basalt
84.6 × 1.8	152.3	0.18	27	2.7	73	Quartz
	$\sum = 308.7$				$\sum = 152$	

The total weight of the volume of stone material of the Sukhodol complex is 424.6 t

Table 2 The composition and the parameters of Sarbulat-1 kurgan with moustaches

Size/diameter (m)	Square (for a circle of $3.14 \times r^2$)	Height (m)	Volume (m^3)	Volumetric weight (t/m^3)	Volume weight (t)	Stone type
The Central and South kurgans						
11(d)	95	0.4	38	2.6	98.8	Granite
The Central and Northern kurgans						
8(d)	50.2	0.3	15.1	2.6	39.3	Granite
Four platforms of moustaches						
4(d)	12.6	0.2	2.5	2.6	$6.5 \times 4 = 26$	Granite
Northern moustache						
164×1.5	246	0.2	49.2	2.6	127.9	Granite
Southern moustache						
138×1.5	207	0.2	41.4	2.6	107.6	Granite

The total weight of the volume of stone material of the Sarbulat-1 complex is 399.6 t

(the average width is 1.8 m). The platforms at the ends of the moustaches are sub-rectangular in shape and vary in size from 4×4.5 to 5.5×6 m, or: the western platform of the southern ridge had a circular shape with a diameter of 4 m (Botalov et al. 2006, 39–40). The moustaches were constructed of alternating stone types with different lithological compositions. The composing rocks of the right shore side of the river valley also alternate, replacing each other in the latitudinal direction, and the moustaches of the Sukhodol complex (intentionally or not) repeat the lithology of the side (Fig. 3, *I*, *II*).

The complex was built using 4 types of rocks: granite, gabbro, basalt, and quartz. The technical and geological parameters of the Sukhodol kurgan with moustaches are provided in Table 1.

The Sarbulat-1 monument consisted of two stone kurgans, from which two stone ridges branched off in the eastern direction. The northern embankment is 8.0 m in diameter and 0.3 m high; the southern embankment is 11.0 m in diameter up to 0.4 m high. The northern moustache extends to the East with an arc length of 164 m. The western and eastern ends are decorated with rounded platforms with a diameter of about 4 m and a height of 0.2 m. The southern moustaches, stretching out from the kurgan to the NW, had the shape of an arc with the length of 138 m; with its ends made in the form of rounded pads with a diameter of 4 m and a height of 0.2 m. The widths of both ridges ranged from 1.0 m to 2.0 m. The Northern kurgan was square-shaped with the side length of about 8.5 m, and the South as a more or less regular pentagon with the length of the northside of 8.5 m, NE—7 m, SE—8.5 m, SW—8 m, and NW—8 m (Botalov et al. 2006, 59–61).

Technical and geological characteristics of the kurgan with the moustaches of Sarbulat-1 are in Table 2.

The kurgans of the central structure and the ridges are composed of leucogranites and individual blocks of quartz. The composition of the rocks of this complex differs

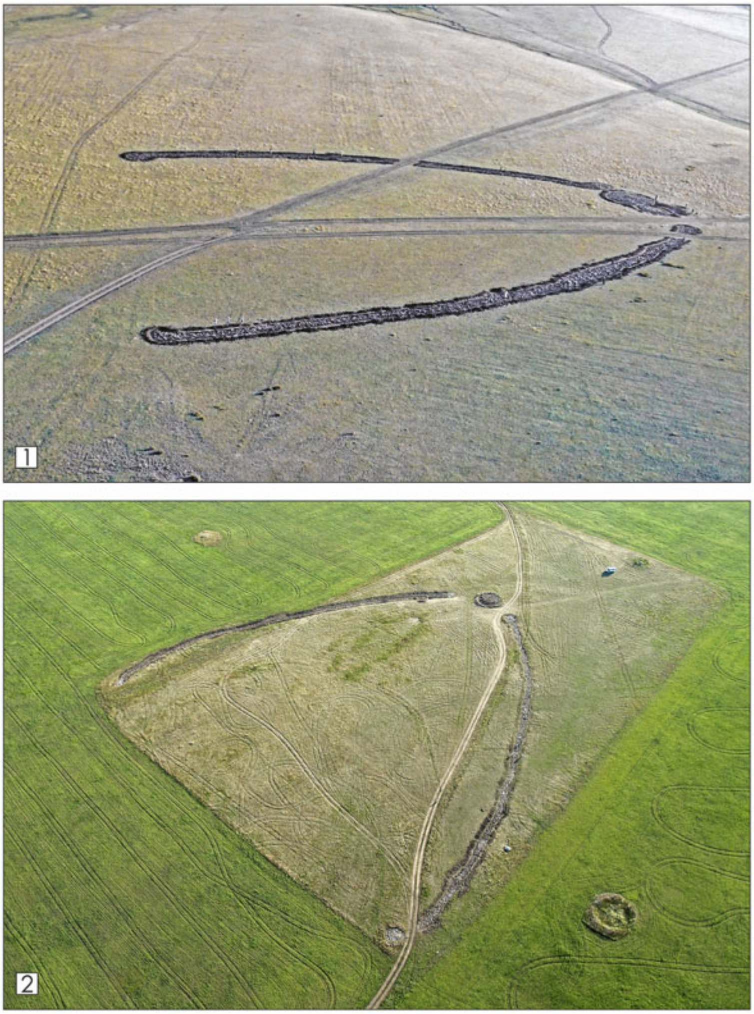


Fig. 2 Kurgans with moustaches of the Southern Trans-Ural Region. 1—Sarbulat-1; 2—Sukhodol

from the site of Sukhodol, mainly because there is no alternation of different rocks throughout the ridges. However, the location of variegated stones and white blocks of quartz is subject to a certain pattern. Their concentrations mark the ends of the ridges and their end layouts, except for the western end of the southern ridge.

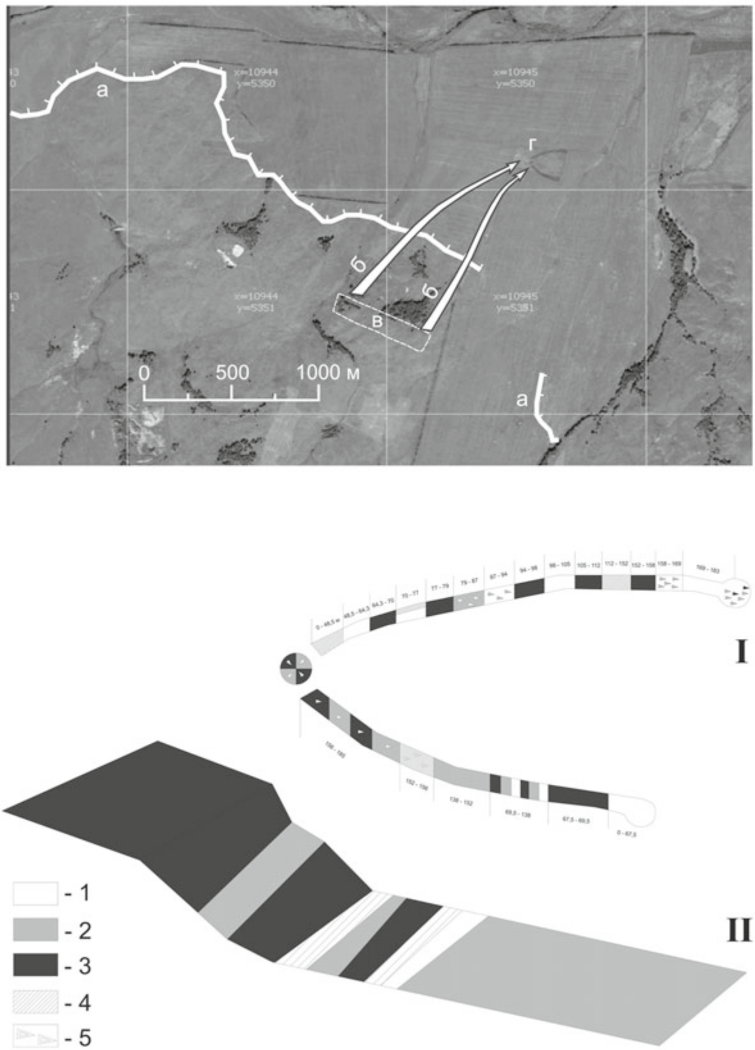


Fig. 3 The layout of the Sukhodol kurgan with moustaches, sources of stone raw material, and the most convenient delivery paths (satellite image with legend). a—tectonic scarp; б—the most convenient delivery path; в—stone storage location; г—the Sukhodol kurgan; I, II—scheme of linking structures of Sukhodol kurgans (I) the lithology of its location (II); I—lithology intervals of Sukhodol kurgan moustaches (no scale); II—geological map of the tape; 1—quartz; 2—basalt; 3—gabbro; 4—granite; 5—inclusion of serpentinites

2.2 Radiocarbon Chronology

As of 2018, we know and processed 16 dates obtained from 12 complexes (Table 3).

Six complexes originate from the Southern Trans-Urals (Sarbulat-1, Sukhodol, Kainsai, Gorodishchenskoe IX, Rymniksky, Selentash) (Botalov 2009, 129; Botalov 2013, 71; Grudochko and Epimakhov 2015), six are from Central Kazakhstan (Tandaily 2, Zhamantas, Kyrykungir, Koytas, Besoba, Kabantau) (Beisenov et al. 2016a, b, 2017, 2018). Thirteen samples are from the kurgans of the central structure, and three came from the end sites of the moustache (Gorodishchenskoe IX, Kabantau). The measurements were conducted in the four laboratories (Le, SPb, Ki, UBA) by scintillation and accelerator mass spectrometry (AMS). The following materials were used as sources of carbon isotopes: ceramics (4), animal bone (9), human bone (2), and charcoal (1). The OxCal 3.10 program (the IntCal13 calibration curve) was used to calculate the calibrated intervals; all uncalibrated dates (BP) are from 1950. The results are presented in Table 3. A combined date was formed for kurgan 5 of the Selentash burial ground (Fig. 4, *selentash_comb*). Despite the relatively low level of statistical agreement between the two dates (Ki-17075 and SPb-958), the result seems quite realistic (1539 ± 29 BP) if compared to the rest of the values in our series. In the further work on the summation of probabilities. In general, the series looks quite homogeneous, which is well recorded on the chart (Fig. 4, *4–5*).

3 Results and Discussion

3.1 Geological Research

The workflow during the construction of the complex Sukhodol can be described as following: (1) collected raw material (Fig. 3, *в*) could be stored in piles or loaded and shipped for the construction site of the monument (Fig. 3, *б*); (2) unloading for the construction and (3) a return for additional material. While constructing the kurgan with the moustache, the horse-drawn transport could be probably used, since many stones could not be moved manually at a distance of about 1.5 km due to their size and weight (this is the distance from the procurement site to the site the kurgan. Theoretically, the team of people involved in the construction was divided into groups by specialization: (1) stone pickers and loaders; (2) people who drove horses and delivered building material to the site; (3) builders. We suppose that the stone pickers and loaders were assigned to spots with various lithological compositions. Therefore, during the delivery and construction of the kurgan, an alternation of intervals consisting of different rocks was obtained. Judging by the

Table 3 Radiocarbon chronology of kurgans with moustaches from Southern Trans-Urals and Central Kazakhstan

Monument	Complex	Lab code	Kind of analysis	Material	Convention date	Calibrated date	
						68.20%	***95.40%***
Sarbulat	Kurgan 2	Ki–15634	Scintillation	Ceramics	1540 ± 80	430-590AD (68.2%)	340-660AD (95.4%)
Suhodol	Kurgan 5	Le-8303	Scintillation	Animal bone	1550 ± 100	410-610AD (68.2%)	250-300AD (3.2%) 310-660AD (92.2%)
Kajnsaj	Kurgan 14	Ki–15635	Scintillation	Ceramics	1470 ± 80	460-490AD (4.2%) 530-660AD (64.0%)	410-690AD (95.4%)
GorodishchenskoeIX	Northern moustache	SPb–535	Scintillation	Charcoal	1460 ± 50	560-645AD (68.2%)	430-490AD (5.0%) 530-670AD (90.4%)
Rymnikskij	Central kurgan	SPb–957	Scintillation	Horse bone	1560 ± 65	420-570AD (68.2%)	380-640AD (95.4%)
Selentash*	Kurgan 5	Ki–17075	Scintillation	Ceramics	1760 ± 150	80-430AD (68.2%)	100BC-650AD (95.4%)
Selentash*	Kurgan 5	SPb–958	Scintillation	Ceramics	1530 ± 30	430-490AD (25.9%) 530-580AD (42.3%)	430-600AD (95.4%)
		*combined date			1539 ± 29	430-490AD (41.7%) 530-570AD (26.5%)	420-590AD (95.4%)

(continued)

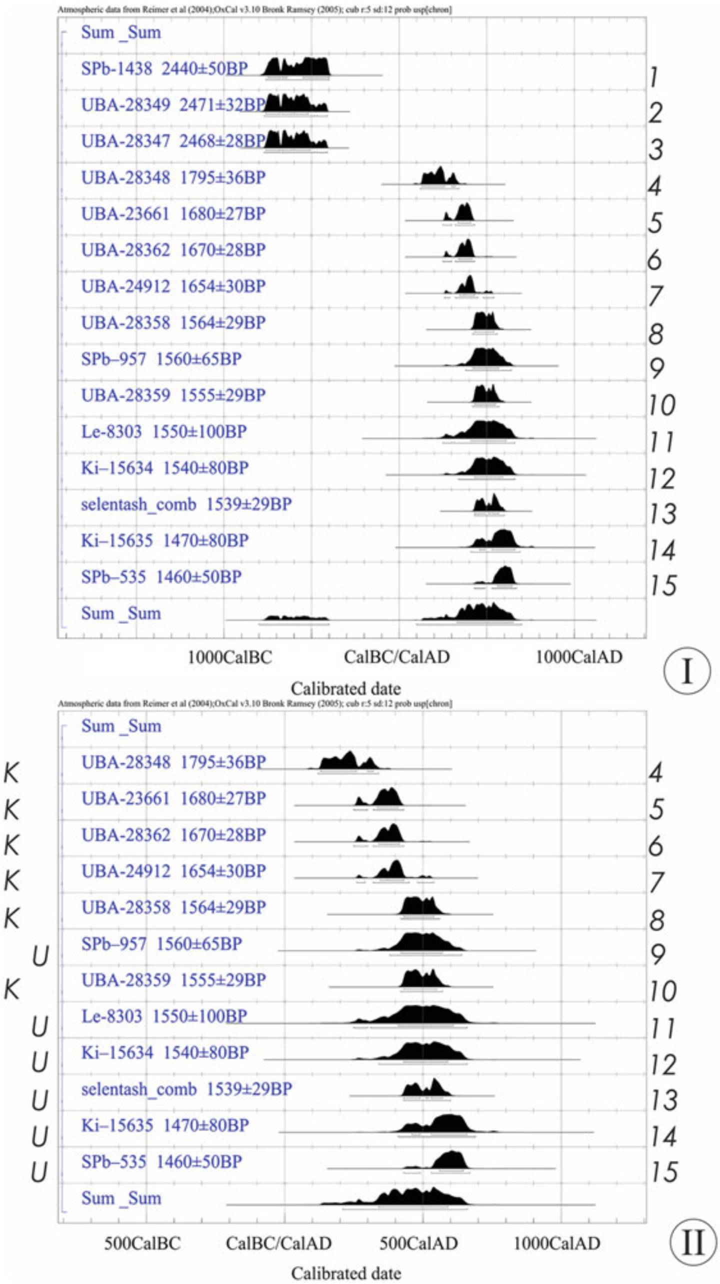
Table 3 (continued)

Monument	Complex	Lab code	Kind of analysis	Material	Convention date	Calibrated date	
						68.20%	***95.40%***
Tandajly 2	Kurgan 2a (east)	UBA-28348	AMS	Horse bone (jaw fragment)	1795 ± 36	300-320AD (6.2%) 130-260AD (62.0%)	120-340AD (95.4%)
Tandajly 2	Kurgan 2 (west)	UBA-28347	AMS	Human bone	2468 ± 28	670-610BC (14.4%) 760-680BC (26.0%) 600-510BC (27.7%)	470-410BC (8.7%) 770-680BC (28.9%) 670-480BC (57.8%)
Kyrykungir	Central kurgan	SPb-1438	scintillation	Horse bone	2440 ± 50	670-640BC (5.0%) 750-680BC (16.9%) 550-400BC (46.3%)	757-678BC (21.2%) 670-400BC (74.2%)
Zhamantas	East kurgan	UBA-24912	AMS	Animal bone (horse?)	1654 ± 30	345-370AD (13.8%) 375-430AD (54.4%)	260-290AD (3.8%) 480-540AD (6.9%)

(continued)

Table 3 (continued)

Monument	Complex	Lab code	Kind of analysis	Material	Convention date	Calibrated date	
						68.20%	***95.40%***
Zhamantas	West kurgan	UBA-28349	AMS	Human bone	2471 ± 32	670-610BC (16.2%) 760-680BC (25.0%) 600-520BC (27.0%)	470-410BC (8.5%) 770-480BC (86.9%)
Kojtas	East kurgan	UBA-23661	AMS	Horse bone	1680 ± 27	335-410AD (68.2%)	250-300AD (12.2%) 320-430AD (83.2%)
Besoba	East kurgan	UBA-28362	AMS	Horse bone	1670 ± 28	340-415AD (68.2%)	250-300AD (8.6%) 320-430AD (86.8%)
Kabantau	East platform of north moustache	UBA-28358	AMS	Animal bone (small cattle)	1564 ± 29	430–540 AD (68.2%)	420-560AD (95.4%)
Kabantau	East platform of north moustache	UBA-28359	AMS	Animal bone (small cattle)	1555 ± 29	430–550 AD (68.2%)	420-570AD (95.4%)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SPb-1438 2440±50BP
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UBA-28348 1795±36BP
UBA-23661 1680±27BP
UBA-28362 1670±28BP
UBA-24912 1654±30BP
UBA-28358 1564±29BP
SPb–957 1560±65BP
UBA-28359 1555±29BP
Le-8303 1550±100BP
Ki–15634 1540±80BP
selentash_comb 1539±29BP
Ki–15635 1470±80BP
SPb–535 1460±50BP
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Atmospheric data from Reimer et al (2004);OxCal v3.10 Bronk Ramsey (2005); cub r:5 sd:12 prob usp[chron]
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K UBA-28348 1795±36BP 4
K UBA-23661 1680±27BP 5
K UBA-28362 1670±28BP 6
K UBA-24912 1654±30BP 7
K UBA-28358 1564±29BP 8
U SPb–957 1560±65BP 9
K UBA-28359 1555±29BP 10
U Le-8303 1550±100BP 11
U Ki–15634 1540±80BP 12
U selentash_comb 1539±29BP 13
U Ki–15635 1470±80BP 14
U SPb–535 1460±50BP 15
Sum _Sum
500CalBC
CalBC/CalAD
500CalAD
1000CalAD
Calibrated date
II

◀**Fig. 4** Radiocarbon chronology of kurgans with moustaches. I—all dates; II—dates excluding early complexes; K—Central Kazakhstan; U—Southern Urals; 1—Kyrykungir (Beisenov et al. 2016); 2—Zhamantas, Western kurgan (Beisenov et al. 2017); 3—Tandajly 2, kurgan 2 (Western kurgan); 4—Tandayly 2, kurgan 2a (Eastern kurgan) (Beisenov et al. 2016); 5—Koytas, Eastern kurgan; 6—Besoba, Eastern kurgan (Beisenov 2017); 7—Zhamantas, Eastern kurgan (Beisenov et al. 2017); 8—Kabantau (Eastern platform of the Northern moustache) (Beisenov et al. 2018); 9—Rymnikski (Grudochko and Epimahov 2015); 10—Kabantau (Eastern platform of the Northern moustache) (Beisenov et al. 2018); 11—Sukhodol, kurgan 5; 12—Sarbulat-1, kurgan 2; 13—Selentash; 14—Kajnsay, kurgan 14; 15—Gorodishhenskoe IX, kurgan 5 (Botalov 2009, 2013; Grudochko and Epimahov 2015)

assortment in the kurgan with the moustache, there were 4 brigades. Each part of the brigade had collectors and transporters with horses. It is also possible that the transporters worked independently and drove up to the assembly points where the stone material was ready for loading.

The average working capacity of one horsepower is 75 kg m/s, which means the power expended when a load weighing 75 kg is lifted evenly vertically at a speed of 1 m/s or 75 kg m of work per 1 s (Work and energy of a horse, 2015). The same value can be represented as 4500 kg m/min or 270 tm/h. The working capacity of a person aged 20 to 49 years on average is from 11 to 16 (average 14.1) kg m/min per 1 kg of body weight. Taking 60 kg as the average value of body weight, we get a working capacity of 846 kg m/min or 14 kg m/s (50.76 tm/h) (Evaluation test 2015). According to other data, the human working capacity of the same age in indicators below the average ranges from 500 to 700 (average 600) kg m/min or 10 kg m/s (36 tm/h) (Sirotin and Belozerova 2015).

To calculate the time required for delivery of the total quantity of stone with one horse, the following calculation will be made 424,6 (the total weight of stones) divide into 270 (the horse performance), and multiply by 1500 (the distance from the place of gathering stones to a kurgan). We get a value of about 2359 h (98.2 days). It does not take into account the time of loading and unloading, weather conditions, etc. It is difficult to say how much time per day people had to work. We will conditionally accept daylight hours with breaks for eating and resting people and horses. If we accept the hypothesis of four brigades and a light day of 12 h, then it would take 2359: 4 (horses) = 589: 12 = 49 days, i.e., about 1.5–2 months to build the Sukhodol kurgan with a moustache. This calculation does not take into account the working capacity of a person, which is approximately 0.1–0.2 of the working capacity of a horse. Theoretically, this could be enough for loading, unloading, and laying the stone.

The scope of work during the construction of the Sarbulat-1 monument was similar to the previous complex: collection, transportation, construction. The total weight of the stone material used to create the kurgan with the moustache of Sarbulat-1 was 399.6 t (see Table 2). The location of granite where the raw material was collected,

Table 4 Modeling the construction time of Sukhodol and Sarbulat-1 burial kurgans with moustaches, depending on the number of horses and working hours

Monument	Distance from the place of collecting stones to the burial kurgan (m)	The number of horses and the total running time at 12-h/6-h workday			
		1 horse (days)	4 horses (days)	10 horses (days)	50 horses (days)
Sukhodol	1500	196/393	49/98	19.6/39.3	3.9/7.9
Sarbulat-1	300	37/74	9.3/18.5	3.7/7.4	0.7/1.5

is at a distance of about 300 m to the west of the monument, that is, 5 times closer than on Sukhodol. The calculation of the time of delivery of stone material when using one horse was made similarly and amounted to 444 h (18.5 days), or about 37 workings 12-h-long days, just slightly longer than a month. Since the structure of the ridges does not show the alternation of sections with different types of stones, it is difficult to assume the number of brigades that could be involved in the construction.

When analyzing the Sukhodol complex, we assumed the presence of the four brigades corresponding to the assembly sites of various bedrock. In Sarbulat-1, 37 working days correspond to the use of only one horse. For both monuments, we have adopted the most minimal values of labor cost resources to fulfill all labor requirements. However, they also allow us to state that the construction of a single kurgan with moustaches could be carried out within no more than one season. The actual number of laborers and draft power remains unknown, but given that these monuments were left by the pastoral population, the number of horses involved as the main draught power was no more than one to four. The construction time of a single kurgan with a moustache would be less if more labor will be involved: draft the horses and people serving them (with a competent organization of the work process). In Table 4, we tried to describe the modeling using different numbers of horses depending on the 12-h and 6-h workday. It should be noted that the proposed scenarios are just a mathematical description of a horse continuously walking for 6/12 h a day with a constant working capacity of 75 kg-m/sec. However, with all the assumptions, it can be assumed that the construction of a burial kurgan with moustaches hardly required colossal labor costs in nomadic communities.

It is most likely that the construction of these ritual complexes was associated with some collective events (holidays, commemorations), which were arranged by the pastoral population during their summer stay in the southern Trans-Urals.

3.2 Radiocarbon Chronology

Before proceeding to a discussion of the results, it is necessary to point out the shortcomings of the initial data. The dates were obtained in different ways (scintillation counting and AMS) from different territories. Table 3 and Fig. 4 clearly show that the dates were distributed in the same way: earlier dates (AMS) in Central Kazakhstan and later ones (scintillation counting) in the Southern Trans-Urals. This nuance must be taken into account when interpreting radiocarbon dates. However, on the other hand, this picture does not contradict our historical knowledge about the vector of nomadic migrations from east to west, implying that the earlier complexes are in the east, and the later ones are in the west.[2]

Summing up the probabilities of the results of radiocarbon dates formed two intervals, amount which the early ones are the large kurgans and the kurgan with the moustache of Kyrykungir (Fig. 4, *I*). The second interval is comprised of the actual kurgans with moustaches and shows the following values (Fig. 4, *II*): 340–590 AD at 68.2%, and—210–660 AD at 95.4%. Thus, the radiocarbon dates available today allow us to state with a high degree of confidence (95.4%) that the events of interest occurred from the beginning of the III to the middle of the VII centuries AD.

The Southern Urals monuments (Fig. 4, *U*) demonstrate the interval of 420–620 AD (68.2%) and 380–670 AD (95.4%), or from the last decades of the IV century AD to the second half of the VII century AD. The Central Kazakhstan monuments (Fig. 4, *K*) are older with 330–550 AD (68.2%) and 160–570 AD (95.4%), or the middle of the II—first quarter of the V centuries AD. The extension is due to the Tandaily-2 complex (UBA-28348, 1795 ± 36), which is still the earliest among the kurgans with moustaches (according to the radiocarbon dating). At the same time, the relative chronology between the earlier (Central Kazakhstan) and the later (the Southern Urals) complexes is documented. It should also be noted that all the dates are consistent with each other, showing a continuous column throughout the entire period of construction of kurgans with moustaches.

Separately, we will single out the Tandaily 2 and Zhamantas complexes from Central Kazakhstan consisting of larger kurgans, to which complexes with a moustache are attached. The dates from the large kurgan date back to the Early Iron Age (2468 ± 28 and 2471 ± 32), while the head kurgan of the complex with the moustache was built some 700–800 years later (1795 ± 36 and 1654 ± 30). This observation is quite consistent with the concept of those researchers who state that in Central Kazakhstan there was a developed tradition of using older kurgans for the construction of kurgans with moustaches (Botalov and Gutsalov 2000, 197–198;

[2] It is quite evident that there are absolutely no AMS dates for the territory of the Southern Trans-Urals to clarify the chronology. Therefore, in 2021, we sent 4 duplicate samples for three burial kurgans with moustaches of the Southern Trans-Urals. Their results and generalization with previously available data will be published in the next papers.

Botalov et al. 2006, 89–91). Only one date of the Kyrykungir complex (SPb-1438, 2440 ± 50) contradicts the general column of radiocarbon values. The monument consists of a single kurgan, from which the ridges depart, but it is not necessary to exclude the secondary use of this kurgan for the construction of the kurgan with the moustache. We also did not use the dates from the Kyzylshilik burial ground, which show significant deviations. The sample from Kurgan 2b was taken from a pile of bones of domestic animals (18 cm from the top of the kurgan) with the result of 99 ± 28. The remaining three samples obtained from different objects of kurgan 6 showed inconsistent values (140 ± 24; 890 ± 26 and 1351 ± 26) (Beisenov and Kasenalin 2018, 97).

We compared the artifacts that relate to the burial under the kurgans with moustaches. The radiocarbon chronology of the kurgans with moustaches does not contradict the typology of the inventory (Fig. 5).

From the point of view of radiocarbon dating, the number of available dates for both, Central Kazakhstan and Southern Trans-Urals is not enough. Nevertheless, the data available today outline the period of construction of kurgans with moustaches during the III/IV to the middle VII centuries AD (95.4%).

4 Conclusions

As we have seen, the geoarchaeological method allowed us to significantly expand our knowledge about the kurgans with moustaches. The earliest complexes (III/IV centuries) appeared in Eastern Kazakhstan, Tarbagatai, and Chingistau as a result of the migration of nomads from Central Asia. For the more eastern regions, we know several complexes from the Xinjiang Uyghur Autonomous Region (Grudochko et al. 2020), where we should look for the origins of this tradition. At the initial stage, the new population develops the Eastern Sary-Arka, and by about the second half of the century reached the Trans-Urals. However, a separate study should be devoted to this issue.

For the construction of kurgans with moustaches (not only Sukhodol and Srabulat-1 but also other similar monuments), it is necessary to align the terrain of the site, the proximity, and accessibility for the extraction of stone material. Judging by the area of the kurgans with a moustache of the Trans-Ural group, all of them are located within the Trans-Ural peneplain and the continental-marine basement plain, which have such surfaces with numerous small rocky outcrops of bedrock and deposits of blocky-gravelly material, especially along modern river valleys. Thus, these geomorphological areas had rational conditions for the availability of stone material and, accordingly, optimal labor costs in the construction of kurgans with moustaches. Simply put, the labor costs for their construction were not as large as it seems at first glance.

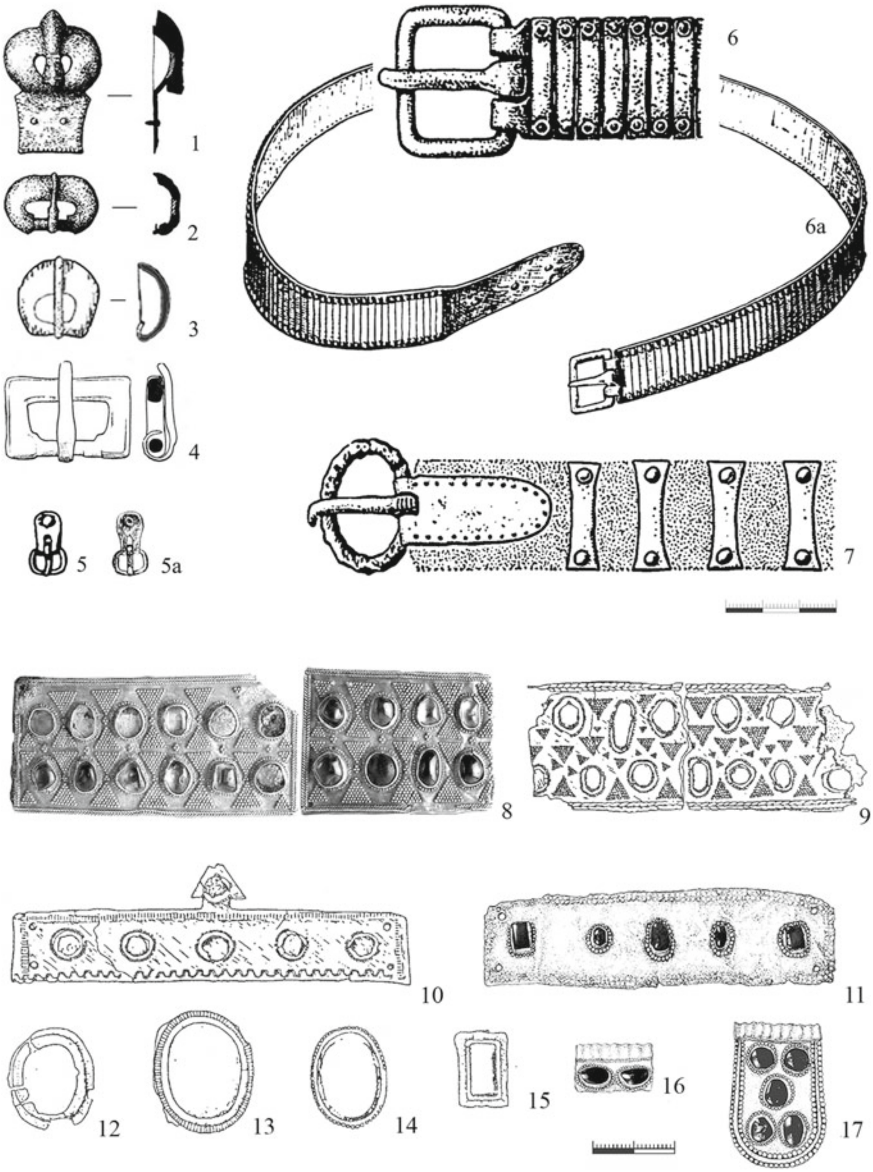

Fig. 5 Inventory from the kurgans with moustaches and synchronous burial monuments of the 5th–sixth centuries in the Ural-Kazakhstan steppes. 1, 2—Kamenny Ambar (kurgan 6); 3—Arkaim; 4—Borovoe; 5, 5a, 6, 6a, 8—kurgan with moustaches Kanattas (kurgan 19); 5/5a—variants of drawings the buckle; 6a—reconstruction of the belt; 7—kurgan with moustaches Zevakino (kurgan 1); 9, 10, 12–15—kurgan with moustaches Solonchanka I; 11, 16, 17—kurgan with moustaches Atasu-2

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The Remote Methods for Search and Study of Archaeological Objects in Bashkortostan

Ramil R. Nasretdinov, Ilshat I. Bakhshiev, and Roman N. Gabitov

Abstract Together with expanding technical and technological opportunities in modern archeology, the methods of geoarchaeology, which are applied in combination with classical methods of archaeological exploration, deem to be the fundamental ones. However, the study of the mound burial grounds located in the steppe zone of the Southern Urals is complicated as they are located in the zone of intensive agricultural development, which has become an essential problem. As a result of years-long plowing, a significant part of the mound surfaces has been damaged and is virtually not visible on the modern landscape. The localization of these objects will help in defining the borders of archaeological sites to take measures for their further protection during construction works and will make it possible to form corresponding programs for their full-fledged archaeological study. The use of the technologies has made it possible to specify the structure and composition of the II Samarsky burial mound located in the steppe zone of the Bashkir Trans-Urals. For many decades, the burial ground has been subject to intensive plowing. This feature makes it possible to use the cemetery as an experimental test site. In this paper, we present the research method to obtain the aerial photography of the site with the help of unmanned aerial vehicles of a geodetic class, combining the photography with the application of aerial geodesy and photogrammetric processing of the received aerial photographs. The results of the conducted remote sensing studies have revealed sixteen stable anomalies, which otherwise can barely be visually identified. In 2020, during the excavation of anomaly №18, two burials of the Bronze Age were found. Thus, it was proved that the previously identified anomalies are the remnants of the heavily destroyed burial mounds.

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Keywords Archaeology · Bronze age · South urals · Archaeological sites · Interdisciplinary methods in archaeology · Unmanned systems and aerial photography

1 Introduction

Modern archaeological research is increasingly dominated by complex research with the active involvement of geoarchaeological methods (Schubert 2016; Asăndulesei 2017; Shakirov & Khuzin 2018; Daragan and Svoyski 2018; Piskareva et al. 2019).

In recent years, our work at the territory of the Republic of Bashkortostan, Russia, has demonstrated an urgent need to review the approaches and methods of analyzing the topography of archaeological sites. It is necessary to pay attention to the data that literally lies on the surface with the help of the micro-surface analysis. The traditional methods of topography hinder to achieve the perceptual unity of the object on the natural landscape. It complicates finding the solution to a number of issues, as it does not reveal the hidden potential of the object under study, even when determining the borders of the site's territory. For conducting an outdoor study of archaeological objects in Bashkortostan, in addition to traditional methods of recording data (e.g., the instrumental survey using ground and satellite geodesy), the remote sensing methods, which have significant advantages in their turn, may also be actively used (Bakhshiev et al. 2018).

A review of works that involved the use of remote sensing methods testifies that many researchers applying aerial photography to take a photo-tone images (orthophoto map) (Bykov et al. 2013; Perkić & Vuković 2018; Wernke et al. 2014) or to create a 3D model of the landscape of various resolution (Tataurova et al. 2016; Vinokurov & Pigin 2016). Others limit themselves to a demonstration of view or panoramic photographs taken with unmanned aerial vehicles.

Out of the total amount of research carried out in the former Soviet Union, the prominent ones are the works by Daragan and Svoyski, whopurposefully used the morphometric analysis of the digital surface model and expressed a number of methodological considerations on the analysis of aerial survey materials (Daragan & Svoyski 2018; Daragan 2020).

The experience of working at the sites of various types has shown that contour lines do not always objectively illustrate the necessary details of individual elements of archaeological complexes (Bakhshiev et al. 2018: 35–37).

The review of the literature on the given topic and the methodological considerations of works by Daragan and Svoyski, our own experience have suggested that there are two methodologically different approaches to the remote method of recording and studying of archaeological sites:

1. The analysis of objects that are well-defined on the landscape, including the use of orthophoto maps, which can be traced visually with the naked eye under any conditions (including conditions of high vegetation).

2. The analysis of barely defined objects, which can be overseen. This depends on the depth and degree of processing of the materials obtained (Daragan & Svoyski 2018: 38).

In the paper, we will touch on the analysis of objects that are weakly defined on the landscape.

2 Materials and Methods

The method is based on the aerial photography of the site with the unmanned aerial vehicles of a geodetic class (the quadcopters and aircraft-type UAV's). Our approach is based on the deciphering of a digital surface model received via the combined use of aerial geodesy and photogrammetric processing of aerial photographs. This approach was applied to study the archaeological sites in Bashkortostan.

The process of deciphering involves an in-depth analysis or assessment of a digital surface model through its mathematical visualization. It provides carrying out a comprehensive or directed analysis of the topographic roughness, the morphometric properties of which can appear on one side but at the same time disappear on the other.

The geodetic component of the method is based on the accurate temporal and spatial tracking of the UAV's flight paths, its height, position, pitching, etc. Owing to this, each photo is assigned with the time it was taken and coordinates. All these calculations are performed during the post-processing with specialized software which calculated coordinates of each photograph. Further, the obtained calculations of coordinates are used in the photogrammetric processing of aerial photographs. In the Russian-language archaeological literature, this part of the algorithm has been thoroughly described (Krupochkin & Papin 2018). The practical advantage of the method was most significantly manifested in the study of the burial mounds of the Trans-Ural part of Bashkortostan. The analysis of objects that are barely defined in the landscape is presented here on the example of the II Samarsky burial mound.

3 Results and Discussion

The early scientific exploration of the II Samarsky burial ground was carried out in 1989 by Morozov, who identified the five earth barrows that are varying from 20 to 33 m in diameter and from 0.3 to 1 m in height. Intensive plowing of all mound barrows was already pointed out during the initial archaeological research of the site.

When examining the mounds in 2010–2011, a significant deterioration in the physical preservation of the site caused by the continuation of intensive plowing was recorded. In addition to the originally known mounds, there were four more weakly defined mounds found, which were practically destroyed by plowing. At that time, it seemed to us that we had managed to record the site in its completeness, including nine mounds. Mounds № 5 and 6 were the largest and quite well defined, while the rest were barely identified.

In 2011, the rescue archaeological excavations of mound № 5 were carried out by Bakhshiev, which resulted in finding the remains of two heavily destroyed burials. The features of the burial rites made it possible to attribute the complex to the Yamnaya (Pit-Grave) Culture of the Southern Urals (Bakhshiev et al. 2014).

In 2017, during the site's inspection, Nasretdinov visually recorded mounds № 3 and 6, as well as the excavated mound № 5. The rest of the barrows were almost undefined, and their safety was not certain.

In 2018–2019 as part of the testing of the applied remote methods of recording and identifying archaeological monuments, Nasretdinov & Gabitov made an aerial survey of the site.

Besides nine mounds recorded in 2011, the results of aerial photography of the obtained digital model revealed additional 16 barrows, which had been identified as anomalies until the moment of our field research (Fig. 1). The comparison of the 2011 map with the results of the aerial survey confirmed the object identification with the help of the digital surface model. Morphologically, the anomalies are identical to each other, including the confirmed mounds № 1–9. The anomalies represented an elevation of the landscape in cross-section, arched with a flattened top and rounded in its layout; a number of them were distorted and elongated under the influence of plowing furrows. At the adjacent territory, other anomalies and technogenic processes that led to their formation were not observed.

Optical or program distortions were also excluded since the survey of the territory of the site had been carried out twice: in the spring of 2018 and 2019, so it can be

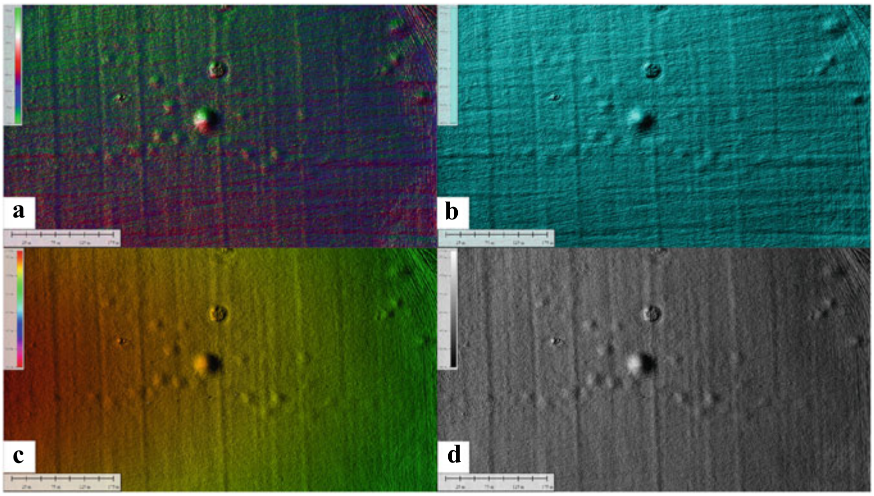


Fig. 1 The II Samarsky burial mound. Digital model of the surface of the territory of the monument (non-deciphered)

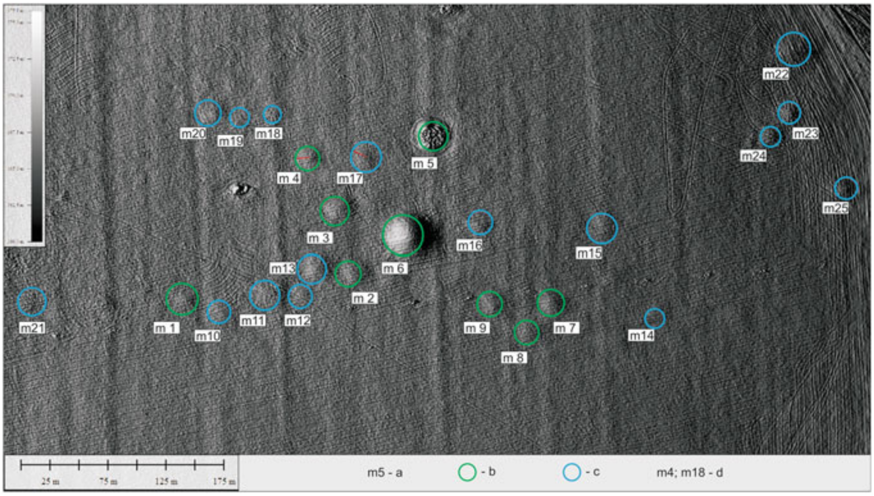


Fig. 2 The II Samarsky burial mound. Digital model of the surface of the territory of the monument (with deciphered elements). a—mound # 5 (explored in 2011); b—mounds found in 2010–2011; c—mounds identified in 2018–2019 based on the results of aerial photography; d—mound # 4, 18 (explored in 2020)

stated that the anomalies are stable. The barrows vary from 17 to 47 m in diameter and from 0.03 to 1.2 m in height (Fig. 2).

In 2019, during the repeated extended aerial survey of the territory of the site, which is located to the east of the main group, at the edge of the high bedrock terrace, four additional anomalies were revealed. Moreover, some of them are definitely identified as mounds in the field inspection. Thus, the number of burial mounds in the cemetery increased to 25 items, including a separate eastern group of four mounds. The exact dimensional characteristics of each object have been established as follows (Table 1).

Considering the current map of the site, drawn up on the results of aerial photography, the barrow field is elongated meridionally. The majority is concentrated around the central mound №6. From the central mound, a group of seven barrows extends in a chain to the west. A group of six barrows is concentrated in the northwest. The third group of six barrows stretches in the opposite direction—to the southeast. A group of four mounds is located separately in the eastern part of the site. The identified mound groups within the burial ground probably reflect different chronological stages of its formation.

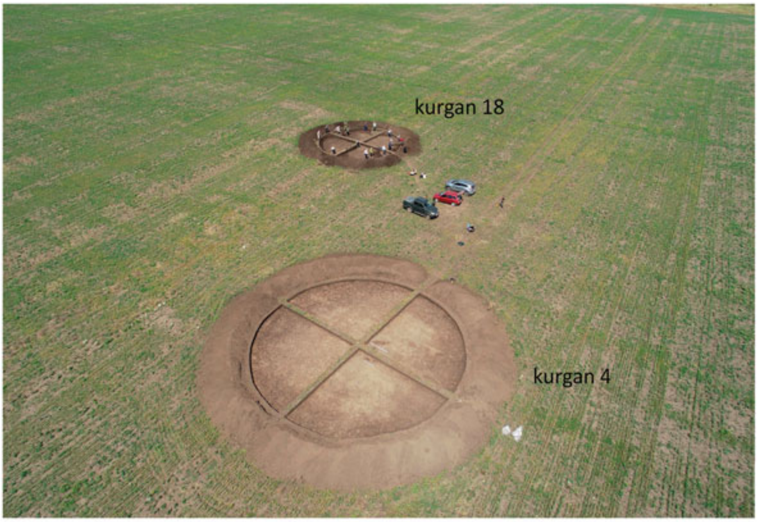
In 2020, in order to verify the data received by the remote sensing, archaeological excavations of mound № 4 and the anomaly (mound) № 18 were carried out (Fig. 3). The results of the excavations confirmed that the outlined “anomaly” is a heavily plowed mound. In mound № 4, a single burial was found, and in mound № 18, there were two burials. The identified complexes are dated back to the Late Bronze Age (the Early Alakul Culture).

Table 1 II Samarsky burial mound. Parameters of the burial mounds

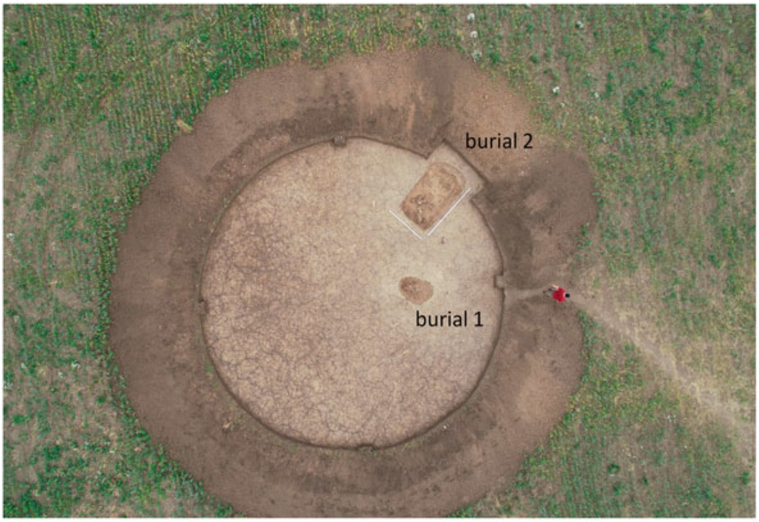
Mound №	Diameter (m)	Height (m)
1	19	0.2
2	18	0.1
3	25	0.4
4	22	0.23
5	Researched in 2011	
6	47	1.2
7	25	0.21
8	26	0.17
9	23	0.17
10	24	0.15
11	24	0.22
12	17	0.13
13	19	0.3
14	20	0.09
15	22	0.16
16	16	0.14
17	21	0.17
18	14	0.1
19	16	0.03
20	23	0.2
21	18	0.1
22	35	0.3
23	17	0.3
24	20	0.2
25	22	0.2

4 Conclusions

Thus, the use of remote sensing made it possible to reveal stable anomalies (mounds), beginning from 0.03 m in height (mound № 19) which are barely identifiable by other methods. Our experience has confirmed that the topographic analysis of the smallest details, barely traced on the digital model of the surface, makes it possible to fully reveal the hidden potential of the monument. This method is specifically relevant for the destroyed sites. For instance, in Bashkortostan, the results of remote analysis of separate settlements have revealed lines of defense that were not previously recorded by archaeologists. Also, it is possible to identify and record housing surface depressions as well as substantially update the object composition of the burial mounds.



a



b

Fig. 3 The II Samarsky burial mound. Archaeological research in 2020: **a**—general view of burial mounds # 4 and 18 under study. The view from the southeastern side **b**—archaeological complexes of mound # 18

Most significantly, the complex of non-destructive methods tested at the II Samarsky burial ground demonstrates its relative versatility in the study of archaeological objects in open space.

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Complex Investigation (GIS, Photogrammetry, and Natural-Scientific Methods) of the Northwestern Colchis Historical and Cultural Landscape in the Late Antique and Medieval Times

Galina V. Trebeleva, Gleb Yu. Yurkov, Andrey S. Kizilov, Konstantin A. Glazov, and Tatiana Yu. Shvedchikova

Abstract The Markul archaeological expeditions have been conducted since 2001. Traditional methods used for the humanities and natural-scientific methods have been applied together with digital technologies. The analysis of written sources and art history, archaeological excavations, photogrammetry, isotope study of anthropological material have been carried out, a geographic information system (GIS) has been created, the chemical composition of artifacts has been recognized. GIS includes more than 500 objects in total. A catalogue (a book) of temples in the western part of the region has been prepared; catalogue for its eastern part has almost been completed. An important result of the research is the precise location of the Great Abkhazian (Kelasur) Wall, which is one of the most controversial and mysterious historical and architectural sites of Abkhazia. The exact GPS coordinates of 208 towers that survived by 2015 have been established, and their plan has been drawn up. Several methods were used: archaeological prospecting with pits, elemental analysis, and spatial analysis to date the site. In 2014, stationary research began at the newly identified Markul settlement, the only large site known today inside Kelasur Wall. Using the isotope method, the characteristics of the people living in this area were revealed.

Keywords Northwestern colchis · Antiquity and the middle ages · GIS · Photogrammetry · Chemical analysis · Isotope analysis

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1 Introduction

In ancient times, Northwestern Colchis played an essential role in the interaction between the ancient world and the world of barbarian tribes. The area was densely populated, as demonstrated by numerous written sources and archaeological evidence. The history of the region is named as "antique-centered" according to available ancient written data; however, archaeologically, this territory has been studied without any generalizations and attempts to evaluate the role of the local population. The present study is based on the analysis of archaeological sources: the occurrence and territorial distribution of artifacts left by the local population.

2 Materials and Methods

Historical methods include a study of written sources, primarily the works of Pliny Secundus, Claudius Ptolemy, Flavius Arrian, Pseudo Arrian, Procopius of Caesarea and Agathius of Myrene, and a number of others; arranging and carrying out archaeological excavations at the Markul settlement; art analysis of ornament; examination of architectural features and other decorative elements in order to find similarities and date the findings more precisely.

Digital technologies comprise creation of a geographic information system (GIS) and photogrammetry. Archaeological research on the territory of Abkhazia is targeted at forming a GIS of archaeological sites was started by the Institute of Archeology of the Russian Academy of Science in 2001, as part of the Black Sea expedition. The first leader of the expedition was Yu.V. Gorlov, and since 2006 the expedition has been led by G.V. Trebelev, Ph.D. in History. Later, the expedition was renamed Markul, when exploration activities were combined with a stationary study of a large fortified settlement discovered in 2013 in the Ochamchir region. Nowadays, the GIS includes about 200 temples of late Antique and Medieval periods which had been either erected on the area of pagan sanctuaries or which were used simultaneously with them and individual fortresses-settlements, preserved as architectural objects, towering above the surface of the earth; 208 towers of Kelasur Wall with sections of the wall connecting surviving towers; about 150 sites where the settlements of Bronze and Neolithic Ages were noted, excavations were carried out in settlements (for example, the Tamysh settlement, Achmardin burial grounds, etc.), i.e. these sites are not found above the daylight surface, but archival data enabled to locate them precisely (Fig. 1). Generally, any GIS is just a tool, not a final product, so its replenishment continues and will continue.

Photogrammetry has been used to investigate the architectural remains of temples and fortifications (Trebeleva et al. 2019a, c). This method consists of software processing of a series of sequential photographs of an object further creating a three-dimensional 3-D model, which is scaled and analyzed in detail by graphic editors. Depending on the size and complexity of the object, a series of photographs may

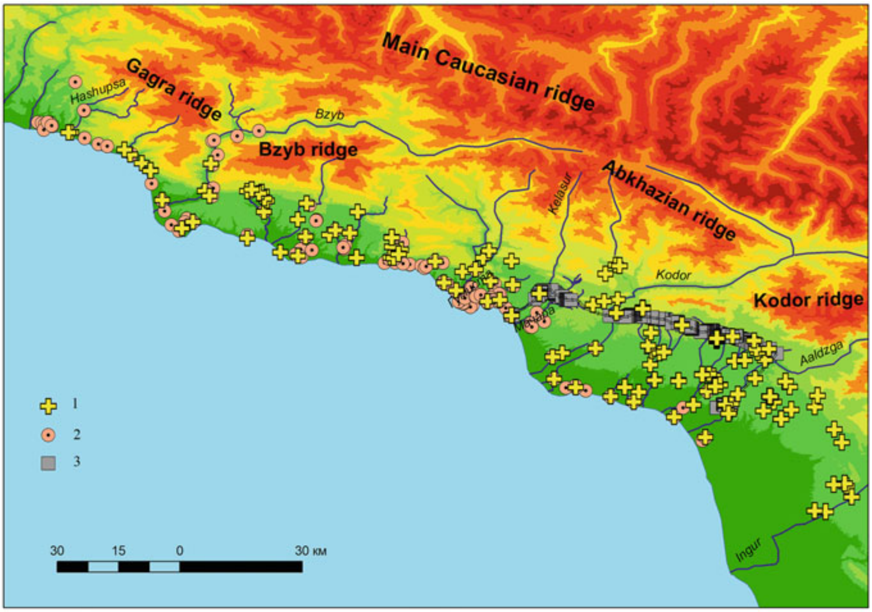

Fig. 1 General map of the region's site, derived from GIS (from Neolithic period until the middle ages): 1-temples; 2-settlements; 3-towers of Kelasur Wall

vary from several tens to several hundreds photographs. The shooting technique depends on the height of the remaining walls and the size of the temple. Usually, shooting is carried out in three rounds with an offset of about 1 m in a circle, from eye level, with arms outstretched and a tripod raised to the maximum height. Thus, three survey cones are obtained, which, given the continuity of the series, allow to obtain a three-dimension object. Frame resolution while shooting depends on the goals and capabilities of the computer. To determine the architectural features of the temple, drawing up a plan, projections and sections, 6–8 Mpx is enough. Nikon 5100 camera was used for shooting. The total number of frames per object is from 100 to 400, with 60–80% overlapping files depending on size and complexity. The accuracy of the model can vary depending on the design of the temple, the complexity of the shooting, the ability to capture high quality hard-to-reach details and the continuity of the series. If the technology is followed, this is confirmed by high-quality stitching of models of the inner and outer surfaces with the door and window openings.

Due to this method, it became possible to obtain any orthographic projections of a structure, sections, etc., allowing to measure the necessary geometric parameters, such as the length, width, height of the wall, including the thickness of the walls in different areas, the depth of the window openings, etc. without coming into direct contact with the object (Fig. 2).

Archeometry methods include isotope analysis of human remains, and chemical (elemental and phase) analysis of the mortar from the masonry of the investigated

Fig. 2 Temple Nizhnyaya Dranda according to photogrammetry data: **a**—plan; **b**—view of the south wall along the section of line aa1; **c**—view of the north wall along the section of line bb1; **d**—view of the western facade from the outside

objects. For isotopic analysis, primary sample preparation was carried out by specialists of the Physical Anthropology Group of the Institute of Archeology, RAS; the analytical part of the study was carried out at the "Mass Spectrometric Research" of the Center for Collective Use (Isotope Analysis) of the Institute of Ecology and Evolution named after A.N. Severtsov, RAS.

Chemical (elemental and phase) analysis of the binder solution from the masonry of the investigated objects makes it possible to determine the method of preparing the binder solution and to suggest the construction technology. Energy dispersive analysis (EDA) was used to determine the chemical elemental composition of the binder solution in the masonry of fortifications. The phase composition of the samples was determined using X-ray phase analysis (XPA), i.e. it was established which chemical compounds formed the elements identified using the EDA method. Carrying out such combined analysis of the binding component of the masonry of archaeological monuments is a new direction in archeology. This is based on the knowledge that contemporaneous objects on a specific limited territory have the same chemical composition, and non-contemporaneous objects have different chemical composition because of altered mineral deposit (gypsum, sand, clay, limestone), different mixing methods and proportions of the components of the used mixture. For instance, the chemical composition of the binder mixture in the masonry of the walls of the contemporaneous monuments will differ in quantity, but will have same composition, while for the non-contemporaneous ones it will differ significantly from each other.

The described studies were carried out on a JEOL JSM 6380 LA scanning electron microscope with an energy-dispersive analyzer and a Shimadzu XRD 6000 X-ray diffractometer.

The method was tested by analyzing the solution from the laying of the Anakopia fortress (Trebeleva et al. 2014), one of the simultaneous medieval site of Abazgia studied by excavations.

In the course of studies of the tower of the southern wall in the second line of defense of the fortress of Anakopia, three main cultural horizons of different time periods were revealed. The first layer dated of 10th twelfth centuries, the second dated of eighth-ninth centuries. The third layer, which is the main layer of towers and walls of the second line of defense, refers to the seventh century. (Trapsh 1975). Seventeen samples were taken from various parts of this fortress and investigated. In total, four types of binding solutions were found on the site. In the first type the admixture of sand is 14–15% in relation to lime, in the second type the sand admixture is approx. 30%, in the third type it is about 50% and in the fourth type the admixture of sand is over 50%. It is necessary to immediately specify that the solution of the fourth type is likely to indicate the rush repairs, since it had not been found in the smooth rows of masonry, but found separately in small spots, and extremely rarely. If we consider the distribution of these types, it becomes obvious that all samples taken from the walls of the fortress do not simply replicate the same type of solution, but almost completely reproduce it. The discrepancy in the ratio between components (Ca and Si) is only one percent. Moreover, the places where these samples were found are located at a considerable distance from each other which indicates that this is a not just a random coincidence but the use of one solution, a single knead following the technology of making a solution (Fig. 3). In general, the variety of types of the solution of the binder composition on the fortress was quite predictable since the fortress was built during several stages of construction. While interpreting the results of the research, it should be taken into consideration that while doing repairs, the defenders of the fortress altered the composition of the solution. The main result is that we were able to observe the reproducibility of the various types of solution and their presence among each other, which confirms that the research method selected were justified and characterize construction technologies and assist in dating. As for the impurities of other components (Fe, Na, Mg and others) on the Anakopian fortress, in all types of solution they were basically identical, which indicates one source of sand taking. If we compare samples from various objects located at a significant distance from each other, for example the Kelasur tower, the same ratio of Ca and Si can be noted with a different amount of impurities, and simultaneously in one object, with different ratios of Ca and Si a set of impurities may correspond. Thus, the ratio of Ca and Si reveal actual construction technology, and other impurities show a source of raw materials.

The sickness of the binding layer and the type of masonry enable to date the sites. All the above said made possible, if not to determine the exact chronological date, then at least to group the monuments according to the simultaneity of their construction time. At the same time, not only one sample from the temple was taken for analysis, but samples of solutions from different architectural elements: apse, narthex, naves, etc., in order to highlight and see the stages of rebuilding and renovation of the same site.

3 Results and Discussion

An important result of the research was the identified Kelasur Wall location (Fig. 4), which has been one of the most controversial and mysterious historical and architectural sites of Abkhazia. (Trebeleva 2019b). This site had been known for a long time (Dubois de Montpéreux 1937: 147, Uvarova 1891: 93, Ivaschenko 1925: 61–89; 1926: 90–92, etc.), but its detailed study had not been done. The most disputable issue of this monument is its origin and purpose. Generally, all the scientific works on the origin and purpose of Kelasur Wall can be divided into several groups:

(1) The Greeks erected it to protect their colony (mainly Dioscuria (Sukhum) and Guenos (Ochamchira)) from the northern barbarians from the mountain (Dubois de Montpéreux 1937: 147; Kudryavtsev 1922: 28, 29, 53). They associate Kelasur Wall with the "Corax Wall" mentioned by Hecataeus of Miletus. (Hecataei Milesii Fragmenta 185);

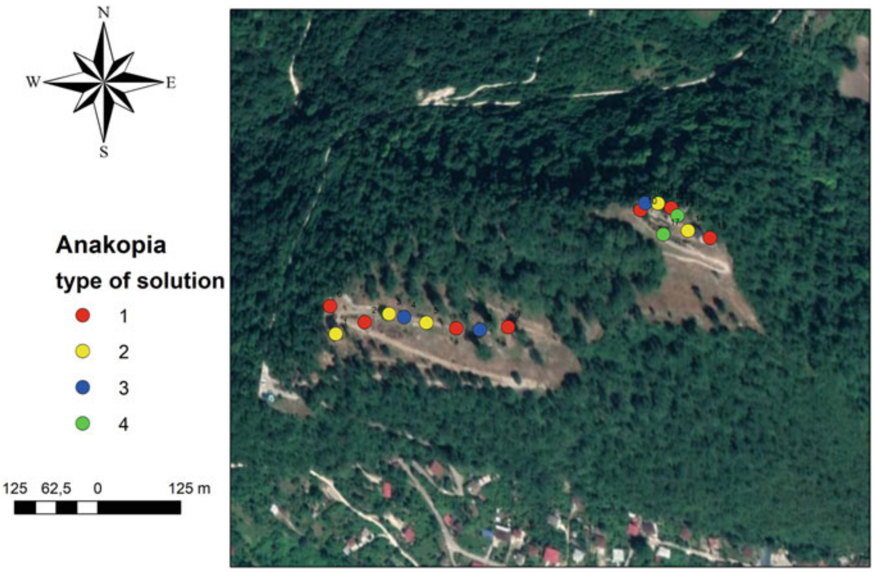

Fig. 3 Anakopia tower, the areas where the samples of mortar were taken from and the type of mortar were coloured

Fig. 4 The first tower of Kelasur Wall (view from the sea)

(2) It was built by the Byzantines or undertheir cooperation with the Abasgians and the Apsils during the war against the Persians. (Chernyavskyi 1882, 18; Miller 1909, 74–76; Ivaschenko 1925, 61–89 Adzinba 1958, 106–152, etc.);
(3) the Persiansbuilt it Alexidze (2000);
(4) Prince Levan II Dadiani built it between 1628 and 1653. (Beradze 1971; Voronov 1973).

Thus, the literature analysis has demonstrated that the researchers' opinions differ drastically, ranging from the period of antiquity to the new time, for as long as twenty-three centuries. There was also no precise location of this site since researchers described not the entire wall in its length but its parts. The methods of finding location existing in the nineteenth-twentieth centuries did not allow to locate the object on the foothills and in the subtropical forest quickly and effortlessly. The most detailed description was done by Yu.N. Voronov. However, in his final article, a number of contradictions can be noted: he wrote that the wall had 279 towers (Voronov 1973: 109), but there were only 268 on the diagram (Voronov 1973: 107). He drew the general scheme of the wall up to the Ingur River, while noting that the last tower stood on the Gedzhir River. (Voronov 1973: 106) An alternative route for the passage of the wall is described by I. Likhachev: after the Otapa cave it turns to the south to Bedia. (Likhachev 1881: 245–248) (Fig. 5). The passing routes suggested by Voronov Yu.N. and Likhachev I. were based on main geographical markers: rivers and settlements in GIS system.

Therefore, the first goal was to obtain the exact geographic location of all towers and fragments of walls between using a GPS receiver. As a result, 208 towers were

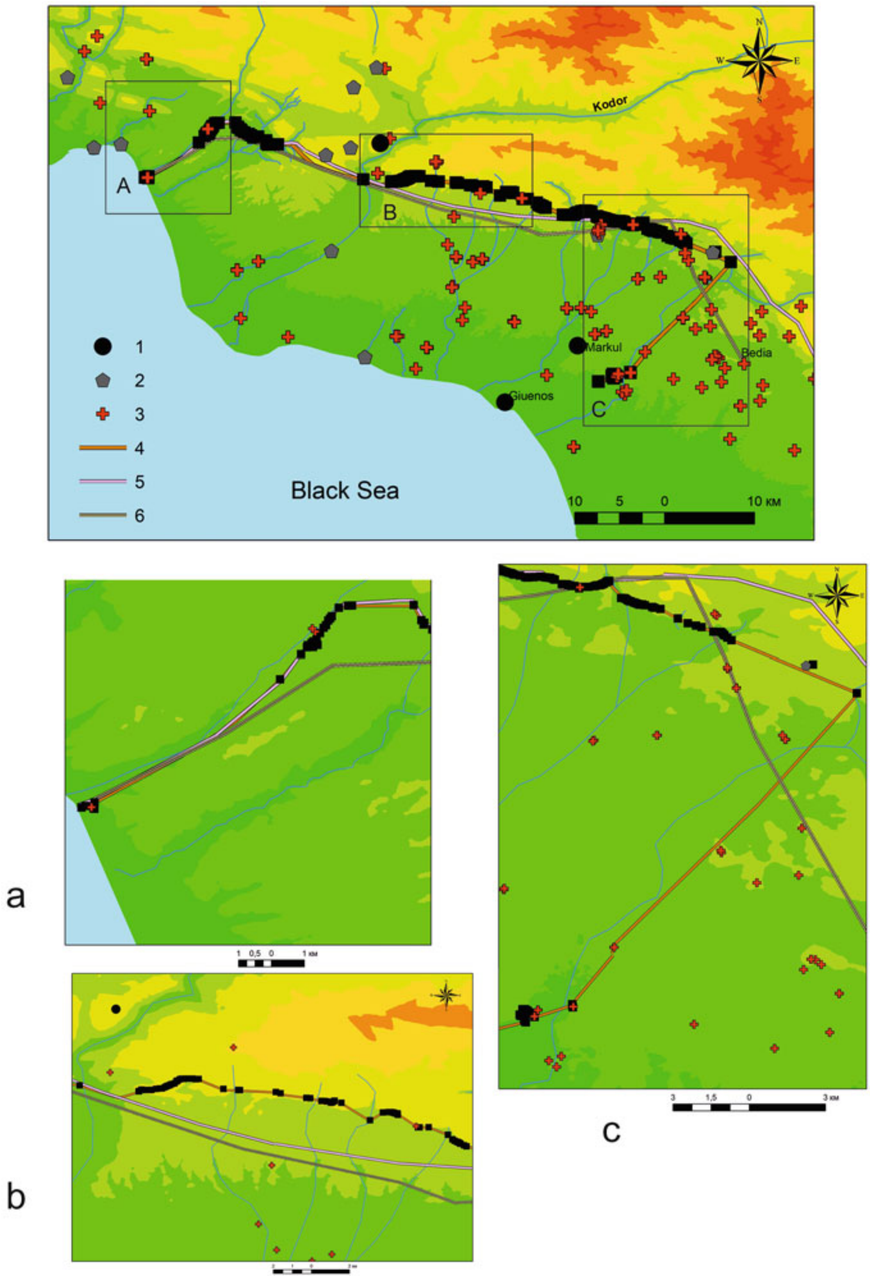

Fig. 5 Kelasur wall and surrounding sites of late Antique and medieval periods: 1–settlement, 2–settlement with temple, 3–fortress, 4–actual route of the Kelasur Wall, 5–the Kelasur Wall by Voronov, 6–the Kelasur Wall by Likhachev

localized on the ground, with sections of connecting walls between them, of which 9 towers were along the Aaldzga river. Previously these towers had not been defined or described. Thus, it can be concluded that Kelasur Wall stretched downhill to the sea along the foothills rather than along the river Ingur, as it had been earlier supposed, but along the river Aaldzga in the area of the modern city of Ochamchir and the ancient town of Guénos. The final length of the wall was 80 km, the accurate location of the surviving towers was defined using GPS coordinates, plans were drawn for 208 towers and sections of the walls that survived until 2015 (see Fig. 5).

Elemental analysis of the chemical composition of the mortar (binder mixture) of 208 towers and sections of surviving walls was used to date Great Abkhazian (Kelasur) Wall. A total of 738 samples from the towers and sections of the walls have been analyzed together with 276 samples from other historical and architectural medieval objects. To exclude the error in determining the composition and possible restoration of Kelasur Wall, samples were taken from different sections of the walls and at different depths in the mortar.

Elemental composition analysis showed that three types of mortar were found in the masonry of Kelasur Wall (3–7% of admixture of lime, 12–18% of lime, 35–45% lime content). Comparison of the composition of mortar of Kelasur Wall with the mortar of other historical objects of late antiquity and the Middle Ages allowed us to conclude that sections of Kelasur Wall with the composition of the mixture of the first group were erected in the era of late antiquity (the early Middle Ages, possibly in the third-fourth centuries). Sections with the composition of the second group were erected in the tenth-eleventh centuries; and the sections of the third type were constructed in the sixteenth-eighteenth centuries. The first type of mortar is found in all objects of Kelasur Wall, and the two other types are found in the western part of the wall, in the section from the river Kelasur to the river Bolshaya Machara. In the same section, the traces of reconstruction of the towers were noted: some of the sections along the Kelasur River were rebuilt into garrisons. During the study, surface material was collected, and the pits were laid on the territory of the towers of Kelasur Wall. The materials date from the third century AD to the fifteenth century.

Another field of work was the continuous investigation in Eastern Abkhazia's territory to accurately locate all medieval objects and analyze their relation to Kelasur Wall. During the explorations, 79 sites were located. Two of them (Chkhotol and Marcul settlements) were discovered for the first time. (Trebeleva and Yurkov 2015). As revealed by spatial analysis of the sites, many temples of the eighth-twelfth centuries were located on both sides of Kelasur Wall, meaning that it was no longer used as a defensive structure (see Fig. 5).

In 2014 stationary excavations began at the Markul settlement. It is located inside Kelasur Wall, 10 km from the ancient settlement of Guenos on two high plateaus, gradually turning into the foothill part. A convenient access to the mountain plateau is located on the south side (Fig. 6).

The following architectural objects have been found: defensive walls (before the start of the access to the plateau and along the southern and northern edges of the plateau), the Southern tower (Alakhash-abaa), the Northern tower, and a temple with a temple fence.

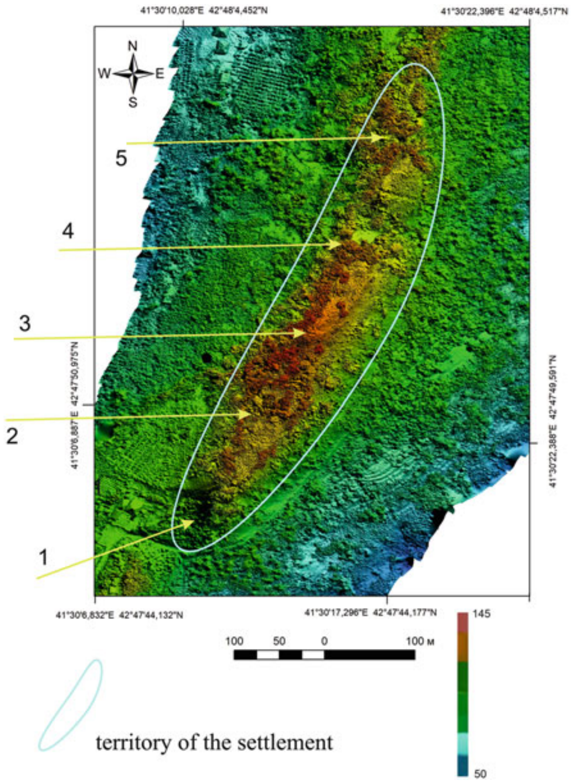

Fig. 6 Orthographic model of the settlement. The numbers denote the following: 1—excavations on the SW slope; 2—South Alakhash-abaa tower; 3—temple; 4—a fragment of the wall; 5—northern tower

The Alahash-Abaa Tower has been preserved in the best state. In 2017, it was investigated by the photogrammetric method, allowing to study in detail its geometric dimensions and architectural features, in particular, the specific elements of timber longitudinal reinforcing belts of the structure (Trebeleva et al. 2019b) (Fig. 7).

The tower is rectangular, measuring 13.9 × 8.5 m, the thickness of the walls in the lower part is 1.2–1.4 m, with an internal size of the lower part of 11.3 × 6.0 m. The tower has survived almost to its entire height which is 6, 5–6.7 m. On the inner side of the walls, at a height of 4.0–4.5 m above the present-day ground level, there are 7 window openings-loopholes that have been preserved, measuring 0.7 × 0.5 m–0.8 × 0.6 m, which are now laid outside. The construction and architectural feature of the tower is the presence of specific elements of timber longitudinal reinforcing belts of the structure. The first belt is located 1.4–1.7 m above the current ground level, the second is 1.1–1.3 m higher above the first. At present, the beam frame has not survived, but according to the shape of the remaining openings, it can be assumed that the beams had a rectangular section along the entire length, measuring 20 × 25 cm. The longitudinal belts of the beams were located on the outer and inner sides of the walls opposite each other and were tied with transverse beams after 2, 5–2.8 m, from which through wholes have also been preserved in the walls. This technology was

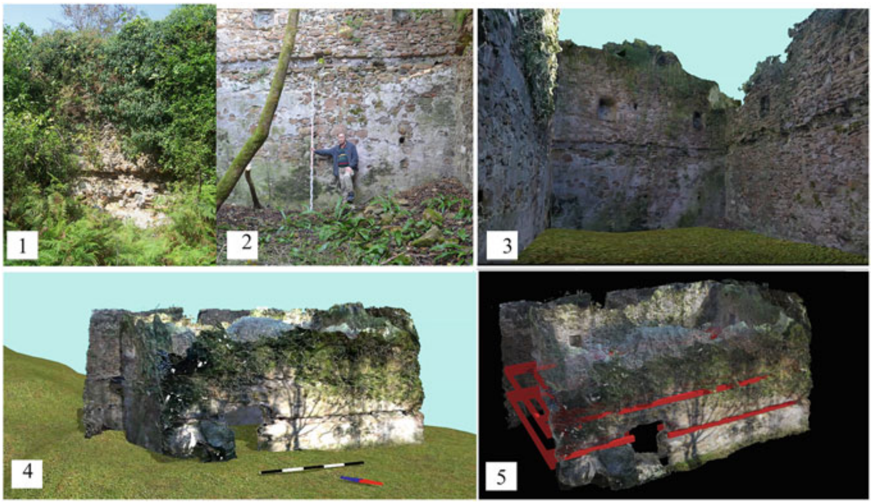

Fig. 7 South tower (Alakhash-abaa): 1—view from the south; 2—eastern wall inside the tower; 3—3D model of the tower, inside view of the eastern wall; 4—3D model of the tower, outside view; 5—3D model of the tower, reconstruction of the beams

described in detail by the Roman architect Vitruvius (Vitr. De architectura I, V, 3). And such a reception was noted during the construction of the Roman fortifications of Sebastopolis (the modern city of Sukhum). (Trapsh 1969: 300). In the medieval fortifications of northwestern Colchis, such a technique as strengthening the walls with longitudinal belts of beams has not yet been recorded. In the fortifications of the Turkish time, similar structures were found, however not rectangular, but round beams, not peeled from bark were used. (Trapsh 1969: 301). Today this tower is the only monument of the local, non-antique population, where the Roman construction technology was applied. Excavations carried out in the Alahash-Abaa tower in 2018 revealed the presence of two levels of floors, and in the lower layers of the tower, ceramics and glass of the Roman and Byzantine (third-fourth centuries AD) time were found. According to the data of radiocarbon analysis of coal, the tower was destroyed by fire at the end of the fifteenth century—at the beginning of the sixteenth century, that is, during the period of civil strife between the influential princes Shervashidze and the Mengrelian princes. (Trebeleva et al. 2019a; Bgazhba and Lakoba 2007: 162–167).

To the north of the Alakhash-abaa tower, at the highest point of the plateau, there are the ruins of a small church (Fig. 8).

The church is a slightly elongated trapezoid with a semicircular apse on the east side, turning into longitudinal walls without shoulders. The masonry is irregular, rubble with double-sided lining when slightly processed blocks were used. The height of the preserved walls varies from 0.1 to 1.5 m. The excavations at the temple, carried out in 2014–2017, allowed to determine its functioning from the turn of the fourth-fifth centuries AD to the fifteenth-sixteenth centuries. The earlier date is determined

Fig. 8 Photogrammetric survey of the temple and its territory (2017)

by the findings from the collective burials on the territory of the temple, the last date is determined by the coins, in particular, the "Nuremberg Tokens" (Fig. 9).

During the excavation of the temple and its territory, burials were also uncovered (Trebeleva and Shvedchikova 2019: 162–173). According to the calculations done, 32 people were buried on the territory of the temple complex with a significant predominance of male burials; burials of children of different ages were also found. To determine the local origin of the buried, an analysis of the content of strontium isotopes in the dental and bone tissue of nine buried people from the excavations in 2016 was carried out. The study was carried out in the All-Russian Scientific Research Institute named after V.I. A.P. Karpinsky (St. Petersburg). (Fig. 10).

Fig. 9 Nuremberg token from excavations at the temple of the Markul settlement

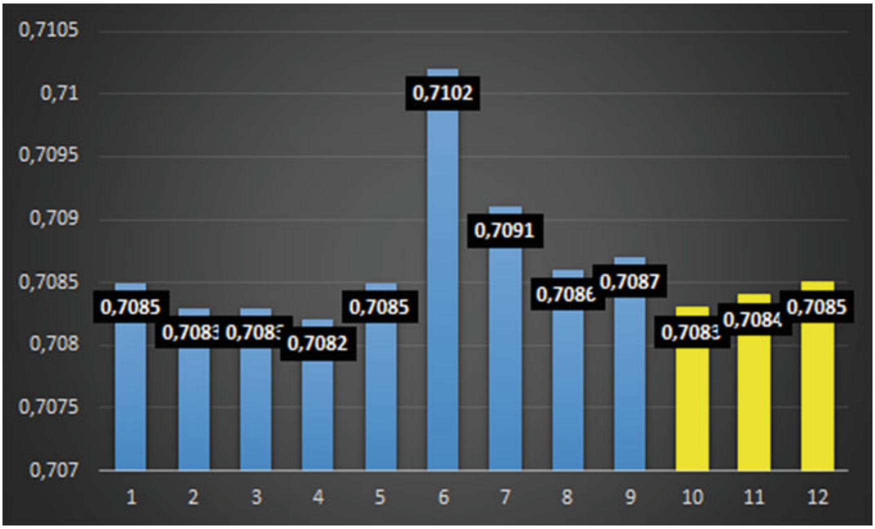

Fig. 10 Isotope analysis of bone remains for Sr (Markul settlement—blue; from the temple in the village of Veseloe—yellow)

Strontium isotope signals in the series ranged from 0.708527 to 0.710201. A group of individuals with values of approximately 0.7091 was distinguished. Their non-local origin can explain the difference of this group from the others. For the correct interpretation of the results, the comparison was based on data of a similar analysis of buried from the crypt of the temple near the village Veseloe (area of Adler) in the 9th—eleventh centuries. The temple was investigated by the staff of the Institute of Archeology of the Russian Academy of Sciences during the preparation for the Olympic Games in 2014. The figures of those buried from the crypt of the temple in the village of Veseloe and those buried on the Markul settlement turned out to be similar. These indicators are also typical to the craniologically defined as representatives of the local population and odontologically being the ancestors of the modern Abkhaz population.

The next stage of work with anthropological material was the study of the isotopic parameters of nitrogen and carbon in human bones and teeth in order to reconstruct the paleo diet. Fifteen samples of bone and dental tissues of individuals were taken from excavations on the territory of the Markul temple, and one sample from the burials at the necropolis on the southwestern slope of the settlement (pit 1).

The average values of 16 samples were −12.88/8.54‰. The highest nitrogen values of 10.4‰ were recorded in a woman from pit 1, the lowest (6.10‰) in a child of the age of infantilis II, as well as the lowest carbon value (−14.23) (works in 2017). In general, the diet of the buried can be characterized as based mainly on plant components with a small amount of meat and dairy foods. The food was based on C4 plant photosynthesis type, taking into account the period of existence of the settlement, this was millet.

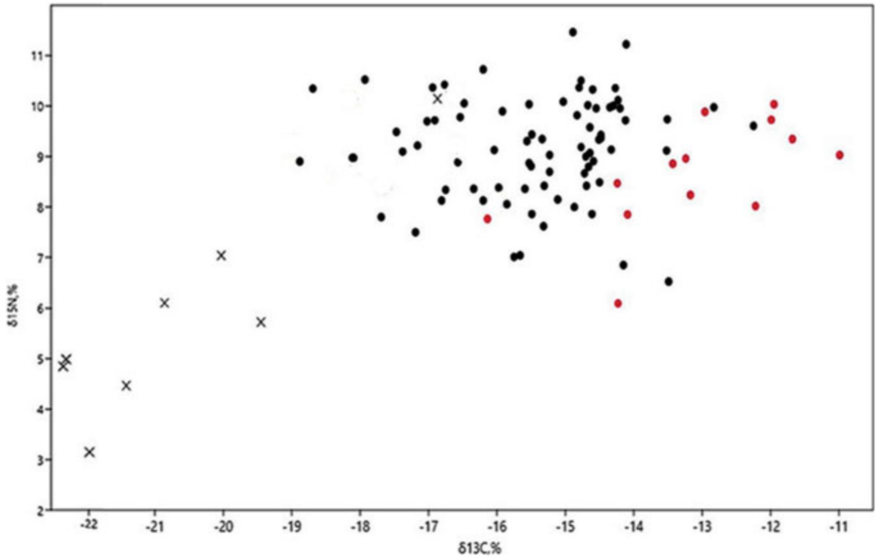

Fig. 11 Isotopic indicators of nitrogen and carbon: comparison of data from the village of Veseloe (black dots) and the Markul settlement (red dots), samples of animals (crosses)

Comparative analysis (see Fig. 11) of data from the excavations of the temple near the village Veseloe 9th—eleventh centuries (Adler district), where 124 individuals were subjected to isotope analysis, showed that in the diet of this population also plant food and C4 plants of the type of photosynthesis prevailed, but in general, it was very diverse. Both groups show similar trends, but the diet of the Markul population has proven to be more specialized and traditional.

"Northern Tower" is located at the northern foot of the second plateau. It is almost completely destroyed. The established dimensions of the tower are 12 × 6 m, the wall thickness is from 1.2 to 1.5 m, and the height of the surviving remains is from 0.1 m to 1.5 m (Trebeleva 2020). In 2019–2020 excavations were carried out at the site of the tower, on an area of 60 sq. meters. Excavations revealed two levels of floors. A significant result was discovering architectural details—capitals of columns and fragments of bas-reliefs, which allowed interpreting the "Northern Tower" as the remains of a dwelling, a "palace" of a local ruler. But given the thickness of the walls and the presence of a buttress, the tower also had defensive functions. The discovered ceramics allows this tower to be dated from the first centuries of our era (red-lacquered ceramics) to the 14th—fifteenth centuries.

In addition to the territory of the plateau itself, the work was carried out on the southwestern slope of the settlement. Here, in the western part of the slope, a necropolis of the Tsebelda time was discovered (Trebeleva et al. 2018). In the central part of the slope, excavations revealed the presence of a settlement of the Hellenistic and Roman times: among the numerous fragments of locally produced ceramics, fragments of black-glazed ceramics (Fig. 12), together with fragments of the necks

Fig. 12 Black-glazed ceramics from excavations on the southwestern slope of the Markul settlement

and bottoms of Chio and Fasos amphorae, were found. In general, ceramics is within in the period from the fourth century BC to the turn of the era. (Trebeleva 2019a).

Thus, gradually, slowly, depict the picture of the life of the people of this area. In the early period of its history, people lived mainly on the south-western slope, but in the first centuries of our era, the situation began to change dramatically: the population ascended to the plateau and enclosed themselves with stone walls. We cannot yet say at what exact period this happened, but it can be assumed that the people, who previously lived on an open slope, began to move to the top of the plateau and build fortifications, probably because of the Gothic-Sarmatian invasions in the middle of the third century: "*When the Scythians began to devastate everything that was in their path, the inhabitants of the Pontic coast retired inland to more fortified places*" (Zosima, I, 32).

Another area of work was the creation of the catalogue of late antique and medieval temples. This category of monuments is remarkable because on the one hand, they are easily found on the ground, since the absolute majority of them rise above the earth's surface. On the other hand, they mark not only the direct spread of the Christian religion but also the demographic situation in the region, as well as its administrative and political division—each temple is political and administrative center, i.e. the temple is considered as "the central place", in accordance with the theory of V. Christaller (1980). Moreover, there is a lot of evidence that Christian churches in Abkhazia were built on the sites of or nearby pagan sanctuaries, which is typical for Abkhazia. For example, there is the famous and recognized Ilor temple, and next to it there is a pagan sanctuary, where priesthood rites are still held (Kvaratskheliya 2020).

This work has not yet been fully completed to date: the catalogue of temples in Western Abkhazia (Gagra, Gudauta, Sukhum regions) has been published (Sakania and Trebeleva 2019), and the processing of materials based on the results of exploration in Eastern Abkhazia (Gulripshsky, Ochamchira, Tkvarchal and Gali districts) is continued.

4 Conclusions

By analyzing the location of the site, a number of principles of forming the settlement system in the geographical and geopolitical space of northwestern Colchis can be noted, both in the area of the seaside lines and in the depth of the country: this is the location of settlements on the routes of the caravan trail, and in the coastal area—at a distance of a day's crossing of the coastal fleet in places with the convenient port for ships. Moreover, we often see the closeness of ancient city-states and fortresses to large settlements of the local population in the Gagra (Nitika) area, traced by multiple burial grounds of the Tsebelda time (traces of the settlement itself have not yet been identified, but explicitly, burial grounds and settlements are not far apart from each other), in the Pitsunda area is the Alasadzyh temple complex and the Ldzaa sanctuary, in the Bambora area it is known that a large settlement was found in this area from the Neolithic period to the Middle Ages, in the Sukhum area there is famous Esher settlement, in the area Santo Tomasso there is a Tamysh settlement. Not all sites have been fully investigated, not all have been identified, but certain trends in their location can be traced quite clearly.

Analysis of the data during a more detailed examination of the sites (Kelasur Wall and Markul settlement) allows us to draw a number of conclusions.

The Tsebeldin period (2nd—seventh centuries) was a turning point in the progress of the life of the people of northwestern Colchis. In this hard period, military tension increased, and massive defensive structures were erected (Kelasur Wall itself, the defensive structures of the Markul settlement, and, possibly, other so far unknown sites). Most likely, the reason behind the construction of fortifications was the Gothic-Sarmatian invasions of the middle of the third century. The basis of the economy during this period was agriculture, and the cultivated crop was millet.

The formation of a unified Abkhazian kingdom in the eighth century is characterized by the flourishing of this territory: the number of temples increased significantly, architecture became more complex, many defensive structures lost their importance (for example, the Kelasur Wall). Agriculture remains the basis of the economy, but the diet became more varied.

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The Use of Remote Sensing Methods for Studying of the Ancient Greek Land Division System of Tauric Chersonesos on the Mayachnyy Peninsula of the Crimea Peninsula

Tatiana N. Smekalova and Edgar A. Terekhin

Abstract A detailed analysis of the 1940s archival aerial photographs and a 1966 satellite image, has shown that the earliest land division of the ancient Tauric Chersonesos affected the Sredinnyy Peninsula of the Crimean Peninsula, as well as the territory to the southeast of the fortification on the isthmus of Mayachnyy, which is on the outside the Mayachnyy Peninsula. Before, it was believed that such division had affected only the territory of the Mayachnyy Peninsula. Land surveying of the Sredinnyy Peninsula probably began from the Great Chersonesos road, as evidenced by the parallel orientation and the regular square shape of the blocks of sections adjacent to the road. Thus, the area of the initial land surveying was probably 930–940 hectares, almost twice of the territory of 460–470 hectares, as is has been previously assumed.

Keywords Tauric Chersonesos · Ancient greek land division system · Mayachnyy peninsula · Remote sensing methods

1 Introduction

The townsite of Chersonesos and its nearby agrarian surroundings (the chora) are now the rare example of a well-preserved ancient Greek cultural landscape in the Mediterranean and the Black Sea region. In 2013, owing to its worldwide scientific importance, the archaeological site of the 'Ancient city Tauric Chersonesos and its chora'

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was included in the list of monuments protected by UNESCO. The Mayachnyy Peninsula constitutes the north-western extremity of the Heraclean Peninsula protruding to the open sea and separated from the latter by the Kazachya Bay deeply cut into the coast from the north (Fig. 1a). It is exactly here, as many researchers suppose, that the earliest Chersonesean land division was carried out in the first half of the fourth century BC. The neck of land 760 m wide, formed by the endpoint of the bay, and the sea is raised 20–36 m above sea level and dominates the entire adjoining area of the Heraklean Peninsula. At this isthmus, not later than at the end of the first—beginning of the second quarter of the fourth century BC, a fortification was erected constituted by two lines of defensive walls with towers (Shcheglov 1993).

The prominent Russian archaeologist Mikhail I. Rostovtsev, informed by Strabo about ruined Old Chersonesos (VII 4. 2), has presumed that the site had been situated on the isthmus of the Mayachny Peninsula and only subsequently was transferred to the place where now the Chersonesean townsite is located (Rostovtsev 1914; Nikolaenko 2018). The discovery of the fortifications on the isthmus of the Mayachnyy Peninsula by Karol Kościuszko-Waluszyński in 1890 initiated the discussion on their character. The scholars considered the hillfort on the isthmus as one of the Chersonesean strongholds mentioned in the Chersonesean Oath (IOSPE I^2, 401), a shelter site barring access to the settled Mayachny Peninsula. Shcheglov (1994) has reconstructed the general plan of the fortifications on the isthmus, drawn their detailed plan, and defined their purpose as a combination of a military fortress viewing the Herakleian Peninsula, the agricultural territory, a dwelling district with a specially allocated sacred area in the south and a haven in the north. An investigation of fortified structures conducted on the isthmus by Dem'yanchuk and Nessel' confirmed the Shcheglov's supposition that the fortification here combined the function of a fortress and a settlement (Dem'yanchuk and Nessel 2011). Based on the aggregate evidence, Nikolaenko (2018) has succeeded in the reconstruction of the history of the chora of the Mayachnyy Peninsula on the isthmus where, in the second quarter of the fourth century BC, a fortified settlement was built. According to Zedgenidze (2019), the purpose of the fortress was that of the protection of the land plots on the Mayachnyy Peninsula, preventing the necessity to construct fortified towers in the estates, like it was within the other area of the Herakleian (надо: Heraklean) Peninsula (Zedgenidze 2019).

The first detailed plan of the Chersonesean land division system was compiled in 1786 by the topographer I.O. Pepelev by the order of Academician K.I. Hablitz. The second,—unique in its information richness,—plan of the remains of the ancient land-division structures on the Mayachnyy Peninsula was drawn by lieutenant-colonel L. Serristori in 1825 (Nikolaenko 2018). The next research stage included a recording of the scheme of ancient land plots in the half-verst map (1 versta = 0.5334 km) of 1886 (scale 1:21,000). Rostovtsev recognized the great significance of the discovery of the ancient land-division system for the entire Black Sea and Mediterranean region. In 1911, Pechenkin, after a recommendation by Rostovtsev, realized a corrected plan of the ancient land plots on the Mayachnyy Peninsula (Shcheglov 1993). In the 1960s, Strzheletskiy in collaboration with Shcheglov, Kutykina (Nikolaenko), and Zherebtsov drafted field drawings of blocks nos. 49–54 on the Mayachnyy Peninsula

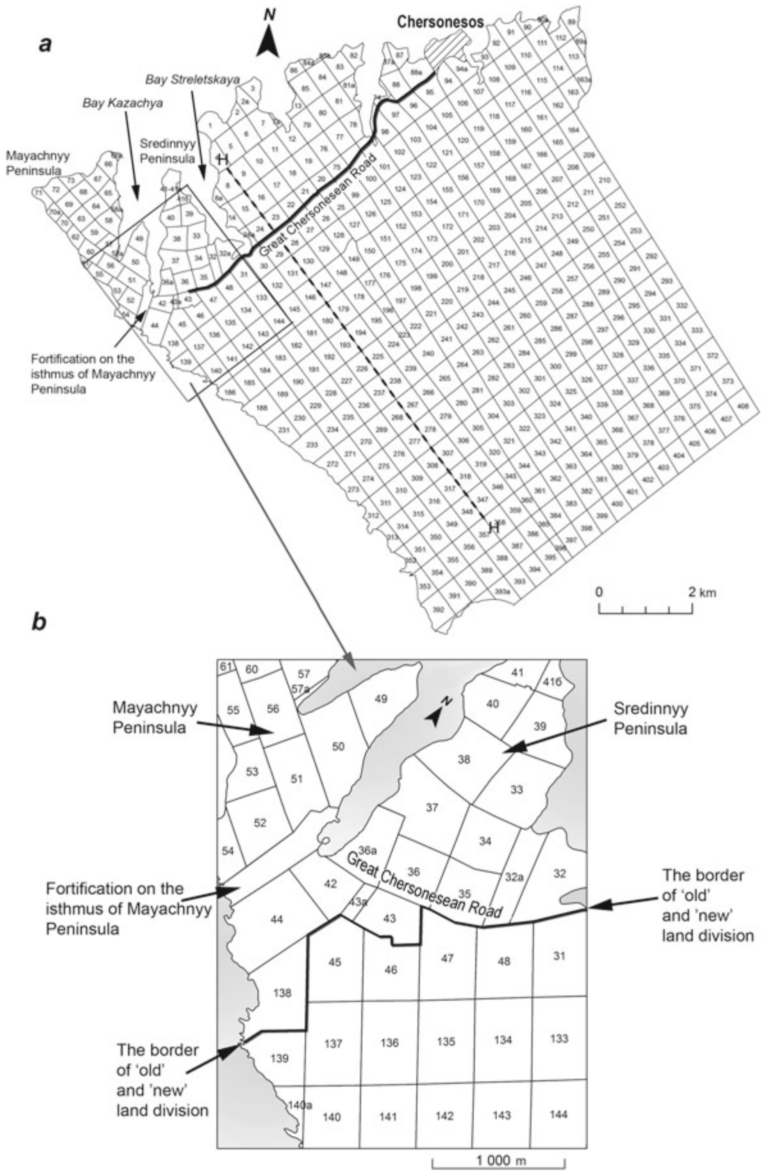

Fig. 1 **a**—plan for the land division of the Herakleian Peninsula created based on archival aerial photographs of the 1940s and satellite image of 1966; **b**—an enlarged part of the ancient land division in the area of the Mayachnyy and Sredinnyy peninsulas

(Nikolaenko 2018). Later, in 1969–1983, the collection of detailed drawings on location was supplemented by topographic plans fulfilled by Ye.N. Zherebtsov on several blocks in the south of the Mayachnyy Peninsula (1985).

2 Materials and Methods

Despite the important attainments of the archaeological cartography in the sphere of recording the remains of the ancient land division, a critical moment in the studies of the ancient land division at the near chora of Chersonesos, including the Mayachnyy Peninsula, has come only when the collection of trophy German Luftwaffe photos of 1941–1944 kept in the National Archives and Records of the United States of America (NARA II) became available. The special importance of this source is in the fact that by the beginning of the World War II, the areas of the Heraklean and Mayachnyy peninsulas still had not been built up and, therefore, the structure of the ancient land division is visible undisturbed in these images. For plotting the grid of land lots, a CORONA panchromatic satellite photograph of 1966 with the spatial resolution of 0.5 m was used. It was obtained from the resources of the National Geological Service of the United States of America (USGS). Based on the mosaic of the geo-referenced aerial photographs of 1941–44, along with the satellite photo of 1966, the grid of ancient land division was plotted with precise geographic coordinates. The detailed plans of the internal division of blocks of the land plots over the entire Heraklean Peninsula including the Mayachnyy Peninsula, were also drawn (Fig. 1a) (Smekalova et al. 2018). The main principles of the Chersonesean land division were thus defined (Smekalova 2019). Also, the examination of the detailed aerial photographs of the 1940s has enabled us to return to the problem of the initial ancient land division which is the subject of the present article.

3 Results and Discussion

In the course of the studies mentioned above, it was established that a *hekatorygos*, i.e., a square with the side of 100 *orgyiai* or 209.4 m, was originally the unit of a singular citizen's land lot (Smekalova et al. 2018). The configuration of the plotted grid of land lots (Fig. 1a) and the direction of the division axes on the Mayachnyy and Sredinnyy peninsulas are different from the other territory of the Herakleian peninsula. The sizes of the blocks on the Mayachnyy and Sredinnyy peninsulas constituted of the four citizen's *hekatorygoi* plots also differ from those on the Herakleian peninsula where the blocks comprised 6 *hekatorygoi* each (Fig. 1b). This fact implies that the Sredinnyy Peninsula was among the first land division areas as well as the Mayachny Peninsula, as supposed by practically all the researchers (Nikolaenko 2018).

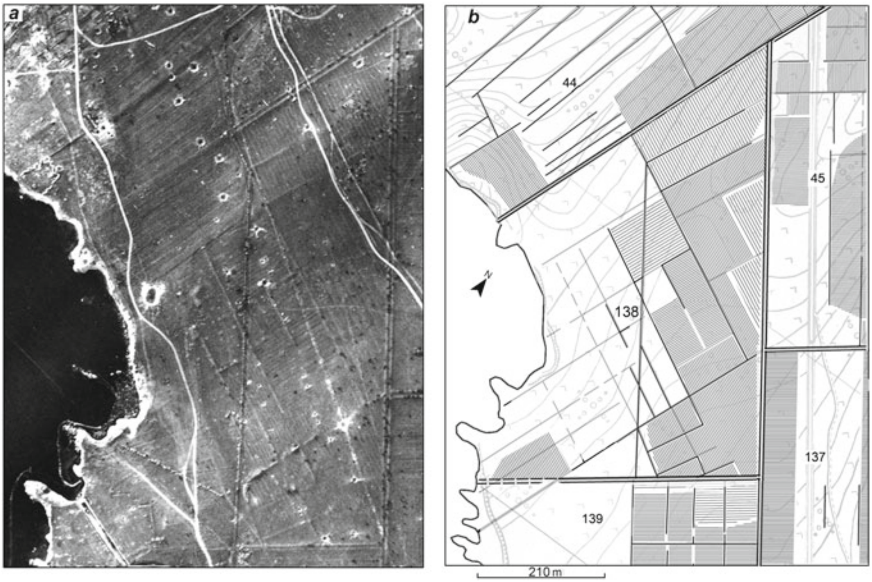

Fig. 2 Block 138: **a**—aerial photograph of April 23, 1944, from the NARA II collection. GX 1893 sd2/994; **b**—a drawing of the internal land division of block 138 against the background of the relief of the terrain

Moreover, the examination of the aerial photos of the 1940s allowed archaeologists to conclude that, according to the 'initial' grid, the land was divided before the construction of the fortifications on the isthmus of the Mayachnyy Peninsula on its south-eastern side and at the joint of the Mayachnyy and Sredinnyy peninsulas (Fig. 2a, b). Here, we see a critical difference between the orientations of the borders of blocks nos. 42, 44, 43, 43a, and 138, and the other vast territory of the Herakleian Peninsula.

At the same time, the orientation of the land division of these 'borderland' blocks coincide with the directions of the walls of the fortress on the isthmus of the Mayachnyy Peninsula (see Fig. 1a, б). Hence, the area adjoining the external side of the fortification was, possibly, divided simultaneously with the construction of the fortress on the isthmus. Block 44, the extreme one on the southwest from the seaward side, adjoins the walls of the fortification. Block 42 adjoins the fortification on one side and the Great Chersonesean Road on the other (Fig. 1a, b). Blocks 43 and 43a, located south from that road follow the orientation of the walls of blocks 44 and 42.

The specially marked difference between the 'initial' plan of the plots and the subsequent total division of the Herakleian Peninsula is discernible at the example of the scheme of the detailed inner division of block no. 138 (Fig. 2b). The external and internal borders of the block, as well as the plantation walls of the vineyards, were traced through a German aerial photo of 1944 (Fig. 2a). Block no. 138 is demarcated according to the the orientation of the walls on the isthmus of the Mayachnyy Peninsula, as well as blocks nos. 44 and 42 (see Fig. 2b). In the junction places of of block no. 138 with blocks nos. 45, 137, and 139, which are divided according to the ‘new’ scheme, we see an abrupt disruption of the inner boundaries and division walls of the vineyards (see Fig. 26). The probable boundary between the ‘initial’ and ‘new’ division system is shown in Fig. 16. Blocks nos. 42, 44, 138, 43, and 43a were demarcated according to the ‘old system. Demarcation of blocks nos. 45, 137, and 139 was carried out according to the ‘new’ rules.

Possibly, the area of the ‘initial’ land division extended also to the territory which later comprised blocks nos. 45, 46, and 137, but subsequently, during the global surveying of the entire Herakleian Peninsula, these blocks were re-demarcated. It is unclear what induced the surveyors to retain the previous inner division at block no. 138. Perhaps, it was the proximity to the seashore with its irregular outlines, which in the case of re-planning would have compelled surveyors to solve a complicated problem of demarcation of marginal areas. It is also cannot be ruled out that blocks nos. 42, 44, 138, and others, adjoining the Mayachnyy and Sredinnyy peninsulas were owned by some influential citizens who did not want to re-plan their long-established vineyards. This fact can be indirectly suggested by the well-known Chersonesean IOSPE I^2 403 inscription where large plots, presumably located in the region of the Mayachnyy Peninsula, are enumerated. Thus, the Pasicharos’ land tenure comprised over 22 *hekatorygoi* or 96 ha. Promathion son of Dionysius, also owned a very large plot of land totalling over 20 *hekatorygoi* or 91 ha; otherwise unknown son of Nanon possessed a plot of over 11 *hekatorygoi* (48 ha) (Smekalova & Terekhin 2018; Smekalova et al. 2018).

The land division on the Sredinnyy Peninsula started beginning from the Great Chersonesean Road that is suggested by the parallel orientation and the regular square form of blocks nos. 35 and 36, adjoining the road, as well as blocks nos. 34 and 37 of the ‘second row’ (see Fig. 16). The bordering blocks nos. 32 and 32a are only blocks of the irregular form, evidently defined by the complex outlines of the Streletskaya Bay. Therefore, we should recognize the high significance of the Great Chersonesean Road that connected the settlement on the isthmus of the Mayachny Peninsula with Chersonesos via the shortest and most convenient land route about 8.5 km long.

4 Conclusions

A detailed examination of archive aerial photographs of the 1940s and a satellite image of 1966 succeeded in demonstrating that the earliest land division took place on the Mayachnyy Peninsula, as supposed earlier, and on the neighbouring Sredinnyy Peninsula, as well as at the outside territories to the south-east from the fortification on the isthmus. In other words, the fortifications on the isthmus defended the Mayachnyy Peninsula itself and also its neighboring territories to the southeast and east from the Peninsula. In case of the enemy’s attack, people working in these lands could have a shelter behind the fortification walls on the isthmus, together with the residents of the Mayachnyy Peninsula.

At the same time, the presence of land plots at the approaches from the external south-eastern side of the fortification on the isthmus of the Mayachnyy Peninsula strengthened its defensive capacity because it created additional obstacles against an attacking enemy. The enemy, having entered a vineyard, which was covered with plantation walls and grape spreading or twisting over the trees, had difficulty getting out from there. If the enemy had found himself in an area where the plantation walls ran perpendicularly relative to the walls of neighbouring fields, he would have finally lost the orientation in such a trap. As evidenced by Aristotle, "so rural dwellers act while planting vines arranging them for safety in crossing rows" (Arist. Pol. VII X.5. 28–30).

Thus, it may be concluded that the area of the initial land division was 930–940 hectares, almost twice the territory of 460–470 ha as supposed before (Shcheglov 1993). This figure takes into consideration the rise of the sea level and abrasion of the shores by now, which increase the area by 10–12%.

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Geoarchaeological Studies on the Territory of Baikal Siberia: Approach and Methods

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Abstract In the work, we offer a brief review of the geoarchaeological research concept, which we use during the studying of the Baikal Siberia archaeological sites. Our developments allow us to distinguish typical sediments and situations for the MIS 2 and MIS 1 geoarchaeological complexes, define the features of the sediments and archaeological complexes in them, create the system of correctness revealing of radiocarbon dates based on geoarchaeological assessment. Our research is based on four positions: (1) Geoarchaeology is a source study discipline with its methods of study. (2) The main object of research is the geoarchaeosite, which is a complexly structured integral system, where the summation of traces of natural and anthropogenic events is encrypted. (3) Geoarchaeology should be a transdisciplinary direction, the nature of which is determined by the complex origin of the geoarchaeological site. (4) Geoarchaeological research should be based, first of all, both on the methods of actualism and stratigraphy with overcoming mistakes in identifying objects and phenomena, as well as on pedolithological and event approaches. Our proposed geoarchaeological developments, which for many years have been successfully used in research on the territory of Baikal Siberia, are in a constant process of refinement and approbation, which significantly expands their capabilities and prospects.

Keywords Baikal siberia · Geoarchaeology · Concept · Geoarchaeosite · Actualism · Stratigraphy · Pedolithological approach Event approach

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1 Introduction

Geoarchaeology implies archaeological research using the methods and concepts of geosciences (Butzer 1982: xi). Its main goal is to build integrated models of human and environmental systems and to investigate the nature, sequence, and causes of anthropogenic and natural impacts on the landscape (French 2003: 3).

The development of archaeology, first of all, of the Stone Age, took place as a part of geological research; therefore geology and archaeology have always coexisted in symbiosis (Medvedev 2008; Kuzmin 2017; Butzer 1982; Waters 1992; Rapp and Hill 2006; Goldberg and Macphail 2006). The starting point for the formation of geoarchaeology is associated with the works of Karl Butzer (1964, 1971), who was the first to use the term "geoarchaeology" (Butzer 1973). The book published a little later with the term "geoarchaeology" in the title was no less important for the development of this discipline. (Davidson et al. 1976). Colin Renfrew proclaimed the basic slogan in the preface to this book: "every archaeological problem starts as a problem in geoarchaeology" (ib.: 2).

Geoarchaeology is provided with a large number of various publications in current world practice, including the thematic journal "Geoarchaeology: an International Journal", monographs, collections, special issues, and individual papers (Butzer 1964, 1971, 1973, 1982; Waters 1992; Goldberg and Macphail, 2006; Rapp and Hill 2006; Woodward and Huckleberry 2010; French 2003, 2015; Gilbert 2017; Kluiving et al. 2017; Siart et al. 2018; and many others).

A huge set of methods has been formed in studying problems associated with the "nature—human" system in all its aspects for more than 50-year history of the development of geoarchaeology as a separate direction (Stein and Farrand 2001; French 2003; Canti and Huisman 2015; Karkanas and Goldberg 2018). By the joint efforts of scientists, starting with Karl Butzer (1982) and Michael (1992), the basic principles, subject areas, research fields, and procedures for geoarchaeology have been determined (Butzer 1982, 2008; Waters 1992; Goldberg and Macphail 2006; Rapp and Hill 2006; Kelley and Sanger 2017). The main research fields are the geochronological context of sites, the spatial context, the preservation of data at and outside the archaeological site, and ancient landscapes (Butzer 1982; Waters 1992). The system of geoarchaeological study necessarily includes the functions of a quick transition to different-scale levels. Macro-scale research is related to the environment. Meso-scale level locates a geoarchaeosite in an environmental system. Micro-scale research investigates the site itself (Butzer 2008).

However, there are methodological differences in the definition of the essence and role of geoarchaeology. Some perceive it as an independent fundamental discipline (Goldberg and Macphail 2006; Bebermeier and Schütt 2011), others as an interdisciplinary approach (Butzer, 1982, 2008; Waters 1992; Rapp and Hill 2006; Kuzmin 2017). Within the last approach, the position of geoarchaeology is defined as a subsidiary, and the use of natural scientific methods becomes an aim in itself (Barrera and Pardo 2020).

Serious problems of geoarchaeology are the problems of interdisciplinary cooperation, the degree of integration and duration of such cooperation, different views on the scope of research, the absence of a common conceptual and terminological apparatus (Butzer 2008; Chazan 2017; Meignen et al. 2017), an arbitrary choice of the geoarchaeological methods, as well as theoretical and methodological fuzziness. These problems are still far from being solved.

In Russia, the development of geoarchaeology as a scientific direction also took place in the system of the world trend of close and mutual cooperation with the Earth sciences. The research tradition of Russian archaeology does not imply the formation of interdisciplinary systems (subdisciplines) in separate directions with their names. However, geoarchaeological procedures can be traced from the 1920s to the works of Alexei Pavlov, Valerian Gromov, and their followers (Medvedev 2008).

The term "geoarchaeology" in Russian literature began to be used in the 1980s, primarily in publications of Siberian researchers of the Paleolithic. But it did not receive wide distribution. Only in the twenty-first century, the geoarchaeological trend is becoming more pronounced (Zaykov et al. 2012; Panin 2012; Kuzmin 2017; Pitulko and Pavlova 2010; Sorokin 2018). Contemporary Russian scientists have an ambiguous attitude towards geoarchaeology, from acceptance to almost complete rejection (Tetenkin 2003; Zolnikov et al. 2013).

The concept of "geoarchaeology" initially contains an axiological aspect of significance, within which it is perceived as an auxiliary discipline for archaeological research. The current situation determines the need to consider the essence of geoarchaeology, its significance, and possibilities in Russian archaeological practice.

At Irkutsk State University, the origin and formation of the geoarchaeological study are associated with the name of the leader of the Irkutsk archaeological school German Medvedev (1936–2015). Our long-term studies, based, among other things, on his proposals, allowed us to create an original geoarchaeological concept (research system) with its methods and procedures, in which the central place is given to the geoarchaeosite. It was formed as a result of cooperation with representatives of natural sciences, regardless of foreign developments (due to limited access to publications on this topic in the Soviet and, partially, in the post-Soviet period). On the one hand, this concept has much in common with global geoarchaeological trends; on the other hand, it opens up new opportunities for geoarchaeological studies. The purpose of this article is to show the results of using our research system in the study of the Late Pleistocene and Holocene geoarchaeosites of Baikal Siberia.

2 Materials and Methods

Our approaches and methods have been tested for nearly forty years on several hundred stratified and exposed geoarchaeological objects of Baikal Siberia[1] of a

[1] In this study, Baikal Siberia is understood as a region located within the boundaries of the south of Central Siberia, the Cis-Baikal mountain region and Western Transbaikal. The expediency of using

wide age range (Stratigraphia 1990; Vorobieva 2010). Including such well-known sites as Malta, Ust-Belaya, Galashikha, Sosnovyi Bor, Strizhovaya Gora, Igetei, Georgievskoe, Kazachka, Gorelyi Les, Ust-Khaita, A. G. Generalov site, Tuyana, I. W. Arembovskii site, Ulan-Khada, Sagan-Zaba 2, Posolskaya, Irkutsk Fortress, etc.

As a result of many years of interdisciplinary geoarchaeological research, we got the opportunity to implement our concept.

And it, as mentioned, was formed at the initial stage independently of the well-known world geoarchaeological developments. We focus on the archaeological site during conducting geoarchaeological research. The term "geoarchaeological object" or "geoarchaeosite" was used to clarify this concept (Medvedev 2008; Fouache and Rasse 2009). Below is the text, we mainly use the second term. If we proceed from the provisions of Karl Butzer on the scale of geoarchaeological research (2008), then micro-scale studies associated with the study of the geoarchaeosite itself are basic in geoarchaeological research.

Geoarchaeology in our developments acts as a source study discipline with its methods of analysis, synthesis, and assessment of the reliability of geoarchaeological data and results. There is such a separate direction (subdiscipline) as "source studies" in the Russian historical tradition, which considers approaches and methods of working with historical sources. The theoretical and methodological development of archaeological source study in Russian science was proposed by Lev Klejn (1978).

Geoarchaeosite is the only source of information about ancient cultures and the environment. It can be defined as an area with archaeological remains, traces of past human activities, and natural processes in an exposed or stratified position. In turn, the geoarchaeosite is a structured integral system of natural and cultural genesis.

The issue of choosing integrated studies and their organization is quite acute today. A wide arsenal of natural-scientific methods of geoarchaeological research requires systematization, determination of their minimum standard set, and determination of the protocol for their implementation (Canti and Huisman 2015; Fouache 2013; Kokinou 2015). This is a quite voluminous work, which, in addition to time-consuming, requires methodic and methodological developments.

In terms of classification, integrated scientific approaches boil down to multidisciplinary, interdisciplinary, and transdisciplinary approaches, which differ in the degree of integration, the capacity of cooperation, and the research motivation. The most effective form of cooperation is transdisciplinarity, which defines new forms of interaction with the crossing of disciplinary boundaries in solving problems and creating a new methodology for gaining knowledge (Mobjörk 2010; Hirsch et al. 2013). This also applies to geoarchaeology, when none of the parties (humanitarian or natural) acts to the other as a leading or auxiliary discipline (Kluiving and Guttmann-Bond 2012).

The most effective form of cooperation for geoarchaeology is transdisciplinarity, which defines new forms of interaction in solving scientific problems and creating a new methodological basis for obtaining knowledge (Clark 2009; Mobjörk 2009,

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this term is fully justified from the point of view of cultural and geographical research. This is also confirmed by archaeological data.

2010; Hirsch et al. 2008, 2013). This is the initial stage of the formation of transdisciplinary cooperation, which will allow the involvement of the public in the future in a wide discussion of the results of geoarchaeological research (Kidder and Liu 2017).

Geoarchaeological research is based on the methods of actualism[2] and stratigraphy with "recognition thresholds". Evgenia (1994) has developed the problem of "recognition" in archaeology. She introduced the concept of the "recognition threshold" of paleolife fragments, which depend on the chronological gap between the present and the past. This gap is the reason for the "recognition mistakes", overcoming of which allows adequately identifying various phenomena in the system of a geoarchaeosite. They include the modernization mistake (when later analogs are used as objects-differentiators), the archaization mistake (when a young source is taken as an earlier one), the socialization mistake (when a natural formation is interpreted as a cultural one), the naturalization mistake (when artifactual objects and traces are considered as results of natural processes), and the substitution mistake (when one formation of the same is taken for another).

Traces set of natural and anthropogenic events sealed in sediments are encoded in the geoarchaeosite. An event is defined as a change in state, and any process consists of a series of explicit or latent events. The principle of eventfulness can be determined as revealing and identification of various traces and remains of natural and cultural origin in the deposits of a geoarchaeosite, and their correlation with different events. The pedolithological and event (event-contextual) approaches were formed on their basis. The pedolithological approach is defined as a set of methods of soil science and lithology in combination with other tools used to decipher the genesis of deposits, reconstruct the paleoenvironment, and the stratigraphic sequence of events (Vorobieva 2010). The event approach is aimed at determining the aggregates of phenomena that are in close connection. The formation of this connection is due to a certain meaning and content. The concept of "context" is widely used in geoarchaeology with its different levels and forms being distinguished (Butzer 1982; Rapp and Hill 2006). The term "geoarchaeological context" was proposed by Mariya Aleksandrova in Russian scientific literature (Aleksandrova 1998). The main task of the event-contextual approach is the identification of archaeological traces in the sediments with overcoming the "recognition mistakes". This, in turn, makes it possible to reliably and fully organize the process of interpreting geoarchaeological contexts and adequately reconstruct the way of life of ancient communities (Berdnikova and Vorobieva 2009).

The classification of geoarchaeosites is based on the structural features of the sediments and the nature of the inclusion of cultural remains in them. Exposed sites,

[2] Actualism (lat. actualis—real) is one of the methodological approaches in the natural sciences. It is based on the principle of uniformity, according to which natural processes occurring in past geological epochs, and the phenomena caused by these processes, have much in common with modern ones (Geological Dictionary, 1978, p. 30).

where archaeological material is out of sediments and stratified sites in which material is confined to sediments are distinguished. Among the latter, there are 'macrolayered', 'microlayered' (thin-layered), redeposited, and their various combinations (Medvedev and Vorobieva 1998; Berdnikov et al. 2017). Macrolayered situation is formed in the profile of a fully developed soil, mainly modern. As a rule, the age of such soils in Baikal Siberia does not go beyond the Holocene, and the chronological interval of the formation of soil horizons with their small thickness (0.1–0.5 m) is several thousand years. Archaeological finds are contained in a "compression" state in these soil horizons, creating a "cultural palimpsest" that is extremely difficult to subdivide into chronological stages. The sites in which cultural remains are included in separate numerous paleosoils (ancient buried soils) are defined as microlayered, where archaeological materials and complexes are located in situ. Buried soils, according to the degree of profile development, are divided into embryonic and less developed soils with a chronological interval of formation usually about ~10–500 years. The lack of paleosoil signs or the presence of only its fragments and derivatives as a lithological basis for the inclusion of cultural remains may indicate the processes of redeposition.

German Medvedev proposed a very apt term "culture-bearing" layers for lithological layers with archaeological material (Medvedev and Nesmeyanov 1988). Cultural sediments of anthropogenic genesis with material that remain included in them are formed in places of long-term human habitation (tells, tepe, long-term settlements, and cities). They can be defined as "cultural" layers (Berdnikova and Vorobieva 2011).

Cultural layers reflect different types of human activities in a particular area. In determining their function, we proceed from the results of studying the post-medieval cultural layers of the historical part of Irkutsk. Among them, layers are distinguished reflecting the use of plots for arable land, pastures, vegetable gardens, a courtyard, a roadway with backfill (poles, gravel, sand, cobblestones), and without backfill. Traces of carts were recorded in the road layers. Areas with improvement elements (slag interlayers, brick pavements), construction layers on which materials were prepared (interlayers of shavings and chips, broken brick mixed with lime mortar) are determined.

3 Results and Discussion

A wide signal variety of global and regional natural events has been recorded in terrestrial deposits. It allowed us to develop the climatic-stratigraphic scheme for the Upper Pleistocene and Holocene of Baikal Siberia, reconstruct the paleogeographic situation from the MIS 5 to MIS 1, and track the dynamics of natural and cultural processes (Stratigrafiya 1990; Vorobieva 2010, 2016).

The typicality of geoarchaeological sections is based on the fact that traces of global and regional natural events reveal certain patterns of manifestations and combinations in sediments.

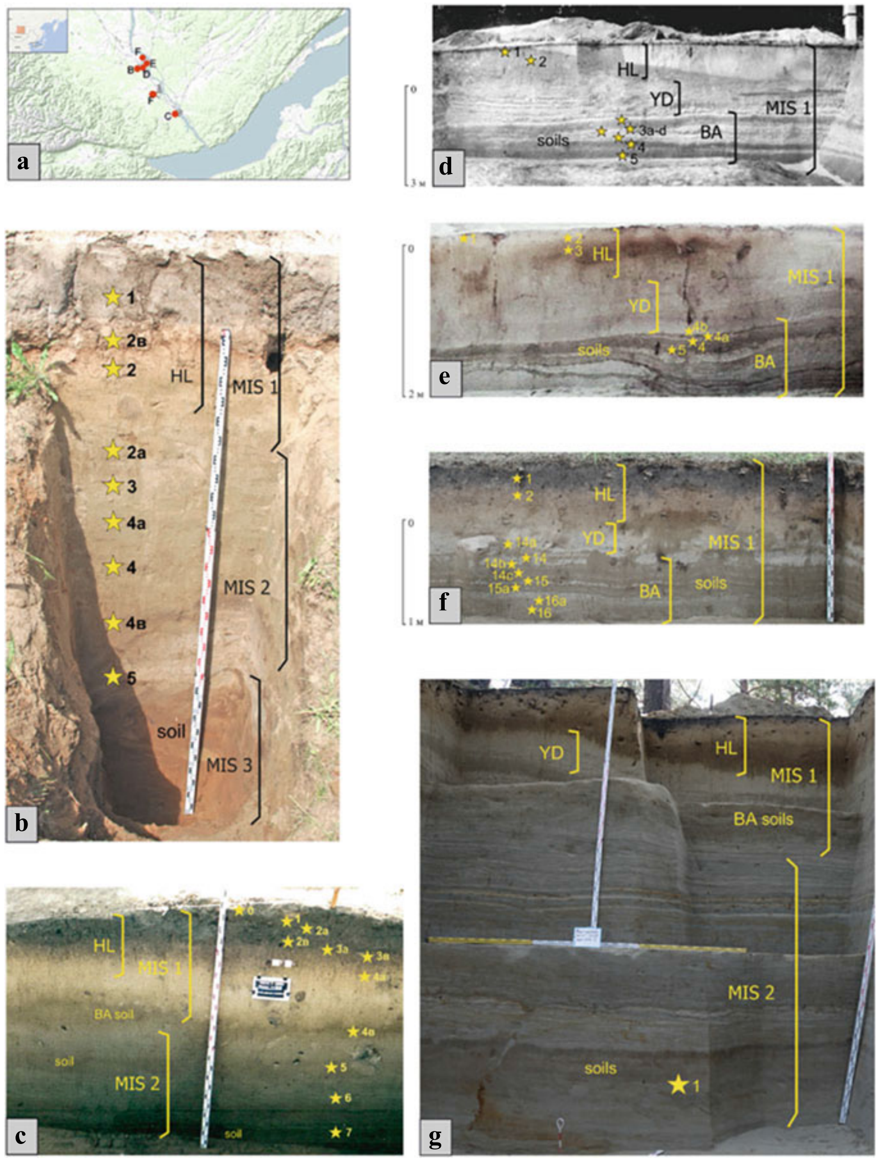
In the terrestrial deposits of geoarchaeosites of Baikal Siberia, a lot of various signals of global-regional climatic and other natural events were recorded, presented by the form of paleosols and loess, traces of cryogenesis, aeolian, deluvial and solifluction processes, catastrophic events, fluctuations in the level of Lake Baikal and descents of ancient lakes. Traces of global regional and local events (climatogenic, seismogenic, various exogenous, anthropogenic, etc.), which are recorded in the sediments, have certain patterns of manifestations and combinations. Signals of recurring natural changes (climatic fluctuations, fluctuations in the level of reservoirs) can be attributed to ordinary events. We refer to extraordinary events as those triggered by some rare and, as a rule, rapid processes (earthquakes, erosion, floods, mudflows, landslides). Sets of combinations of traces of ordinary and extraordinary events can be noted in separate sections and have a unique character, or they can have certain stability of their manifestation and be recorded in many sections. Thus, the typicality of the deposits for different chrono-sections and their visual recognition are formed.

Typical sediments of geoarchaeosites based on forecasting global and regional climatic events, various local seismic processes (climatogenic, anthropogenic, various exogenous, anthropogenic, etc.), which are recorded in the sediments and have certain patterns of the display and combinations. Typicality expressed in the regular recurrence of the strata system is formed, first of all, by global and regional climatogenic factors. As a result of the long-term research, the opportunity of distinguishing the typical deposit systems for the different chronointervals of the Pleistocene and Holocene of Baikal Siberia has appeared (Vorobieva 2010; Stratigrafiya 1990). The classification of geoarchaeosites, the specificity of the formation of culture-bearing sediments, and the typicality of land sections for different chronointervals allowed us to create information form for various sites of Baikal Siberia from the end of Pleistocene to the Middle Holocene.

The typicality system of the geoarchaeosites of the MIS 1 and MIS 2 is the most developed on the modern research level in Baikal Siberia. As a rule, the series of soils with cultural remains, which formed the multilayered situation, are recorded in the sediments of this age. There are about 50 geoarchaeosites, where the multilayered situation is formed by the microlayered and microlayered combination (Berdnikova and Vorobieva 2012).

Geoarchaeosites of the MIS 2—early MIS 1 of Baikal Siberia (Fig. 1) occupy the middle and lower tier with relative elevation marks in the range of 9–30 m. Materials of these sites are connected with a soil formation of different genesis: proluvial (Makarovo 2), aeolian (Krasnyi Yar 1, Sosnovyi Bor), mixed aeolian-colluvium (Kitoiskii Most 1), eolian-colluvium-alluvial (Ust-Belaya, Galashikha), with loess-like deposits with a predominance of the colluvium component. From 2 (for example, Cheremushnik 2) to 10 cultural-bearing layers (Ust-Belaya) are recorded at many sites.

Despite the diverse genesis of sediments, the typical stratigraphic situations, which represent the global and regional paleoclimatic changes are revealed (Vorobieva 2010). The Bølling-Allerød (BA) soils are well expressed in the soil-loess sections. The substantial split (up to 10 layers) and archaeological material saturation are



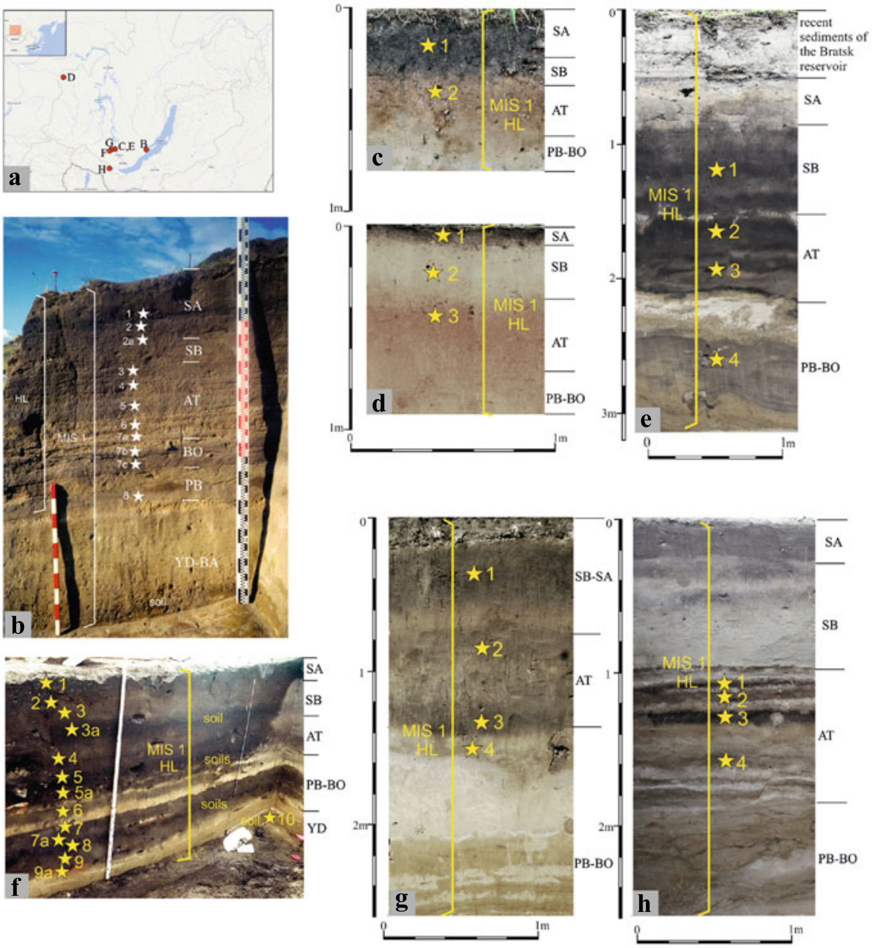
observed for the BA soils in the sediments with a predominance of eolian component independently of the hypsometric position of the geoarchaeosites (Sosnovyi Bor, Ust-Belaya, Galashikha). The sandy strata of the Younger Dryas (YD) well manifest in such deposits (Berdnikova et al. 2015). The cryoarid environments are characterized for the Younger Dryas on the territory of Baikal Siberia(Vorobieva 2010). We created

◀**Fig. 1** Typical deposits of Final Pleistocene geoarchaeosites of Baikal Siberia —geoarchaeosites on the map 3—culture-bearing layer (c.l.) and its number. MIS 3, MIS 2, MIS 1—Marine Isotope Stages 3, 2, 1, BA—Bølling-Allerød, YD—Younger Dryas, HL—Holocene. **a** Map of the location of geoarchaeosites: B—Malta-Most 1 (52°49′40.23"N, 103°32′31.98"E); C—Novyi Angarskii Most (52°15′20.17"N, 104°16′26.88"E); D—Sosnovyi Bor (52°50′06.9"N, 103°35′37.7"E); E—Galashikha (52°54′40.61"N, 103°38′54.93"E); F—Ust-Belaya (52°55′15.54"N, 103°39′7.86"E); G—Kitoiskii Most (52°28′40.2"N, 103°46′26.7"E). **b** Malta-Most 1: 20–23 m terraced surface, right bank of the Belaya River, excavations by Natalia Berdnikova in 1991–1993, photo by Natalia Berdnikova. HL—light and medium loams, gray forest soil. Early MIS 1—high-carbonate loess-like loams. MIS 2—sandy loam, medium loam, sands with burial soils. MIS 3—heavy loams, soliflucted pedocomplex. Age-based on ^{14}C-dating for c.l. 3–18, 7–18, 2 cal BP. **c** Novyi Angarskii Most: 14–16 m terraced surface, left bank of the Angara River, excavations by Irina Lezhnenko in 1999–2000, photo by Irina Lezhnenko (Vorobieva 2010). HL—light, medium loams, dark gray forest soil. Early MIS 1—loess-like medium loams with Bølling–Allerød burial soil. MIS 2—medium, heavy loams with burial soils. Age-based on ^{14}C-dating for c.l. 5–18, 7–17, 8 cal BP. **d** Sosnovyi Bor: 22–24 m terrace surface covered with a 4–5 m layer of aeolian sands, right bank of the Belaya River, excavations by German Medvedev in 1966–1969, photo by German Medvedev. HL—sandy loams, sod-podzolic soil. Early MIS 1—layered aeolian sands with a series of underdeveloped Bølling–Allerød burial soils. Age-based on ^{14}C-dating: c.l. 3b–14, 3–13, 6 cal BP; c.l. 4–14, 8–13, 6 cal BP; c.l. 5–14, 9–14, 2 BP. **e** Galashikha: 8–9 m terrace, right bank of the Belaya River, excavations by Natalia Berdnikova in 1999, photo by Natalia Berdnikova. HL—sandy loams, gray forest soil. Early MIS 1—layered aeolian and alluvium sandy loams and sands with a series of underdeveloped Bølling–Allerød burial soils. Age-based on ^{14}C-dating: c.l. 4–13, 6–13, 4 cal BP; c.l. 5–14, 1–13, 6 cal BP. **f** Ust-Belaya: 8–9 m terrace, left bank of the Belaya River, excavations by Ivan Berdnikov and Natalia Berdnikova in (2012), photo by Ivan Berdnikov. HL—sandy loams, gray forest soil. Early MIS 1—layered aeolian and alluvium sandy loams and sands with a series of underdeveloped Bølling–Allerød burial soils. Age-based on ^{14}C-dating: c.l. 16–14, 2–13, 8 cal BP; c.l. 14—from 14, 3–13, 8 to 13, 6–13, 4 cal BP. **g** Kitoiskii Most: 20–24 m terrace, right bank of the Kitoi river. Excavations by a team of Irkutsk State University in 2019: photo by Natalia Berdnikova. MIS 1—subaerial sediments with Holocene sod-podzolic soil, Younger Dryas deflated sands, and Bølling–Allerød burial soils (up to 5). MIS 2—layered aeolian and colluvial (?) sands with a series of underdeveloped burial soils. Age-based on ^{14}C-dating for c.l. 1: from 18, 7–18, 1 to 18, 2–17, 5 cal BP

the database of the ^{14}C-dating for the MIS 2—early MIS 1 archaeological complexes, which has 141 definitions. This made it possible to enough confidently determine enough the age of certain sediments.

Lots of multilayered Holocene geoarchaeosites of Baikal Siberia, which have geomorphological features and specificity of the sedimentation, different degrees of informativeness, are studied (Berdnikov et al. 2017). The sediments in which the cultural remains of Holocene cultures are enclosed are presented by several variants (Stratigraphy 1990; Vorobieva 2010; Berdnikov et al. 2014, 2017). These are subaerial (aeolian) sediments with a fully developed modern soil profile, subaerial (mainly colluvium with aeolian and in some cases proluvial components) sediments of acclivous slopes, and alluvial cones (Fig. 2).

The most common types of Holocene sites in Baikal Siberia are microlayered sites with subaerial sediments, represented by developed modern soil profiles. Holocene microlayered sites are associated with floodplain, slope, and fan deposits.



Floodplain sediments in the valleys of the Angara river, its tributaries of the first order (the Irkut and Belaya rivers), and the right-bank part of the Middle Yenisei (the Kan River) include thin (~5–20 cm) humus horizons, which are embryonic and underdeveloped soils, to which archaeological complexes are confined. The thickness of the Holocene strata, the number, and the color of soil vary, although the patterns of paleoclimatic environments are traced in them—from weakly humified soils of the Early Holocene to the greater thickness and more humified soils of the Middle Holocene, which was the warmest period.

The subaerial sediment of slopes and cones have been studied in detail on the west coast of Baikal Lake (Stratigraphy 1990; Vorobieva 2010, 2016). The part of the Holocene sections has a layered structure and culture-bearing sediments are recording in buried soil as on river floodplains. As a rule, they are divided by the

◀**Fig. 2** Typical deposits of Holocene geoarchaeosites of Baikal Siberia. ●—geoarchaeosites on the map ☆3—culture-bearing layer (c.l.) and its number. MIS 1—Marine Isotope Stage 1, BA—Bølling-Allerød, YD—Younger Dryas, HL—Holocene, SA—Subatlantic, SB—Subboreal, AT—Atlantic, BO—Boreal, PB—Preboreal. **a** Map of the location of geoarchaeosites: B—Berloga (53°1′55.36"N, 106°51′12.06"E); C—Ust-Belaya (52°55′15.54"N, 103°39′7.86"E); D—A. G. Generalov site (57°24′18.01"N, 97°39′54.67"E); E—Ust-Belaya/floodplain (52°55′22.05"N, 103°39′22.04"E); F—Ust-Khaita (52°51′40.91"N, 103°10′24.88"E); G—Kholmushino 3 (52°51′42.07"N, 103°19′1.56"E); H—Elovka-Nugan 1 (51°44′25.96"N, 102°46′25.22"E). **b** Berloga, multilayered (microlayered) site in slope sediments: 3–7 m slope, Kurkut Bay, Little See of the Lake Baikal, excavations by Olga Goriunova in 1976–1982, photo by Olga Goriunova (Vorobieva 2010). YD–BA—colluvial and colluvial-aeolian sands with burial soils, HL—colluvial loams, sandy loams, and sands with burial soils. Age-based on ^{14}C-dating: c.l. 2–2, 5–1, 7 cal BP; c.l. 2a–3, 0–2, 7 cal BP; c.l. 3–5, 3–4, 8 cal BP; c.l. 6—from 10, 2–9, 5 to 9, 0–8, 5 cal BP (incorrect); c.l. 7a–7, 6–7, 1 cal BP; c.l. 7b–9, 6–8, 7 cal BP; c.l. 7c—from 11, 4–11, 1 to 10, 5–10, 1 cal BP; c.l. 8–12, 8–10, 8 cal BP. **c** Ust-Belaya: 8–9 m terrace, left bank of the Belaya River, excavations by Ivan Berdnikov and Natalia Berdnikova in 2012, photo by Ivan Berdnikov. Archaeological complexes in microlayered sediments (sandy loams, gray forest soil). **d** A. G. Generalov site: 15 m terrace, right bank of the Chuna River, excavations by a team of Irkutsk State University in 2013–2014, photo by Ivan Berdnikov. Archaeological complexes in microlayered sediments (sandy loams, slightly soddy, strongly podzolic soil). **e** Ust-Belaya/floodplain, multilayered (microlayered) site in floodplain sediments: 4–5 m floodplain, left bank of the Belaya River, excavations by Ivan Berdnikov in 2017–2018, photo by Ivan Berdnikov. Floodplain sediments (sandy loam, sands, light clay loams) with burial soils. Age-based on ^{14}C-dating for c.l. 3: from 6, 8–6, 5 to 6, 5–6, 3 cal BP. **f** .Ust-Khaita, multilayered (microlayered) site in floodplain sediments: 7–8 m floodplain, right bank of the Belaya River, excavations by a team of Irkutsk State University in 2001, photo by Natalia Berdnikova (Vorobieva 2010). Floodplain sediments (sandy loam, sands, light clay loams) with burial soils. Age-based on ^{14}C-dating: c.l. 5—from 8, 4–8, 1 to 7, 2–6, 9 cal BP; c.l. 5a—from 8, 4–8, 1 to 7, 3–7, 0 cal BP; c.l. 6—from 9, 5–9, 0 to 9, 0–8, 6 cal BP; c.l. 7—from 9, 5–9, 1 to 9, 1–8, 7 cal BP; c.l. 8–10, 2–9, 6 cal BP; c.l. 9—from 12, 5–11, 9 to 11, 2–10, 7 cal BP; c.l. 10—from 12, 7–12, 2 to 12, 5–11, 9 cal BP. **g** Kholmushino 3, multilayered (microlayered) site in floodplain sediments: 7–8 m floodplain, left bank of the Belaya River, excavations by Ivan Berdnikov in 2016, photo by Ivan Berdnikov. Floodplain sediments (sandy loam, sands, light clay loams) with burial soils. Age-based on ^{14}C-dating for c.l. 3: 8, 6–8, 3 cal BP. **h** Elovka-Nugan 1, multilayered (microlayered) site in floodplain sediments: 5 m floodplain, left bank of the Irkut River in Tunka valley, excavations by a team of Irkutsk State University in 2015, photo by Ivan Berdnikov. Floodplain sediments (sandy loam and sands) with burial soils. Age-based on ^{14}C-dating: c.l. 1–5,9–5,7 cal BP, c.l. 2 – 6,2–5,9 cal BP

light interlayers of sandy and sandy-gravelly composition, their thickness is about 5 cm that 2–3 times less thickness of humus horizons of soils, and in some cases also thick proluvial layers.

The microlayered sites where cultural remains are included in the buried soil of floodplain sediments are the most informative for the archaeological reconstructions. Typical examples include such sites as Gorelyi Les, Ust-Khaita, Kholmushino 3, Ust-Belaya (Southern Angara region, Belaya river), Kazachka 1, (Kansk-Rybinsk basin, Kan river), Elovka-Nugan 1 (Tunka valley, Irkut river) (Saveliev et al. 1974, 2001; Berdnikova et al. 1991,2015; Berdnikov et al. 2015, 2017, 2017a). The formation chronointerval of buried soils in the floodplain sediments can vary from several tens to several hundred years.

The microlayered sites where the archaeological materials included in the sediments of slope genesis also have enough high informational degrees but have their specificity. In Baikal Siberia, these include mainly the sites of the Baikal coast, for instance, Ulan-Khada, Sagan-Zaba 2, Buguldeika, etc. (Goriunova 2012; Losey et al. 2014). The stratigraphy of the Baikal sites, due to the powerful slope processes occurring in some areas, is much more complicated than at the sites with floodplain sediments (Vorobieva 2010).

Currently, more than 30 microlayered sites of the Holocene age in which sediments are from 3 to 20 isolated cultural horizons, are known in the Baikal Siberia. There are Gorelyi Les, Ust-Khaita, Kholmushino 3, Ust-Belaya in the Southern Angara Region (Saveliev et al. 1974, 2001; Berdnikova et al. 1991; Berdnikov et al. 2017), Kazachka 1 in the Kansk-Rybinsk basin (Generalov 1979; Saveliev et al. 1984), Ust-Yodarma 2, Ust-Keul 1 in the Northern Angara region (Lipnina et al. 2010], Ulan-Khada, Sagan-Zaba 2, Ityrkhei, Buguldeika 1 and 2, Berloga, Tyshkine, Pad Dolgaya 2 on the Baikal coast (Losey et al. 2014; Timoshenko and Bocharova 2016), Elovka-Nugan 1 in the Tunka Valley (Berdnikov et al. 2015).

The database of the ^{14}C-dating contained 330 values defining for the Early and Middle Holocene microlayered sites is collected. Natural science dating methods, primarily radiocarbon and paleomagnetic, in combination with typology methods make it possible to create high-resolution "cultural records" that allow developing the relative and absolute chronology of Holocene complexes in a particular area.

The example of using one of the main approaches (event) in our researches can be demonstrated in the studies of geoarchaeosite Malta-Most 1 (Fig. 3). This approach, in particular, allows identifying the features of cultural-bearing horizon 3 of this site (Berdnikova et al. 2007). Malta-Most 1 is located on the right side of Belaya River (left tributary of Angara river) on the lower outskirts or Malta village, on the flattened terraced surface with relative elevations of 21–23 m from the edge of the river Belaya. Nine cultural-bearing horizons are recorded in the sediments of MIS 2—MIS 1 age. The cultural remains of layer 3 are connected with an underdeveloped soil with a pygmy profile A-B-C, where A is low-humus horizon 3 up to 5 cm thick, B—brownish illuvial horizon 5–7 cm thick. Its age is determined in the interval 19.046–18.750 cal BP.

The compact congestion of the finds on the square about 150 m^2 with remains of the bonfire was found. 79 dolomite slabs ranging in size from 10 to 60 cm in diameter, which was located along the perimeter of an oval-shaped spot of finds, elongated along the north–south line, were fixed. The part of small slabs was in the center of the find spot. Microstratigraphic studies have revealed the different degrees of preservation of the soil profile depending on the intensity of use of the habitat surface.

The deposits around the find congestions on some areas were tighter and were changing the colors from grey to ash yellowish. According to our opinion, this phenomenon is connected with trampling by the ancient people of the habitat surface. The strongest seal of culture-bearing sediments is recorded in the north part of the complex, where the least number of finds are noted. Besides the habitat surface was

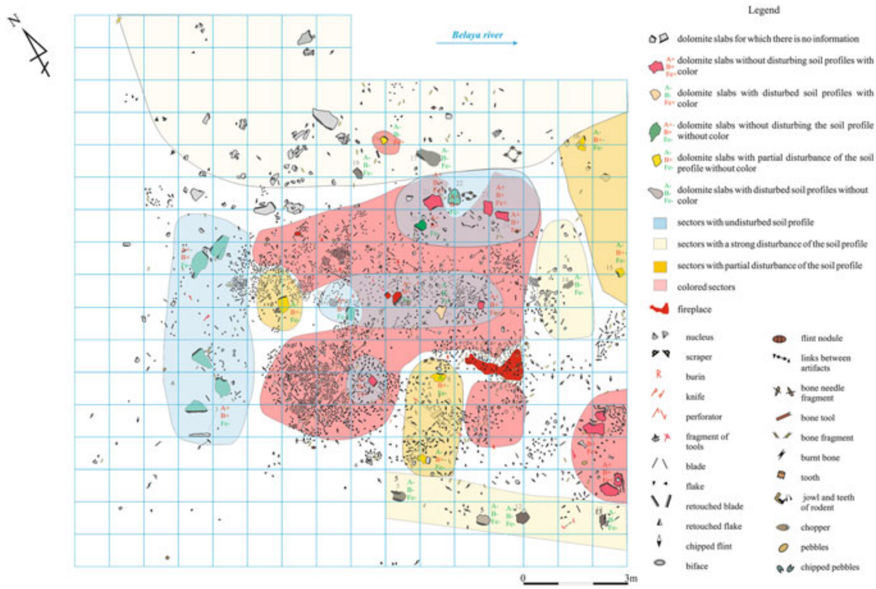


Fig. 3 Geoarchaeosite Malta-Most 1. Plan of the activity use of the sectors and distribution of archaeological finds in culture-bearing layer 3

covered by the powdered hematite (ochre). Thanks to observations during excavations, it was revealed that the artifacts were covered with ochre, and the slabs had already laid on the surface covered with ocher. It allows distinguishing three stages of human use in this area. The first stage is connected with habitation and economic activity, as evidenced by artifacts, a few faunal remains, and a fireplace. After the end of the use of this territory, the habitat surface was covered with ochre (second stage). Finally, slabs were laid on top of the ochre backfill (third stage). One slab was also placed on the fireplace. There were no noticeable traces of pyrogenic and temperature effects on it. Traces of sub-horizontal passages of burrowing insects have been preserved under the slabs.

Analysis of the soil cover state of the site in combination with data on the development cycles of soil entomofauna made it possible to determine the time of the site's functioning. It has been established that the laying of insects masonry (presumably wasps) in the soil occurred before the surface was covered with ochre and the slabs were laid, and the appearance of mature individuals after these actions. This is evidenced by the change in the direction of movement of insects from vertical (top to bottom) to subhorizontal, parallel to the base surface of the slabs, which became an obstacle for insects. Subhorizontal passages of insects were easily traced due to their ochre coloration. Since in most cases the underground development cycle of burrowing insects covers the warmest summertime and does not exceed 1.5 months, it can be assumed that the sprinkling of the habitat with ochre and the laying of slabs was carried out in the summer, presumably in July.

Planigraphy of finds of the layer 3, the Malta-Most 1 site suggests the presence of living space, represented by a compact accumulation of archaeological material with a bonfire on its periphery, around which a trampled surface is fixed. At the final stage of the site's functioning, the entire area was covered with ochre and filled with dolomite slabs, which is probably associated with some kind of ritual action. "Closure" of the habitat surface and bonfire sites also noted during excavations of several Late Paleolithic complexes of Baikal Siberia, including such objects as Kulakovo 1, Cheremushnik 1, 2, Sosnovyi Bor, Kholmushino 1, Ust-Belaya, and Galashikha (Berdnikova et al. 2007).

To verify the results of any analyzes, in our opinion, a geoarchaeological assessment should be applied, which is an expert opinion. The main purpose is to determine the conformity degree between various data, both archaeological and natural science, including data of geomorphology, stratigraphy, and absolute dating. We carried out a geoarchaeological assessment of the results of ^{14}C dating of complexes with ancient ceramics from the Far East and Transbaikalia, which showed the presence of serious problems based on the discrepancy between radiocarbon and geoarchaeological data to test this approach (Berdnikova et al. 2018).

4 Conclusions

Thus, our developments made it possible to identify typical sediments and situations for geoarchaeosites MIS 2 and MIS 1 in the Baikal Siberia to determine the features of culture-bearing sediments and archaeological complexes in them, and to create a system for revealing the correctness of radiocarbon dates based on a geoarchaeological assessment.

When conducting geoarchaeological research, we are based on several provisions:

(1) Geoarchaeology is a source study discipline based on the system of work with a source, which includes methods of synthesis, analysis, interpretation, and criticism, both of the sources themselves and research procedures.
(2) The main object of research is the geoarchaeosite. It is a complexly structured integral system in which a set of traces of natural and anthropogenic events is encoded. The geoarchaeosite acts as the main source of information about ancient cultures and the environment, for example, on the changes in climatic conditions for the interval of the studied sediments, the features of landscape situations, extraordinary natural events, the peculiarities of the territory inhabited by ancient people (reasons for choosing a place of residence, its comfort, protection of the habitat from natural and anthropogenic risks, threats); the peculiarities of life. Studies of the territory surrounding the geoarchaeosite supplement the obtained data.
(3) Geoarchaeology is a transdisciplinary direction, the nature of which is determined by the complex nature of geoarchaeosite. It provides constant cognitive and communicative relations between representatives of various sciences,

which are aimed at expanding the disciplinary vision of the research subject and the formation of new knowledge levels.

(4) Geoarchaeological studies are based, first of all, on the event approach, within which it is possible to separate events of a global, regional and local character, as well as on the method of actualism corrected by the "thresholds" and "mistakes of recognition".

Proposed geoarchaeological developments are in a constant process of refinement and testing, which expands its opportunities and prospects, and now they can be defined as a new tradition of research. It has been successfully used in geoarchaeological researches on the territory of Baikal Siberia for many years. The geoarchaeological study makes it possible to see informational forms of the unique and typical structures of geoarchaeosites and their groups. The event approach allows distinguishing out different levels of reality of geoarchaeosites and forming adequate archaeological ideas, which means to see the past in a model of a set of states and events. This, in turn, leads to a confident cultural and chronological identification of the objects themselves and the archaeological complexes included in them. Various categories of geoarchaeosites form models of their states and relationships. This allows us to solve the problems of standardization and verification of the archaeological research process, adequate preparation of information for formalization to store and process it in big data systems.

We hope that the development of our proposed geoarchaeological concept will allow in the foreseeable future to form a Russian school of geoarchaeology. Moreover, this school will not be inferior to foreign ones in terms of technical equipment and at the same time will have sufficient originality to withstand strict scientific competition.

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Reviews. Thoughts. Memoirs

Historical Experience and Ancient Metal Production in the South Trans-Urals

Nikolay B. Vinogradov

Abstract The article highlights the need to consider and understand the historical experience of environmental management in connection with the early stages of the history of mining and nonferrous metallurgy in the Southern Urals. The author agrees with the opinion of a historian of ancient metallurgy, E. N. Chernykh, who proposes to push back the initial stage of the anthropogenic transformation of the environment in connection with the rapid development of mining of nonferrous metals during the Bronze and Early Iron Ages.

Keywords Metallurgical production · South Urals · Anthropogenic impact · Late Bronze Age · Early Iron Age

1 Introduction

The idea of such an article first came to my mind when I was a student and visited a house of a former dredge maintenance master who lived in the Leninsk Village near the Town of Miass (Chelyabinsk region, Russia). One of the results of this visit was a small collection of archaeological artifacts collected on the canvas of a dredge which was presented to me. And how many witnesses of ancient history have perished forever for science in dumps of dredges? Growing up in the northern part of Miass, I walked and traveled a lot in the valley of the Miass River and personally observed the scale of the man-made disaster (Fig. 1).

It is believed that anthropogenic changes of the environment initially became noticeable since the industrial revolution. This is the eighteenth to nineteenth centuries for Russia. During this period, the signs of civilization's pressure on the environment had appeared. For example, only the Chelyabinsk Forest has decreased by two-thirds over 230 years (from 1736 to 1966) (Samarin and Volgin 1983: 20).

Archaeological discoveries of the second half of the twentieth century and the early twenty-first century made it possible to push back the beginning of the anthropogenic

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Fig. 1 A man-made quarry in the upper reaches of the Miass River—the consequences of the activities of gold miners. Photo by Nikolai B. Vinogradov

transformation of the nature of the region by several thousand years. One of the most important reasons is metal production that used charcoal in the metallurgical process (Fig. 2). Already in the Bronze Age (3rd–1st millennia BC), metal production in the Southern Urals changed the environment both underground (mines), surface relief (quarries), and, probably the vegetation coverage of the region (nullification of large forest tracts). Before the advent of modern mining methods, this aspect of anthropogenic impact was the strongest. It is unlikely that we will be able to correctly count the many thousands of hectares of forests, recycled for several thousand years in the charcoal.

Nonferrous metallurgy has been both the happiness and the curse of our land for five thousand years. It is suffice to say that communities specialized in metal production that exploited a large number of deposits, primarily copper-bearing minerals, appeared with enviable constancy and flourished for several hundred years in the Southern Urals. Their life was confined to copper deposits and woodlands which were sources of charcoal. These are the communities (clans) that inhabited the fortified settlements at the turn of the Middle and Late Bronze Age (twenty-first to eighteenth centuries BC) (Fig. 3) and the population of the Itkul culture of the mountain-forest Urals in the seventh to third centuries BC (Vinogradov 2018: 74–75) (Fig. 4).

Nowadays, a whole series of mines with unambiguous traces of development during Antiquity and, in particular, in the Bronze Age is known in the Southern

Fig. 2 The Orenburg expedition. Eighteenth century. Heap charcoal burning. Picture from open internet sources

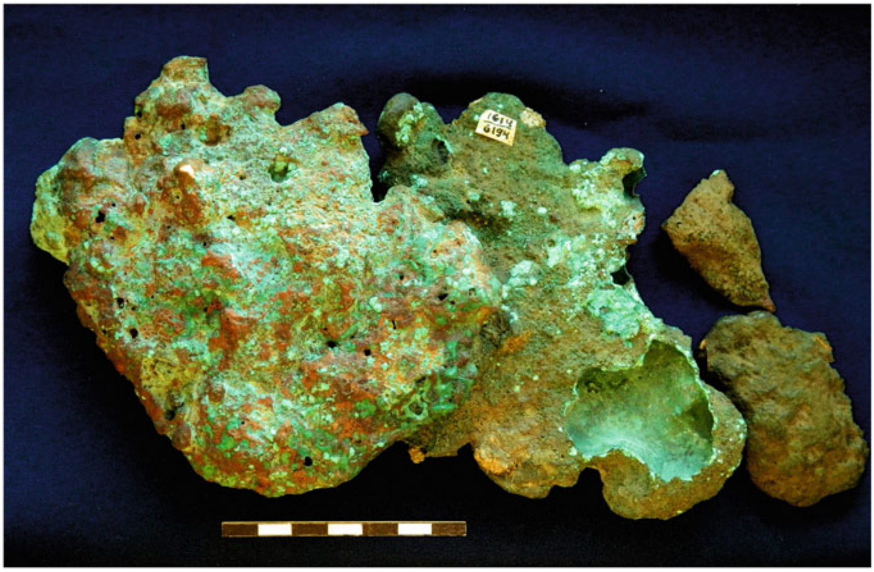

Fig. 3 The Late Bronze Age. The fortified settlement of Ustye I. Blister copper ingots. Photo by Nikolai B. Vinogradov

Fig. 4 The Early Iron Age settlement of the Bolshoi Itkul. Artistic representation of the life of the inhabitants. Painting by Yu. Shmelev

Urals (Zaykov et al. 2005: 101–115; Ankushev et al. 2018: 87–110; Ankusheva et al.: in print).

The mining work of the ancient peoples of the Urals was so extensive that the Russian industrialists of the eighteenth century very clearly oriented themselves in the search for ore deposits to the so-called "Chud" mines. This historical experience is well known.

A Russian archaeologist E. N. Chernykh believes that only a single ore field of Kargaly in the Northern Orenburg region yielded up to 1 million tons of good quality copper ore during the Bronze Age (1995: 118). He also gives data on the scale of forest destruction in the region in Antiquity. According to Chernykh, smelting of one ton of copper requires 1.5–2 hectares of forest as fuel (charcoal) (1995: 115; 1997: 66–67). And this is in the Orenburg region, which has never suffered from an abundance of forests!

It is unlikely that the Russian industrialists who exploited the copper deposits of the Southern Urals in the eighteenth century were aware of the experience of their predecessors from the Bronze Age. However, in 1760 (only 25 years since the founding of the first copper smelter in the South Urals), Orenburg Governor-General Johann Reinsdorp wrote to Empress Elizaveta Petrovna of Russia: "… scaffolding and wood-burning scaffolding has become so scarce that one has to drive for the five to six hundred versts from Orenburg" (Materials on the history of the Bashkir ASSR 1956: 479–480).

The administration of the Orenburg Cossack army in the eighteenth-nineteenth centuries took some protective measures to protect forests. These measures were applied to metallurgical plants that consumed large quantities of charcoal. Moreover, the Cossacks were forbidden to use the pine located in the vicinity of the villages forest from for construction (Chernov 2013). This caused a forced surge of public interest in stone architecture and the emergence of artels of builders engaged in the construction of such buildings (Fig. 5). Due to these protective measures, we still have the opportunity to breathe the healing air of the remaining 17 ancient relict tape pine forests in the Chelyabinsk region (Samarin and Volgin 1983: 15–21).

Since the nineteenth century, the "gold rush" has been added to copper smelting and iron-making industries in the Southern Urals (Fig. 6). It is important to note the complete adherence by the miners and prospectors of the Southern Urals from the Bronze Age to the present day to the same concept, which can be expressed by the phrase: "After Us The Deluge!" There was no place for reclamation.

Fig. 5 A shed with walls and roof of the limestone of the stone slabs. The village of Chernorechye, Troitsky district, Chelyabinsk region. The ban on the use of wood for construction contributed to the emergence of such architecture. Pay attention to the roofing material—stone slabs. Photo by Nikolai B. Vinogradov

Fig. 6 The Svetlinsky quarry near the modern town of Plast. Photo by Nikolai B. Vinogradov

The landscape of the floodplain of the Miass River in its upper reaches (up to the Town of Karabash) has become largely anthropogenic for several centuries due to the gold rush. Metals and money instantly left, and they still leave our places, and only disfigured landscapes, carved forests and strange names of settlements in the mountain-forest part of the Southern Urals, such as Northern Ovens, Kovalevsky Ovens, Kiolimsky Ovens—the former settlements of coal burners—remain the inhabitants of these places.

The twentieth century added a fighter nature of technical equipment, but absolutely nothing has changed in the people's awareness of the extent and consequences of this tragic problem. Look at these giant quarries near such towns as Korkino (coal), Plast (gold) (Fig. 6), Satka (magnesite), Bakal (iron). Look at the dead mountains near Karabash poisoned by sulfur (copper-smelting production since 1908) (Fig. 7), at the Sak-Elga river with the entire periodic table in the water. And this list is getting longer every year. We risk waking up one day on the isthmus between two quarries.

The mineral wealth of the Southern Urals has served people for many thousands of years. Radically change the pattern of their use, by adding only one element—the restoration of mutilated quarry and mine workings landscapes still does not work.

Fig. 7 The mountains near the Town of Karabash. Photo by Nikolai B. Vinogradov

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The Problems with the Definition of Artifacts Material (Geologists' Help for Archaeologists)

Larisa Ya. Kabanova and Elizaveta V. Zaykova

Abstract Often archaeologists may face difficulties determining the rock type from which prehistoric artifacts are made, even using microscopy and various analytical methods. To help archaeologists give the correct name of the rock, the article describes various types of rocks with an emphasis on their macroscopic features: color, structure, size of the constituent particles. Igneous rocks are characterized as plutonic (intrusive) as well as poured to the surface—volcanic (effusive). Rocks of various compositions such as ultrabasic, basic, medium, and acidic are described. In each group, rocks of volcanic and plutonic facies are distinguished. Macroscopically, volcanic rocks differ from plutonic rocks in the presence of volcanic glass and porphyry texture. The unevenly grained texture of plutonic rock differs from the porphyry texture of volcanic rock by the presence of larger crystals in the background of a full-grained or a fine matrix. Rocks with high silica content usually have a light color and consist mainly of leucocratic minerals. Also, they are distinguished by high hardness. Rocks of ultrabasic and basic composition are composed entirely of dark-colored minerals or contain a small amount of leucocratic minerals (main plagioclase for the normal series rocks). For sedimentary rocks, their division by particle-size distribution and roundness degree is given. Macroscopically, they are usually characterized by a layered structure. A large section is devoted to siliceous rocks, which in ancient times were used for various purposes; visually they differ well by structural and textural features. For their full characterization, chemical analysis has been made. Photos of various types of rocks and their description are given. To diagnose rocks in the field, we use data obtained in the laboratory during a detailed study of them in thin sections and polished sections.

Keywords Artifacts · Rocks · Intrusive · Plutonic · Volcanic (extrusive) · Sedimentary · Color · Structure · Texture · Photos

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1 Introduction

Recently, many archaeologists have begun to use the names of rocks and minerals that make up archaeological sites more competently. Scientific meetings to help archaeologists were held in Bulgaria (2008) and Germany (2011). Since 2014, Miass has hosted annual conferences on geoarchaeology. However, often archaeologists (especially, young ones) have difficulties in determining rocks. The minerals used in the artifacts are usually known and their number is limited: quartz, quartz crystal, malachite, azurite, native copper, but with the diagnosis of rocks there are some difficulties. This article provides a summary of the macroscopic features of various rocks.

2 Materials and Methods

The samples of plutonic and volcanic rocks described in the article are taken from various facies and formations, mainly from the Southern Urals. Ultramafic plutonic rocks (dunite, pyroxenites. harzburgite, lherzolite) and basic (gabbro) are collected from outcrops of the Nurali massif. Leucocratic and two-mica granites were studied using samples from Chashkovsky, and rapakivi granite of the Berdyaushsky massifs.

Ultrabasic and basic volcanic rocks occur in different geodynamic settings. Picrites in contact with aphyric and variolitic basalts are analogous with the Siberian traps, and a sample of tholeiitic basalt is an analog of compact basalt flow from the Hess basin. The amygdaloidal and variolitic basalts are taken from the Baymak-Buribay formation in the Southern Urals.

Volcanic rocks of medium and acid composition (andesibasalts, andesites, dacites, rhyolites) form dikes and extrusions within the Magnitogorsk zone.

Sedimentary rocks, represented by gravelites and quartz sandstones, are taken from the Devonian age outcrops in the Uchalinsky zone of the Southern Urals. Fine-and fine-grained sandstones, alternating with clay and siliceous siltstones, are made up of rocks from the volcanic-sedimentary section of the Middle Devonian Karamalytash formation.

Special attention was paid to the study of igneous rocks—plutonic and volcanic. In the macroscopic study, the color of the rock at first has been studied. The color of the rock depends on the silica and the dark-colored minerals content. Ultrabasic and basic rocks are dark-colored, medium, and acidic are light-colored. Rocks of moderate-alkaline and alkaline composition differ in appearance from the rocks of the normal series with lilac or lilac-bluish tint.

The next step in the macroscopic description of the rock is to study the size of the minerals, their shape, relationships, and the quantitative composition. Determination of structural and textural features of rocks allows making their preliminary determination. Volcanic rocks, in contrast to volcanic rocks, contain a glassy phase, the quantitative content of which is also a criterion for determining the types and varieties of volcanic rocks. Volcanic rocks of different compositions sometimes have the same color (gyalobasalt and obsidian). A steel needle is used for microscopic examination. Basalt and andesite volcanic glass is scratched by a needle, and acidic glass does not react to the needle. For a complete determination, a chemical analysis is carried out.

The rock samples selected from parent outcrops, then in the laboratory of them made the thin sections, polished sections, and polisheds.

Microscopic examination using a polarizing microscope allows by the crystal-optical method and microstructural analysis, as well as quantitative calculations of minerals in the section, to more exactly diagnose rocks.

For the study of sedimentary rocks, the granulometric method and structural-textural analysis are used. Minerals are determined using binocular and polarizing microscopes. X-ray diffraction analysis is performed to more exactly diagnose some minerals.

3 Results and Discussion

Igneous rocks are formed from magma as a result of its cooling and solidification (Petrographic… 1995, Kabanova 2008; Geological… 2011; Tolkovyi… 2002) have been divided into two classes:

(1) Plutonic, formed during the long-term crystallization of magmatic melt in the earth's crust, holocrystalline;
(2) Volcanic—formed during the relatively rapid magma crystallization on the earth's surface, with a microcrystalline, cryptocrystalline, or glassy groundmass, sometimes with inclusions of crystals (porphyry rocks).

By silica content, igneous rocks are divided into ultramafic, basic, intermediate, and acidic.

Among **igneous ultramafic (ultrabasic) rocks** represented by dunites, olivinites, and peridotites, plutonic rocks are predominated (Fig. 1). Pyroxenites, according to the modern classification, are transitional from ultramafic to basic rocks. All of them are massive, sometimes banding, usually fine-grained rocks, in color dark olive-green sometimes nearly black, but usually they are serpentinized and took greenish color. Fully serpentinized hyperbasites are called serpentinite. On the weathered surface, they are covered with a brownish-brown weathering crust (Magmatic… 1983).

The ultrabasic volcanic rocks are rare and represented by meimechites, picrites (Fig. 2), and komatiites. Picrites are characterized by spheroidal or block parts.

Igneous rocks of the basic composition—a large group that includes basalt, gabbro, and anorthosite.

Basalt (Fig. 3) is a widespread volcanic rock, massive, or amygdaloidal, dark, nearly black. In outcrops, there is often columnar or stratified jointing. Underwater basalts have a pillow or tubular structures. Changes in basalts are usually expressed in chloritization. Unlike serpentine, chlorite is much darker.

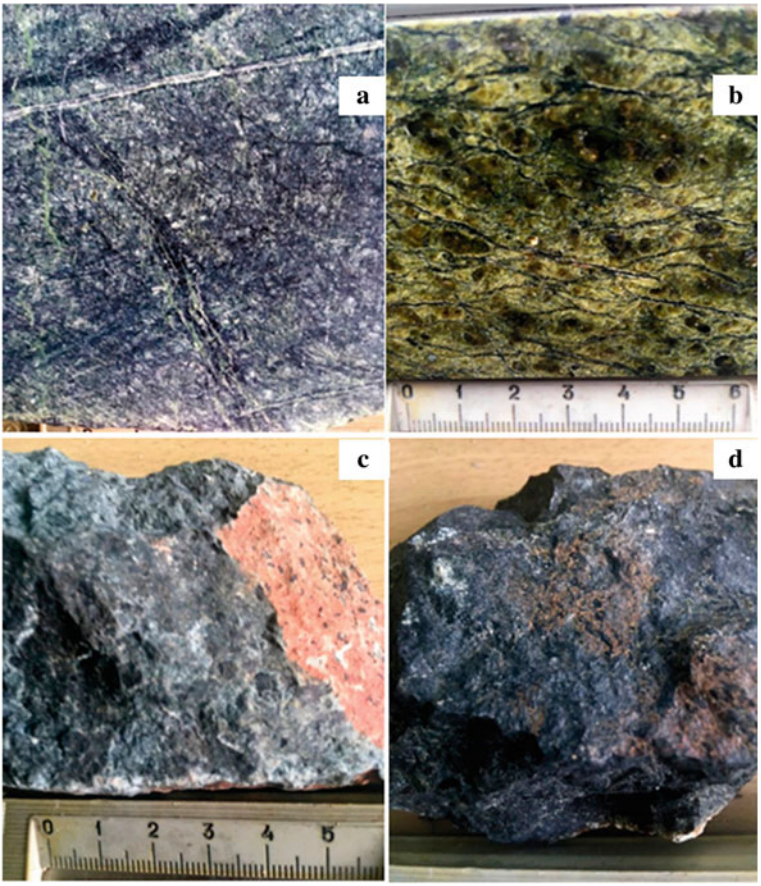

Fig. 1 Ultrabasic plutonic rocks: **a**—weakly serpentinized dunite; **b**—serpentinite (olivinite) with an orbicular texture; **c**—harzburgite with a pseudoporphyric structure and a brown weathering crust; **d**—lherzolite

The term "gabbroid" is generalized for all basic plutonic rocks. Ore varieties are usually darker in color (Fig. 4b).

More often **intermediate igneous rocks** are represented by volcanic varieties than plutonic.

Among volcanic rocks, andesibasalts and andesites are often found. They usually have a manifested porphyry texture (Fig. 5). Andesibasalts are darker and sometimes amygdaloidal.

The **plutonic** analog of andesibasalt is diorite, and andesite is quartz diorite. Diorite is a greenish-gray, dark gray to near black rock with a coarse-grained, coarse, medium, and finely granular, rarely porphyritic texture. Quartz diorite contains from 5 to 25% quartz which fills the gaps.

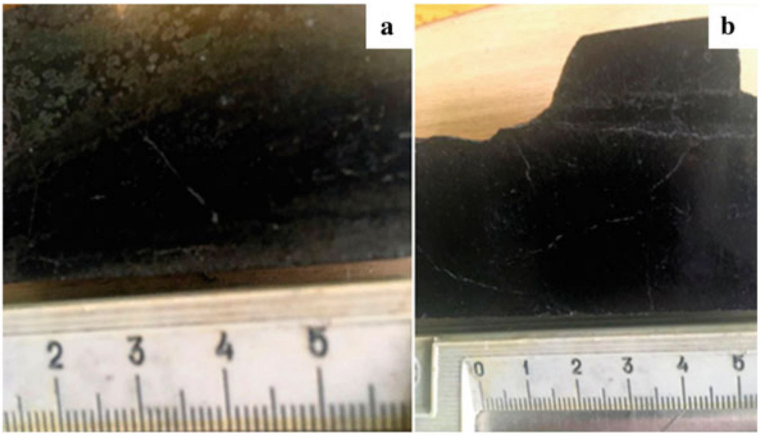

Fig. 2 **a**—contact of picrite with basalt; in basalt, variolite texture is shown; **b**—contact of picrite with glassy basalt

Acidic rocks usually are represented by granites and granodiorites, rare there are volcanic varieties.

Granites are large-, medium- and fine-grained, rarely pegmatoid rocks, equigranular or porphyraceous (Fig. 6), pink, gray, and yellow. Sometimes rocks are gneissoid, as a result of replacement layered strata, or developed under crystallization unilateral pressure, or in under superimposed dynamometamorphism.

A beautiful variety of granites is rapakivi. In them, large rounded secretions (ovoids) are represented by orthoclase often with a margin of plagioclase (Fig. 6c). Most researchers believe that they have a metasomatic origin (Petrographic… 1981).

Acidic volcanic rocks are represented by dacites and rhyolites.

Dacites are gray, sometimes pinkish-gray rocks with an aphyric or porphyry texture and a massive or fluid-structure (Fig. 7a). The glass is dark, sometimes pinkish-gray or greenish, opaque. Sometimes there are bubbly and pumice varieties of dacite.

Rhyolites can be massive and banded. Massive rhyolites have a greenish-gray and white color. Banded rhyolites are characterized by alternating bands of white, pink, sometimes light violet or lilac color (Fig. 7b).

In subvitreous rhyolites, there is an alternation of varying degrees of crystallized bands, black, brown, or white less often lilac in color volcanic glass. Glassy rhyolites differ in color from their crystallized analogs. Massive glass usually has a black (Fig. 7c) or smoky color, there are variegated varieties in which there is an alternation of black and reddish-brown glass; some varieties of glass have a characteristic silvery luster. Often there are cream or nearly white rhyolites. There are pumice and perlite of rhyolite composition (Fig. 7d).

The presented material on different composition igneous rocks allows us to identify criteria for determining rocks by macroscopic diagnosis, among which the

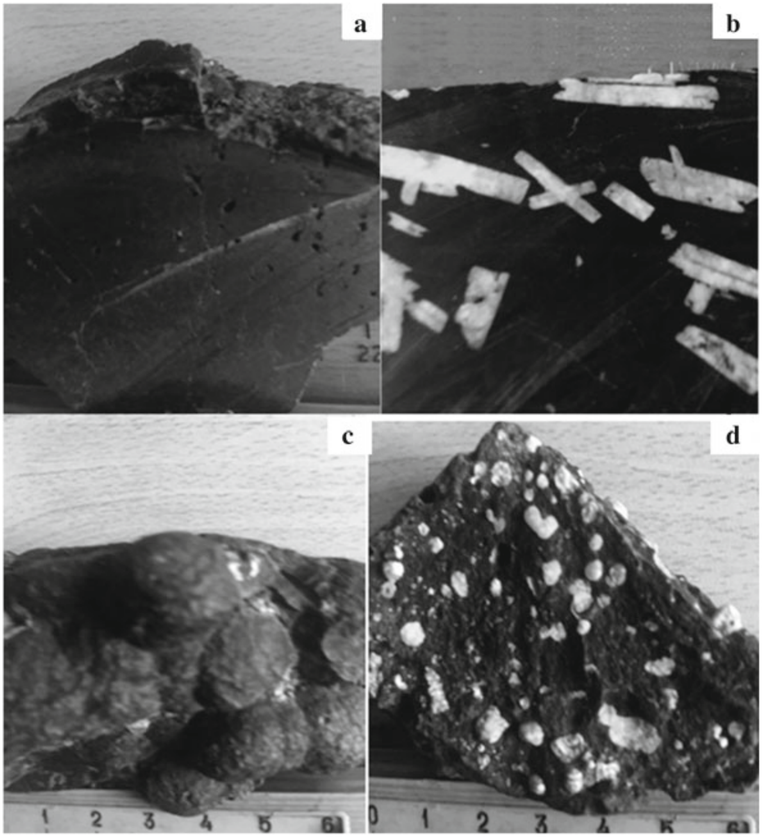

Fig. 3 Basalts: **a**—aphyric oceanic basalt with a glassy crust in the upper part and a porous texture; **b**—plagioclase basalt with a megaporphyric structure; **c**—variolite basalt; **d**—almond-stone basalt

main ones are the color of the rock, the size of mineral grains, their quantitative composition, mineral relationships, and structural and textural features.

Sedimentary rocks should be considered mineral or organic rocks that have arisen on or near the surface of the lithosphere and exist under a thermodynamic environment that are characteristic of the upper part of the Earth's crust (Pustovalov 1940; Strakhov 1960; Pettijohn 1961; Frolov 1992–1993). The reference book on lithology (1983, p. 25) gives more exact determination: sedimentary rock is the geological body that coming into being as products of physical and chemical destruction of the lithosphere by chemical deposition and vital activity of organisms, or both at the same time. This does not contradict the classification given in the 1998 work «Systematics and classification of sedimentary rocks and their analogs». There are several groups of sedimentary rocks.

"Clastic rocks should be considered sedimentary rocks with a clastic structure and quartz-silicate composition (except for fine clay rocks" (Frolov, book 2) (Fig. 8).

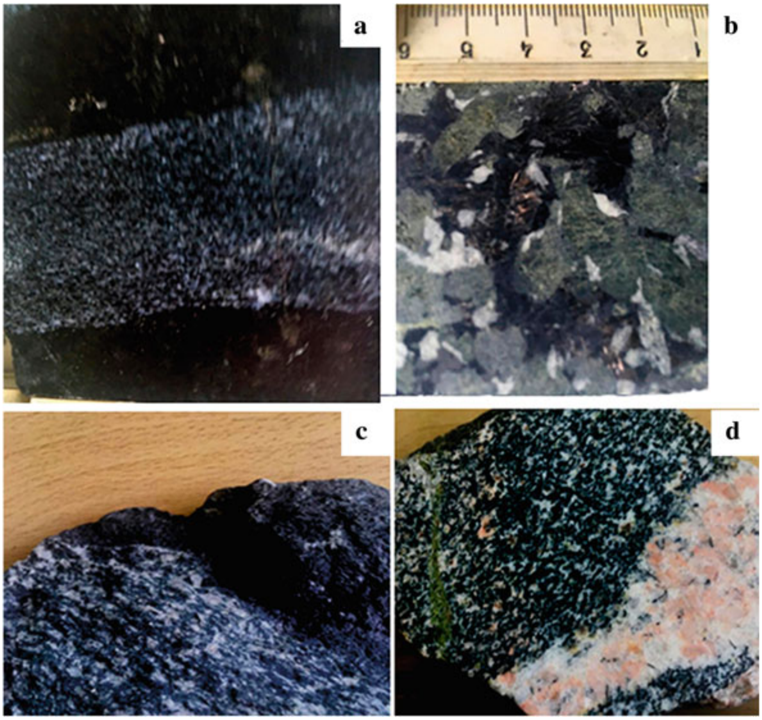

Fig. 4 Plutonic rocks of the basic composition: **a**—orthopyroxenite with fine-grained gabbro vein; **b**—ore clinopyroxenite; **c**—contact of gabbro with hornblendite; **d**—gabbro with epidote vein (left) and pegmatite vein

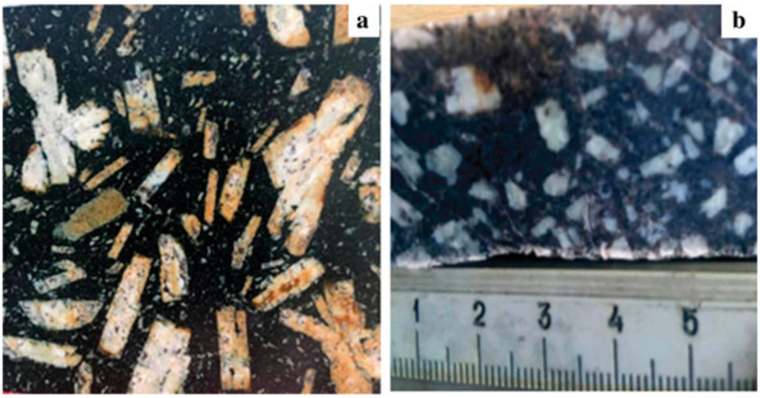

Fig. 5 Intermediate volcanic rocks: **a**—andesibasalt with a megaphyric structure; **b**—andesite with a porphyry texture

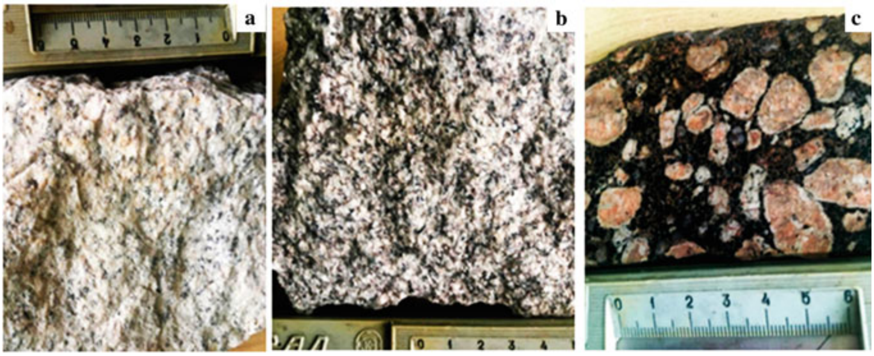

Fig. 6 Granites: **a**—equigranular granite, leucocratic; **b**—two-mica granite; **c**—rapakivi granite

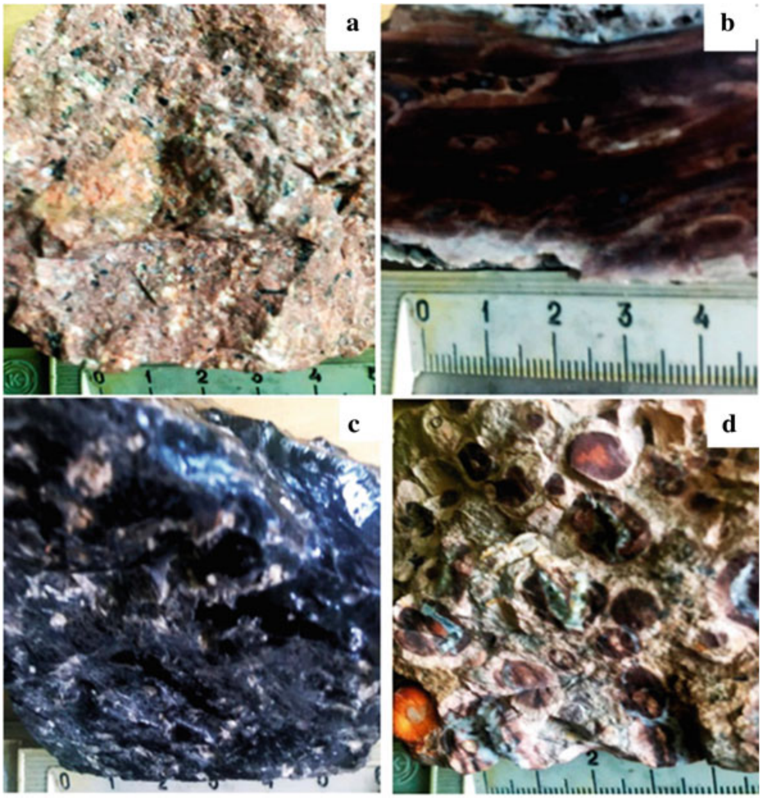

Fig. 7 Acidic volcanic rocks: **a**—dacite with porphyritic texture and cataclastic structure; **b**—banded rhyolite with spherulite perlite textures; **c**—glassy rhyolite with porphyry texture and massive structure; **d**—rhyolite with lithophysae

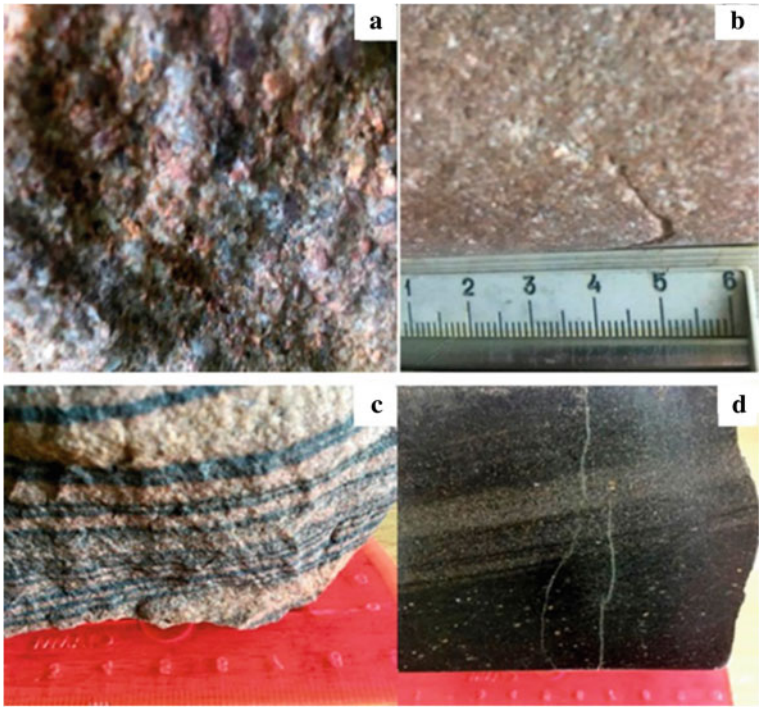

Fig. 8 Clastic sedimentary rocks: **a**—polymictic gravellite; **b**—fine-medium grained quartz sandstone; **c**—banded quartz sandstone; **d**—alternation of clayey siltstones with sandstones

The granulometric classification is the main one for clastic rocks (it gives the main name of the rock). The most common division by size of composing particles is given below (Pustovalov 1940; Pettijohn 1961; Frolov 1992–1993): conglomerates with the size of the fragments of 10–1 cm (unrounded varieties are called rubbler formations); gravelites—1–0.1 cm; and sandstones—0.1–0.01 cm. Sandstones with a size of fragments 0.01–0.005 cm are fine-grained sandstones that are transitional to siltstones. If up to 20–30% of silt or clayey particles are found in sandstones, the rock is called silt or clay sandstone.

Further classification of sandstones is based on the composition of fragments. Most often these are quartz or quartz-feldspar sandstones (Fig. 8b, c). Fragments of quartz grains, as the most resistant to weathering mineral, usually predominate in sandstones over all other fragments. If there is a lot of calcite in the cement of quartz sandstone, such a rock is called "calcareous sandstone".

Siltstones are dense, cemented fine-clastic rocks (0.005–0.0001 cm). It is very difficult to see grains even by a binocular microscope (Fig. 8d).

Mudstones (cemented clay) are composed of particles less than 0.0001 cm. Their composition is diverse and compound.

The fragment's size in the rock can vary greatly. In poorly sorted varieties, the maximum size of fragments can be ten times larger than their average size, although there are coarse-grained rocks with more or less the same size of fragments.

Large fragments usually are represented by rocks, not minerals.

Siltstones and mudstones usually have a polymictic composition, but visually it is difficult to determine.

An additional characteristic of sedimentary rocks is stratification (Fig. 9).

Silicites (siliceous rocks)—a term used by G. I. Teodorovich, G. I. Bushinsky, V. T. Frolov, I. V. Khvorova, etc. to refer to the class of siliceous sedimentary rocks in which free or aqueous silica of biological or chemical (not clastic)

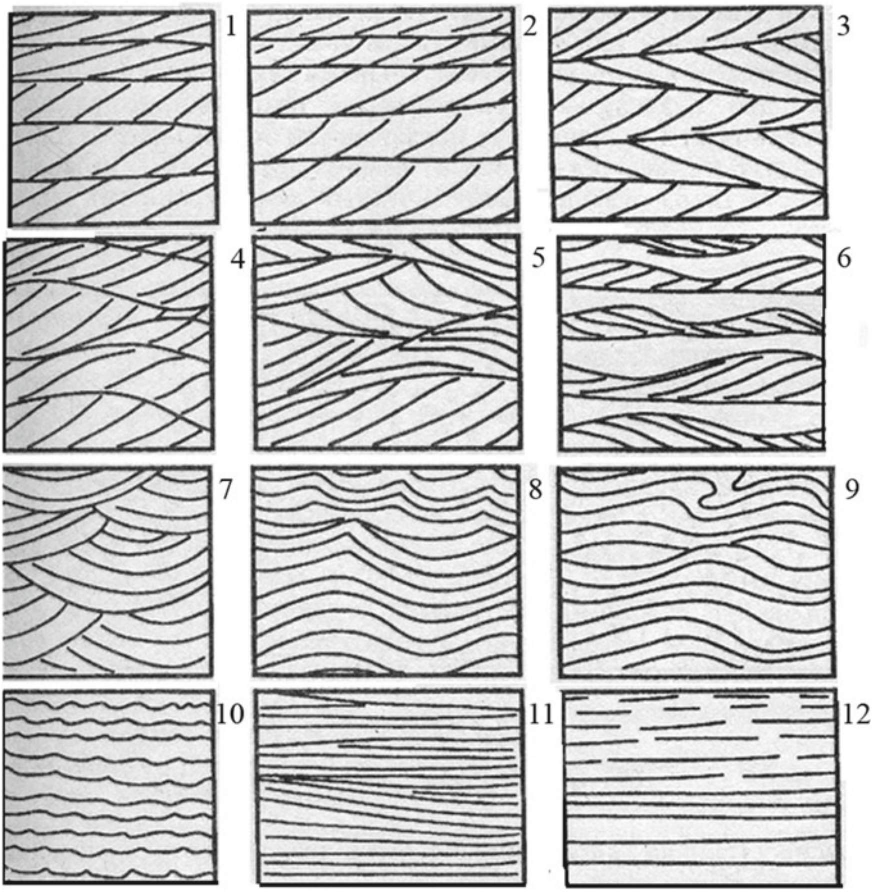

Fig. 9 Types of bedding. 1, 2—cross unidirectional: 1 with straight, 2—with concave lamina; 3—cross diversidirectional with wedge-shaped straight seams; 4–10—wavy: 4—unidirectional, 5—diversidirectional, 6—flasher; 7—arge wavy or trough-like, 8—the waves are mainly symmetrical, 9—asymmetric waves and landslide folds, 10—wavy-horizontal, 11—cross-horizontal, 12—horizontal interrupted and uninterrupted

origin prevails (Frolov 1992–1993; Khvorova 1994, 1995). The composition of the Mesozoic-Cenozoic varieties is usually opal-cristobalite, and the older ones are chalcedony-quartz.

In English literature, the term *siliceous rocks* and *silicalites* are used to rocks with a high content of free silica.

Of particular interest, both now and in ancient times, are *jaspers* (Zaykova 1991). These are mainly red-colored rocks with various, often whimsical patterns, consisting of silica (SiO_2) and iron oxides, characterized by high hardness. Although only thin-layered rocks, often containing radiolarians, are purely sedimentary in origin, and many others formed with the participation of hydrothermal material, but, as a technical term, this name is applied to all groups of rocks. The exact name of the rock requires not only microscopic study but also knowledge of theirs chemical composition (Fig. 10).

In English, «*jasper*» is a dense cryptocrystalline opaque or a weakly translucent variety of silicites associated with iron ores. The typical color is red, although yellow, green, grayish-blue, brown, and black are found too. It is also used to refer to all red silicites irrespective of an association with iron ores (Fig. 11).

Thus, most authors the term «jasper» understand as rock consisted of micro- and cryptocrystalline quartz (quartz-chalcedony), painted mainly in a various tint of red.

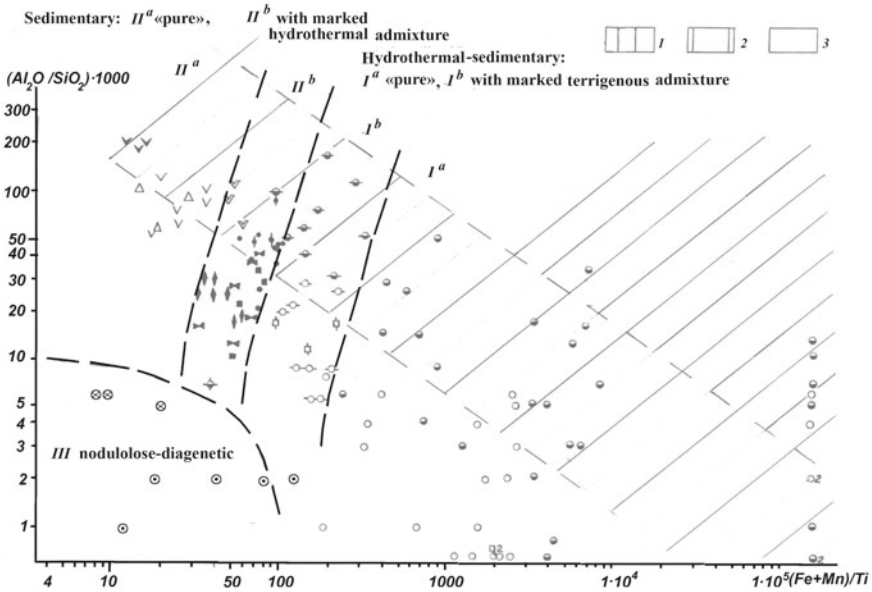

Fig. 10 The genetic plot of silicites by chemical composition. The diagram is based on chemical analyses of samples collected by the authors in Mugodzhary and Bashkiria. Data on nodule-digenetic silicites are from the opencut mining Dalny (Magnitogorsk) and some analyses from Japan. 1—ferruginous, 2—subferruginous, 3—non-ferruginous (Zaykova 1991)

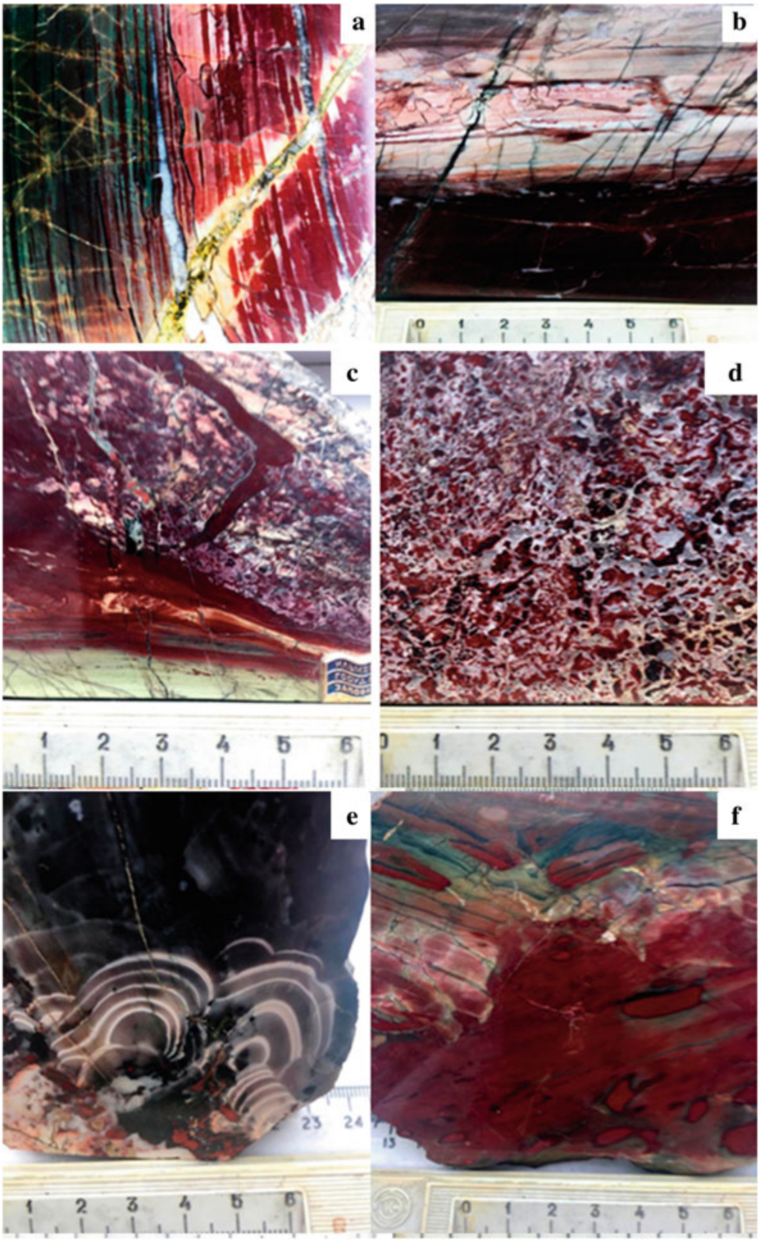

Fig. 11 **a**–**d**, **f**—jasper: **a**–**b**—thin-laminated, apparently hydrothermal-sedimentary; **c**—brecciated with additional hydrothermal material: **d**—brecciated «calico» **f**—«landscape», brecciated; **e**—phthanite

In the fieldworks, jaspers are easily determined by their appearance and high hardness, as they consist of silica mainly. Decorative character landscape jaspers depend on a variety of colors and a whimsical pattern.

Phthanites differ from jaspers: they are gray, dark gray to black, hard, dense siliceous rocks of quartz or quartz-chalcedony composition. The color is associated with organic carbon, sometimes with manganese oxides, sometimes with bivalent iron compounds (Fig. 12).

Among siliceous rocks, siliceous siltstones and siliceous shales—sedimentary thin-plate rocks composed of cryptocrystalline or micro-grained quartz, sometimes of chalcedony, are very common. They may contain spicules of sponges, radiolarian residues, and plant detritus. The colors are different.

Flints (cherts)—gray, dark gray siliceous rocks with concentric separateness are nodules among sedimentary rocks (Zaykova 1991).

For an approximate name of siliceous rocks, it is a necessary attention to the hardness—it is high of all silicites, then refer red-colored varieties to jaspers, gray-colored ones to phthanites, spherical ones with concentric jointing to flints. For jasper and frantov it is desirable to note the presence of stratification, the features of the figure. The exact name of the rock is possible if you know its chemical composition.

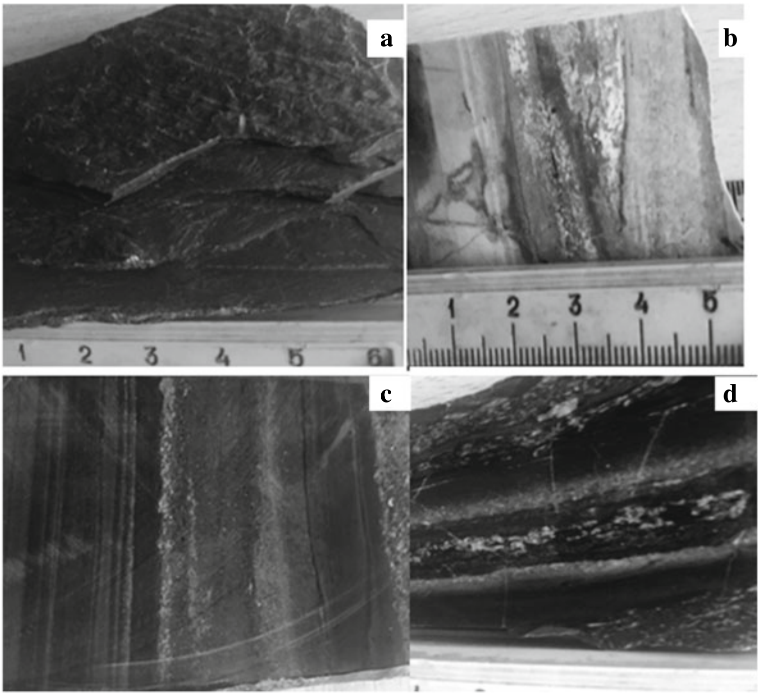

Fig. 12 Siliceous gray-colored rocks: **a**—phthanite; **b**—light siliceous layers among fine-grained sandstones with cross-bedding; **c**—alternation of siliceous layers with siliceous-clay and sandy ones; **d**—siliceous layers in volcanic (grauwacke) sandstone

4 Conclusions

Examples of macroscopic description of rocks which have different composition and genesis determined by the data of various investigations are presented in the article. A general scheme of macroscopic rock description is proposed:

(1) The color of the rock with an indication of the uniformity or heterogeneity of the color;
(2) Grain size and shape. For sedimentary rocks, the degree of roundness;
(3) Mineralogical composition of the rock;
(4) The genesis of the relationship of minerals or minerals and glass in the rock. For sedimentary rocks, the presence and nature of stratification;
(5) Other structural and textural features.

To classify the rock as siliceous, it is necessary to check its hardness and to classify it as jasper or phthanite, specify the color.

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Search and Mining of Silver in the Urals

Evgenii A. Kurlaev

Abstract The collocation "Zakamskoye silver" is mentioned in the Russian historical records and silver items were regularly found in the Urals and Siberia. The common view of many historians and archaeologists is that it was about this term refers to silverware made in the East. At the same time, searches for precious metal ores in the Urals and adjacent territories have been going on for centuries since the first mention of the mountains in the Russian chronicles. The author demonstrates that there is silver in the Urals in great quantities in polymetals, and the earliest known mining of silver and copper in Russia began in 1492 on the Pechora River. Accordingly, the term "Zakamskoye silver" refers to another silver-copper deposit located in the northern Urals. Whether it was exploited in the Antiquity and Middle Ages has been the subject of contention, but by the beginning of the Russian colonization, it had been already exhausted and abandoned. During the industrial development of the region in the eighteenth century, silver contained in copper ore was recognized as unprofitable for extraction. However, the presence of silver in copper ore was proved. In the nineteenth to twentieth centuries, silver in the Urals began to be mined in significant quantities from polymetals due to technological progress. In archaeological and historical research, this fact allows us to look differently at the presence of silver in copper items and copper in silver items, indicating that these items are made from local raw materials. The study covers the period from about the 12th to the early twentieth centuries.

Keywords Ural · History of mining · Protoindustrial archaeology · Silver mining · "Zakamskoye silver"

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1 Introduction

In the archaeological literature in Russian, the collocation “Zakamskoye silver” (meaning, “silver which was obtained from the people, who lived to the east from the Kama River”) has become a historical term for Middle Age silver items that originated in the East from the Russian Towns. Since the eighteenth century, such silver items have been found in hoards in the Kama region and Western Siberia. Actual silver artifacts as well as the chronicle mentions of the tribute collection in the form of “Zakamskoye silver” have led scholars to the conclusion that silver objects from the hoards were a special type of tribute. Moreover, many scholars have believed that at that time Middle Ages silver deposits were not yet discovered and were not exploited in the Urals (Bader and Smirnov 1954: 3). This uncontested point of view on “Zakamskoye silver” has not changed in Russian literature even until the present day: “for the Russians, the main prey … is silver in the form of coins and various silver utensils. In the Kama region and general in the Urals in the Middle Ages, there were no silver mines, and all the ancient Ural silver was imported. The appearance of many silver items or silver-containing items in the Antiquity and Middle Ages in the Urals was associated solely with trade” (Belavin 2013, 2014).

But what this statement is based on? Of course, it is impossible to refute the fact of numerous archaeological finds of silverware (dishes) and coins of oriental origin. Still, in the Novgorod chronicles (PSRL 1841: 21, 65) once tributary relations are mentioned, there is no word about these items. At the same time, the amount of silver that the Novgorodians paid,—paying off from the conquerors,—is huge: at the beginning of the fifteenth century only the Lithuanian prince Vitovt received from them 60 poods of silver (983 kg) (Karamzin 1817: 386). In my opinion, a considerable amount of silver items was made from metal that came from sources in the northern Urals. For my part, I will try to demonstrate that in the Middle Ages the Russians were actively searching for and mined silver in the northern Urals. I rely on historic records to identify these sources. This means that the term “Zakamskoye silver” at least partially may signify metal obtained from polymetallic ores of the northern Urals. Later on, in the course of history, the Urals had become the source of silver for the Russian State.

2 Discussion

In this section, I discuss the evidence that silver was available in the northern Urals; that it had been searched and mined since the Middle Ages; and that what is referred to as “Zakamskoye silver”, is metal obtained from polymetallic ores of the northern Urals. Silver in its native form is rare, but non-ferrous metal ores can be the source of both, gold and silver. The most important source is the mining of gold and silver from copper, copper-nickel, and lead–zinc ores. In this work, information about the industrial smelting of silver in the Urals from gold, silver, and copper ores is presented.

At the beginning of the XIV century, the famous Venetian traveler Marco Polo (1254–1324) wrote about the extraction of silver by the Russians: “They have a lot of silver ores; they mine a lot of silver” (Readings… 1862: 215–348). The Berber traveler Ibn Battuta (1304–1377) and the Arab historian Ibn al-Wardi (mid-fifteenth century) spoke about the silver mine in the Rus country.

It is hard to guess what kind of deposit these authors mentioned, but the testimonies of the medieval travelers of the fourteenth to fifteenth centuries are more reliable. The development of the territory of the Pechora River and the Polar Urals is associated with the repeated and numerous military campaigns that went to collect tribute from the eleventh century from Novgorod, and from Moscow in the following centuries. The Russian governors demanded furs and silver from the local people of Yugra (a collective name for lands and peoples between the Pechora River and the Urals). In 1193, when the Novgorod army approached the walls of the Yugra Town, the defenders offered the Novgorodians a ransom: “silver, and sables, and other ornaments” (PSRL 1841: 21).

Other documents mention a dispute over this tribute between Moscow and Novgorod. So, in the annals of 1332, there is a record relating to the Moscow Prince Ivan I Kalita, which says: “The Grand Duke Ivan came from the Horde and reignited anger at Novgorod, asking them for Zakamsk silver” (PSRL 1841: 65). Around the beginning of the XIV century, “The Novgorodians promised Mikhail Tverskoy 6000 pounds of silver, and Vitovt paid about 60 poods (1 pood = 16.38 kg): before the discovery of America, that was a lot” (Karamzin 1817: 386). The mines of “Zakamskoye silver” (a silver mine in the Ural Mountains) in the XII centuries were owned by the people of “Yugra”, and in the XIV century, it was already controlled by the Novgorodians. As a result of the Moscow-Novgorod War in 1478, Novgorod lost its independence.

Already in 1491, Moscow organized a geological exploration expedition for copper and silver ore by order of Tsar Ivan III to the former Novgorod colony on the Pechora River (PSRL 2001: 223). It was the first industrial production of non-ferrous and precious metals known in Russia. N. M. Karamzin wrote: “This important discovery made the sovereign the greatest pleasure. And from that time, we began to mine, smelt metals and mint coins from our silver” (Karamzin 1998: 506). Later, the presence of copper, silver, and gold on the Pechora River was confirmed by the famous Russian geologists A. A. Chernov and I. P. Bartenev (Bartenev 1897: 53–66).

In the XVII century, there were 20 geological survey expeditions sent to the Urals and adjacent areas in silver’s search (Kurlaev 2006). In 1617, a peasant Yakov Litvinov reported to Moscow the discovery of copper on the banks of the Kama River near the village of Grigorova. Litvinov identified the areas of ancient mines: “… in the old days they made silver in Vogulichs …, and before there, up to Vogulich, 320 versts… (presumably, the legendary “Zakamskoe silver”); used to make silver in the old days in the Pechora” (the above-mentioned deposit on the Pechora River) (Russian State Archive of Ancient Acts. Case 365. 1618. № 1: 12, 14, 15).

Table 1 Smelting of silver at the Berezovsky state-owned industries in 1814–1819

Year	Silver received		
	Poods[a]	Pounds[b]	Kg
1814	11	6	182.63
1815	14	12	234.23
1816	7	25	124.89
1817	3	14	54.87
1818	2	22	41.76
1819	1	29	40.87

[a] 1 pood = 16.38 kg
[b] 1 pound = 0.4095 kg

In 1663, an expedition to the northern Urals,—"in vogulichi",—was organized in Cherdyn under the leadership of foreman Blinov. The route passed along one of the ancient waterways leading to the eastern slopes of the northern Urals. In 1669, experiments with copper ore from this area yielded 0.2% silver. The memory of the search for silver ores was preserved among the people: one tract was called a "silver mine", and a rock nearby was called a "silver cliff" (Chupin 1873). A century later, the merchant M. Pokhodyashin built the Petropavlovsk plant (the modern City of Severouralsk) nearby these places. In the copper ore of six mines, 0.07% silver in copper was found, although, only 0.18% silver in copper was considered economically viable for industrial extraction at that time. Nevertheless, in the early 1770s, silver copper was sent for ligature to the St. Petersburg Mint, and 2000 poods of silver copper were taken to Kolyvan for cleaning.

Thus, during 1754–1920, silver was retrieved from gold in the Urals' Chemical and Gold Alloy Laboratory. Since 1799, there was already more than 1 pood mined and since 1824 there was a sharp increase in the amount of silver obtained, coming to over 10 poods. Already in 1880, 68 poods (1114 kg) of silver were obtained using this technology. As an example, Tables 1 and 2 show the dynamics of metal smelting from silver ore at the Berezovsky state-owned fields in 1814–1819 (Table 1) and the Ural copper smelters in 1904–1914 (Table 2) wherein in 1912, the maximum amount of extracted silver was 666 poods (10,909 kg) (Rukosuev et al. 2020, 294–300). This book was the first to show the presence of silver in the northern Urals and the first place in mining in Russia during the First World War (Shumkin 2021: 11). In the USSR, the volume of smelting of precious metals was classified.

So, there is silver in the Urals, which was mined on an industrial scale, which becomes the basis for subsequent reflections. In my opinion, the testimonies of medieval travelers were true: at that time the Russians were exploiting mines and smelting silver, primarily in the Pechora River region. By the XVII–XVIII centuries, these deposits were probably depleted and were economically unprofitable for operation, but they were still remembered and the Russians who occasionally tried to resume the production. The Great Russian historian N. M. Karamzin also drew attention to the depletion of the source of "Zakamsky silver". He wrote: "Until now, we

Table 2 Silver smelting at copper smelters in the Urals in 1904–1914

Year	Silver received		
	Poods	Pounds	Kg
1904	67	33	1098.81
1905	73	02	1195.82
1906	78	06	1277.89
1907	69	32	1131.53
1908	59	27	967.53
1909	452	–	7403.76
1910	371	18	6077.72
1911	387	01	6339.10
1912	666	02	10,909.16
1913	31	18	508.52
1914	79	33	1295.37

have used other people's precious metals, obtained by foreign trade and exchange with Siberian peoples through Yugra; this last source, as it probably depleted, for in the annals and treaties of the fifteenth century there is no longer a word about Zakamsky silver. But for a long time, we had a rumor that the half-worn countries near the Stone Belt abound in metals…" (Karamzin 1998: 505).

3 Conclusions

In this paper, I have demonstrated that silver existed in the Urals in great numbers included in polymetallic ores in combination with gold, copper, or lead. In the Middle Ages in the Ural region, there were at least two centers for obtaining silver: one in the Pechora river area and another one near the Lake Vagran in the Northern Urals. This latter one, I associate with the chronicle "Zakamsky silver". By the time the Russians arrived at the Urals, the mines were depleted, and the extraction of silver became economically unprofitable before the advent of progressive technologies in metallurgy.

Having demonstrated the existence of a source of silver copper in the northern Urals in the Middle Ages according to written sources, I aim to draw the attention of archaeologists to the presence of silver in bronze items and vice versa copper in silver, as a sign of local production, as well as an abundance of silver items in medieval cultures of the Urals, in particular, local silver torcs (the "hryvnias" in Russian) of the Glazov type in the basin of the Vyatka River on the sites of the Polomskaya (the VI–IX centuries AD) and Chepetsk archaeological cultures (the X–XIII centuries AD).

For example, the knowledge of the existence of a deposit of silver copper in the northern Urals allows us to look differently at the finds containing silver copper objects of the early metal era. So, during the excavations of Geological III settlement on the Kondé river, attributed to the Polymyat type of the pre-Seima period of the Bronze Age (the end of the 3rd–1/3rd millennium BC), 12 copper finds were discovered and analyzed by spectral analysis, 10 of which had 0.13–0.43%, and lunar—1.6% silver. The researcher analyzed various versions of the origin of such a composition: from natural ore, in particular, from cuprous sandstones of the Nizhnekamsk metallurgical region to artificial alloy or the result of import (Koksharov 2012). I believe that the source of raw materials was the silver-copper deposit I have indicated, located in the region of Severouralsk, approximately 250–300 km west of the Geological III settlement.

Currently, in the northern Urals, geologists are searching for ancient mining and silver-bearing minerals. The author's hypothesis should be further tested by the study of the chemical composition of bronze and silver items.

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Problems and Perspectives of Stone Type Investigation: Attempts to Find Out an Origin of Medieval Sculptures of Eurasian Nomads

Aleksandr V. Yevglevskyy

Abstract The 7th–13th-century medieval Eurasian sculptures contain a lot of information about nomads' spiritual culture. Unlike other works of ancient art, statues, being bulky, are often stand in the open air while exhibited in museums. As a result, natural and anthropogenic factors have a destructive effect on them, which makes it difficult to analyse their iconography and to identify places of their origin. The experience in studying the stone type of medieval sculptures under a magnifying glass in cooperation with geologists, but especially using mineralogical and petrographic analysis, helped to identify plausible places of origin for some of unidentified sculptures. In other words, it helped to localize an approximate area of their manufacture, to outline landmarks for finding quarries for the extraction of raw materials and ways of moving them to religious sites, to create conditions for identifying the school of artisans and the style of the master, which significantly depends on the type of stone.

Keywords Medieval sculptures of Eurasian nomads · Stone type · Origin of statues · Mineralogical and petrographic analyses

1 Introduction

The partial or complete absence of identification of archaeological objects complicates the extraction of scientific information. This is especially true of medieval statues, which are kept outdoors of many museums in Eastern Europe. This has led to a tangible effect on them of natural and especially anthropogenic (storage negligence, polluted environment, vandalism, etc.) factors, aggravating the clarification of their origin.

Perhaps the only way to approximate the region of origin of unidentified sculptures is a detailed comparison of their stone type with the geological characteristics of stone samples taken in places where it exits on the surface, or, at least, focusing on the geological maps. In rare cases, similar statues, which have precise or approximate

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indications of their origin may help to find out the origin of unidentified statues. However, the mini-lessons received from geologists on determining the rock type, its properties, and theoretically possible areas of its emergence on the surface, as well as the author's accumulated observations, are only an insufficient minimum for scientific research. We need closer cooperation with geologists, in particular, to apply their mineralogical and petrographic analysis for studying stone types.

The dominance of a certain stone type in the region, more precisely, the ornamental qualities of stone could affected sculptors, determining them to use certain tools and provoking the appearance of pictorial nuances, which were not obligated by the canon. Finally, the type of stone played an important role in the formation of sculpture iconography among a particular group of nomads at a certain period in a particular territory. The examination of the rock is of great importance when there is practically nothing left of the sculpture, i.e. when it is only clear that it conveys an image of a deceased medieval nomad. In this case, by analogy with the structure of the stone type of other adequately studied statues, one can approximate the period of the sculpture's origin.

2 Materials and Methods

Only a few specialists on the nomad medieval sculptures turned to the mineralogical and petrographic analysis (Pletneva 1974; Geraskova 1991; Yevglevskyy 2005). Sometimes researchers simply stated the importance of such a method and outlined the ways of work (Isaieva 2006), but most of them determine the stone type, so to speak, "by the eye," which often leads to errors. Although the petrographic-mineralogical method, due to objective and subjective reasons, does not guarantee an accurate result (which is difficult to achieve even with a whole range of additional measures). Nevertheless, it helps to approximate the area of the statue's manufacture and reveal the ways of their movement to religious sites (burial mounds and enclosures). In many cases, it could contribute to determining the typological and chronological characteristics of sculptures. In the future, this method may create conditions for delineation of the area of a particular nomad's tribe ofr even a kin, as they undoubtedly had their own ethnic and cultural traditions and styles. In some cases, it may be possible to identify the quarries for the extraction of raw materials. Finally, such an analysis helps to choose an individual method of restoration for each sculpture and to identify the museum conditions which are necessary for the proper storage.

The petrographic-mineralogical method could be very useful in many cases that are difficult to explain by providing their plausible explanations. For example, in some cases, judging by iconography or type of a sculpture, one could suppose that it should had been produced in a certain area. However, the corresponding stone type is not marked on the geological map of the corresponding region. For example, in the North-Western Azov Sea Littoral (between the Dnieper and Molochnaya rivers), at least fifteen limestone sculptures of the 2nd half of the 12th—the 1st half of the thirteenth century were found. There are three more sculptures that are made from shell rock and shell rock-limestone. Moreover, the overwhelming majority of these findings are concentrated in the coastal zone of the Azov Sea (in the Sivash region), where it is logical to expect a significant release of limestone to the surface. However, the geological map does not show any limestone deposits there. There can be three explanations for this: (1) people brought monoliths for making sculptures from neighboring areas where there is limestone; (2) all the samples interpreted with a magnifying glass as limestone are incorrectly identified. Such an assumption is possible but the shell rock barely can be confused with another type; (3) limestone outcrops, for some reason, are not marked on the geological map. If so, why? This stone type is not among the rare ones, it was impossible to miss it during any superficial way of exploring the geological structure of the region.

In connection with the problem of limestones in the Sivash region, a sculpture of the 2nd half of the 12th—the 1st half of the thirteenth century, made from ditrite-nummulite limestone, from the "Askania-Nova" biosphere reserve deserves special attention. Nummulites (from Lat. Nummulus—a little coin) are a genus of unicellular organisms of the order of foraminifera. Nummulite limestone is composed of shells impregnated with fine pores, symmetrically spirally twisted, and in the form of a rounded plate or biconvex (less often up to a spherical shape). Fossil remains of nummulites are known in the Upper Cretaceous and Paleogene deposits of the tropics and subtropics of Europe, Asia, Africa, and America. Thus, we can resanobably expect their presence in the North-Western Azov Littoral, but for some reason, they are not marked on the geological map of the Sivash region. Consequently, the sculpture or a blank monolith was most likely brought there from the Crimea Peninsula, where nummulite deposits are found in sufficient quantities. If this is the case, it is still unclear why the craftsmen did not use the easily available numerous outcrops of different types of sandstones, which are even more malleable for skillful sculpting?

Unfortunately, we cannot solve such problematic cases within the limited space of the article, and the title of the article focuses on tasks aimed at the prospect of research.

A considerable problem is the condition of the taken samples, which often turn out to be practically unsuitable for objective exploration (or it is very difficult), since the upper layer of the rock is weathered, i.e. the informative structural elements of the stone were destroyed. First of all, we are talking about sandstones, the weathered samples of which, when examined through a magnifying glass by an experienced geologist (not to mention an archaeologist), can be confused with limestone and even with granite. However, the problem is not only in the poor preservation of most of the statues. It is also the fact that it is often impossible to take a sample from a sculpture in good condition, either because of a ban by the museum administration (and no arguments help) or because of the absence of damaged areas on statues, which makes it impossible to take a sample without causing visible damage to a sculpture. In this case, we need some kind of non-contact research methods, somewhat close to laser technologies, with the help of which modern specialists harmlessly restore sculptures.

The catastrophic lack of funds to pay for the professional examination of specimens adds to all the mentioned difficulties in the investigation of statues. This is especially true for the post-Soviet states, where there is often no funding even for rescue work in the zones of the destruction of archaeological sites. Therefore, it is difficult to overestimate every sample taken from the sculpture, with the preserved top layer of stone. However, even in this case, it is not always possible to make a thin section from the sample, since it turns out to be too thin for a mechanical cut or too fragile.

3 Results and Discussion

The work on taking the samples of medieval nomads' stone sculptures is in full swing at the Donetsk national university. However, the general tendencies, i.e. where and how many sculptures were made from certain stone types, have already been determined. As for the Eastern European steppes, we can confidently say that the majority of sculptures were made of grey and yellowish-grey fine-grained quartz sandstone with contact and film-porous cement. However, the thin sectioninng suggests that the number of sculptures made of feldspar-quartz sandstones and it is likely that their number will increase significantly, since when viewed through a magnifying glass, feldspar is often not visible. Besides, feldspar intensively erodes, clay mineral replaces it and, as a result, it is carried out of the surface of the rock. Instead of feldspar grains, pores remain, so it often seems that the sandstone has a primary quartz composition (Isaieva 2006). Sculptures made of limestone are about two times less than those made of sandstone; limestone is either an oolitic structure or an oolitic one with an admixture of whole and detrital shells (shell-detrital-oolitic). Allied rocks, i.e. limestone-shell rock and shell rock, are concentrated, as a rule, in the coastal zones. Sculptures made of granite are found in the Eastern European steppes about five times rarely than sandstone statues. In rare cases, the sculptures are made of gneiss, crystalline schist, marl, chalk.

At the moment, the analysis of a large number of sculptures by a pair of combined features "a rock type" and "an iconographic type" (the ethnic and cultural layers) permits us to confidently say that, for example, sculptures made of granite, wherever they were recorded now in Eastern Europe, most likely come from the Northern Azov region. For sculptures made of gneiss, quartzite, or chalk, we also may approximately determine the production area. A completely different situation is for numerous types of sandstones and limestones. Their outcrops are common in the vast expanses of the Eastern European and Asian steppes, but the deposits formed under specific conditions. Therefore, not an archaeologist nor even a geologist could examine the samples through a magnifying glass properly; the only hope is on thorough professional petroglyph and mineralogical research, firstly on the microscopic study of rocks in transparent thin sections.

After getting the characteristics of the sample, the next step is the search for similar stone types by passing along promising routes and recording every outcrop of bedrock on the way. Then, one should make a general comparison of recorded samples with sculpture ones in the laboratory. After that, one needs to compare the samples more accurately by microscopic methods and, if it is necessary and possible, involves spectral, chemical, and other analyzes. Such research steps (field explorations and laboratory work) could help to narrow the area of distribution of probable raw materials or even, with luck, to find a specific place of its extraction by a medieval craftsman (Isaieva 2006).

For now, we have only two dozen thin sections; in other cases, we get information on the stone type of sculptures literally in an artisanal way, i.e. “under a magnifying glass”. However, we hope that in the future, our university will significantly improve its financing and, as a result, we will be able to produce at least a few more thin sections. Then, for sure, we will supplement our superficial results with numerous corrections. In any case, we have advanced much further than S. Pletneva did, who in her fundamental research “The Polovtsian stone statues”, without close contact with geologists, had to give such vague definitions for many sculptures as “greystone”, “flagstone”, etc. (Pletneva 1974).

In addition to the problem of undocumented sculptures, a thorough comparison of the typological and chronological characteristics of the sculptures with the archeo-petrographic data puts forward the following questions: to what extent and under what circumstances the accessibility of raw material suitable for sculpting influenced the master’s choice of stone type, and what other factors could also influence them. So to say, to what extent did the master become dependent on a fashion for the stone type, its color, hardness, and graininess? Whether the level of craftsman’s skills, they need to do the work as quickly as possible, the wishes of a family group, etc., influenced on his choice of the stone type as well?

At the same time, we can say that the choice of the stone type has no correlation with social, age, and sex characteristics in any way. It is quite another matter that nomads could not have such motivations by a certain period in principle.

4 Conclusions

In general, it is clear now that the paradigms in the tradition of making sculptures, at least for Eastern European sculptures, have undoubtedly changed over time, including the attitude to the choice of stone type.

In any case, at the pinnacle of the heyday of the sculpture-making, they used the softest stone types, i.e. fine-grained sandstone of light shades and especially chalk, which was suitable to perform on it the subtle details of clothing, weapons, jewelry, hairstyles, faces and other nuances of iconography. Likely, archeopetrography could also help to solve other related questions that not only are not mentioned in the article but also have not even been raised for today.

I would like to emphasize once more that it is important to have as many stone samples with mineralogical and petrographic characteristics, which were obtained using the thin section method, as possible.

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About the Life and Work of Archaeologist Prof. Gennady B. Zdanovich

Natalia Ankusheva

On November 19, 2020, a great scientist, professor of Chelyabinsk State University, archaeologist Gennady B. Zdanovich passed away. It is hard to believe this loss. The activity of Prof. Zdanovich was wide and various. These are both archaeological discoveries, and wide educational, public activity. But the main thing that he left, what he opened for us is a special approach to archaeological antiquities and through them to the man. Prof. Zdanovich is a Doctor of Historical Sciences, Professor; General Director of the Specialized Natural Landscape and Historical and Archaeological Center "Arkaim"; Head of the Department of Archaeology, Ethnography and Socio-Natural History at Chelyabinsk State University and author of more than 150 scientific publications, including 4 monographs.

Gennady B. Zdanovich was born on October 4, 1938 in Makhachkala, Dagestan. After high school graduation, he entered Alma-Ata film college, graduated from it in 1959, and till 1961 worked as a projectionist. His way in archaeology began in 1961 when he joined the Department of History of Ural State University. As a student, he began working in the university laboratory of archaeological research headed by the great Soviet archeologists Vladimir F. Genning. Then he took part in archaeological expeditions on the territory of the Urals.

In 1966 Gennady B. Zdanovich graduated from the University and left for Petropavlovsk city in Northern Kazakhstan where he became the teacher of Petropavlovsk State Pedagogical Institute and researcher of the North Kazakhstan Historical and Local Lore Museum. In 1967 he organized the North Kazakhstan archaeological expedition.

By this time the Northern Kazakhstan steppes were practically a blank spot on the archaeological map of the country. Already in the first years of work, the expedition

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has found out the monuments of the unknown Bronze Age culture which was named "Petrovsky". Petrovka II, Novonikolskoye I, Bogolyubovo IV fortified Bronze Age settlements were discovered and investigated. The results of these works were highly evaluated by the leading domestic specialists.

In Northern Kazakhstan, Gennady B. Zdanovich developed and introduced a new method of excavation of Bronze Age multilayer settlements by wide areas with the construction of stratigraphic columns. For the first time in the region, Gennady B. Zdanovich began to involve specialists in natural science methods to archaeological research and analysis of material. He developed a new periodization of the Bronze Age cultures of the Ural-Kazakhstan region. In 1976 by results of these researches he defended the dissertation on a scientific degree of the candidate of historical sciences.

Since the end of the 1960th years based on the North Kazakhstan archaeological expedition, the scientific collective which subsequently became the basis of the Chelyabinsk archaeological school was formed. The collective included: Svetlana Ya. Zdanovich (now Ph.D., the associate professor of ChelSU), Victor F. Zaybert (now the corresponding member of National Academy of Sciences of Republic Kazakhstan), Maral K. Khabdullina (the doctor of historical sciences, the director of Scientific Research Institute of Archaeology named by K. A. Akishev), Alexander D. Tairov (Doctor of History, Head of the Department of History and Ethnology, SUSU), Anatoly A. Pleshakov (Ph.D., Head of the History of Kazakhstan Department at North Kazakhstan University), Tatiana S. Malyutina (Ph.D. in History, Associate Professor at ChelSU), Natalia S. Tatarintseva (curator of the "Nature and Man" Museum on Arkaim), Nadezhda O. Ivanova (Deputy Director of the Chelyabinsk Region's Regional Museum of 'Nature and Man'), Nadiya Konstantinova (Deputy Director of the Chelyabinsk Region's Regional Museum of 'Nature and Man'), etc. When creating the scientific team, Gennady B. Zdanovich showed great ability to unite and captivate young researchers with the ideas of studying antiquity and creative talent for posing and solving archaeological issues.

In 1972–1975, Gennady B. Zdanovich worked as the senior teacher of the Karaganda State University, and in 1976 together with the collective he moved to Chelyabinsk and created a Laboratory of Archaeological Researches in Chelyabinsk State University. For many years he headed this laboratory, and in 1994 he became the Head of the Department of Archaeology, Ethnography, and Social and Natural History.

The Ural-Kazakhstan archeological expedition headed by Gennady B. Zdanovich was formed in 1976 and based on the North-Kazakhstani expedition, deployed large-scale research in the territory of the Southern Urals. Together with the Ural Archaeological Expedition of Vladimir F. Genning, they conducted multi-year researches of the Bronze Age cultural complex on the Sintashta River in the Breda district of the Chelyabinsk region.

Here the first fortified settlement in the steppe Trans-Ural region of the circular plan of the beginning of II millennium BC was excavated, rich burial complexes with a circular arrangement of burial pits, complex grave structures, remains of wooden chariots, and numerous animal sacrifices in the burial chambers were studied. Ethnic interpretations Vladimir F. Genning and Gennady B. Zdanovich concluded the settlement in the Southern Urals in the Bronze Age Indo-Iranian tribes with high culture.

In the Ural-Kazakhstan archaeological expedition headed by Gennady B. Zdanovich, the students and young specialists worked, who became now the leading Chelyabinsk archaeologists: Nikolay B. Vinogradov (Doctor of History, Head of the Archaeological laboratory of the Chelyabinsk State Pedagogical University), Sergey G. Botalov (Doctor of History, Director of the Archeological Scientific Center), Vadim S. Mosin (Doctor of History, Director of the South Ural Branch of the Institute of History and Archaeology UB RAS), Stanislav A. Grigoryev (Ph.D., senior researcher of the Institute of History and Archaeology UB RAS), Dmitry G. Zdanovich (Ph.D. in History, Director of the Scientific and Educational Complex for studying the problems of nature and man at Chelyabinsk State University), Andrey V. Epimakhov (Ph.D. in History, Associate Professor of SUSU), Ilya E. Lyubchansky (Ph.D. in History, Associate Professor at Chelyabinsk State University), Nikolay M. Menshenin (Chief Specialist at the State Research Center for the Protection of Historical and Cultural Monuments in Chelyabinsk Region), etc. The Chelyabinsk archaeological school was being formed and the works are well-known not only in Russia but all over the World.

In 1987 the expedition team led by Sergei G. Botalov and Vadim S. Mosin, researching the Bredinsky area in the territory to be flooded by Karaganda Reservoir, discovered Arkaim fortified settlement, a wonderfully preserved site, sincultural complex explored on the Sintashta River. The excavations began in the same year under the leadership of Gennady B. Zdanovich. On Arkaim, archaeological groups from all over the country worked—in different periods in excavations participated over 400 people. Archaeological researches combined with geodesic and geophysical works allowed restoring the appearance of the ancient monument.

Arkaim is one of the brightest phenomena in the history of mankind's architecture. It consists of many elements designed in a single space: deep moats, high defensive walls, 60 houses, drainage waterways, complex complexes of four fortifications, inner and outer defense systems were implemented in a single structure and built on the model of concentric circles with an overall diameter of 170 m. This is a huge geometric symbol, built by the ancient people in the space of the steppe sacred to them.

The studies of the scientific team headed by Gennady B. Zdanovich provided to examine that the Arkaim was built about 4000 years ago in the beginning of the II millennium BC. It was inhabited by people of Caucasoid appearance, whose culture was associated with the Indo-Iranian tradition. They can make strong pottery and decorated it with geometric ornaments, bronze metallurgy, processed lead, tin, gold, and silver, raised livestock, cultivated small fields, and vegetable gardens. They were excellent horsemen and creators of light steppe chariots. Among them were priests and poets, creators of myths and rituals.

The efforts of the scientific community, organized by Gennady B. Zdanovich, resulted in stopping the construction of the Karaganda Reservoir. In 1991 the area of the Arkaim valley around the ancient monument was declared a protected area.

At the end of the 1980s, the work of the research group was joined by the group of deciphering of the aerial photos headed by Ia M. Batanina. As a result of the work of this group in the Chelyabinsk region and adjoining areas of the Orenburg region, Trans-Ural Bashkiria, and the Republic of Kazakhstan over 20 fortified settlements, archaeologically referred to as “monuments of Sintashta type” were discovered. Each settlement has the strong geometrical form—as a rule, circle, rectangular or oval. All of them were protected by complex fortification systems, including moats, ramparts, defensive systems, towers, and fortification complexes.

Under the leadership of Gennady B. Zdanovich and Ia M. Batanina for the first time in Russia, the deciphering of aerial photographs began to be used for a comprehensive archaeological survey of vast areas. As a result of the use of aerial photographic method, Archaeological atlas of Kizilsky area was published, which contains information about more than 800 archaeological sites.

The territory of location of Sintashta type monuments was named “Land of Cities”. For its protection and research by the Administration of the Chelyabinsk region in 1994 was organized a Specialized Natural Landscape and Historical and Archaeological Center “Arkaim” headed by Gennady B. Zdanovich and started to work an Integrated Archaeological, Ethnographic and Environmental Expedition of the Center “Arkaim”. Summarizing the results of the researches, G. B. Zdanovich defended the doctoral dissertation in 2002, where he presented his vision of the Bronze Age cultures of the of the Ural-Kazakhstan steppes.

On Arkaim, Gennady B. Zdanovich gathered the specialists in natural sciences: geologists, soil scientists, hydrologists, botanists, zoologists, and paleozoologists.

In the late 1990’s—early 2000’s a scientific base and a large museum complex were created on Arkaim, the building of the Museum of Nature and Man was constructed, where not only the demonstration but also the storage and processing of the most valuable collection material is carried out. The open-air historical park was created—a system of reconstructions of domestic and sacred buildings from the Stone Age to the late XIX century and the Museum of ancient technology.

Later Prof. Zdanovich headed the scientific team, which conducted complex research on the territory of the steppe and forest-steppe of Trans-Urals. Archaeologists and ethnographers of the “Arkaim” Center studied the stages of cultural landscape formation, the history of Trans-Ural cultures and their interaction, and, first of all, the culture of the “Land of Cities” population. Now the development of museum activities at Arkaim is continued. Gennady B. Zdanovich was undoubtedly the main linchpin of this great team.