The Functionality of Building Structures at the Bronze Age Vorovskaya Yama Mine in the Southern Trans-Urals (Based on the 2021 Excavation)

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Abstract. This study investigates two Alakul structures discovered at the Vorovskaya Yama Bronze Age mine in the southern Trans-Urals (c. 1900–1500 BCE). Based on the 2021 excavation data, the structures can be characterized according to the following features: their construction and filling; the presence of traces of metal in the hearths; a high density of the mass material (ceramics and bones) in the cultural layer; and the functionality of tools. We assume that Structure No. 1 was a production building that housed mining and smelting processes, while Structure No. 2 was probably a household building. These results, which demonstrate a division into residential and industrial zones, find parallels in the mining and metallurgical complexes associated with the Srubnaya culture.

Keywords: Late Bronze Age · Copper Mine · Southern Trans-Urals · Alakul culture

1 Introduction

The Late Bronze Age (c. 2000–1500 cal BCE) represents a key historical period during which the zone of metal production in Northern Eurasia expanded to encompass a hitherto unprecedented area. The Srubnaya and Alakul cultures, conditionally separated by the Ural Mountains, were responsible for the largest metal-producing assemblages in this territory, with which the development of numerous copper deposits in Eastern Ukraine, the Southern Urals, and Central and Eastern Kazakhstan was associated (Chernykh 2008). However, the organization of copper ore mining in the deposits of Northern Eurasia remains an insufficiently studied issue due to the small number of excavated ancient mines. In particular, wide-area excavations and related complex multidisciplinary studies have been carried out only at a few sites, mainly those associated with the miners of the Srubnaya culture. These include the Gorny-1 settlement in the Cis-Urals,

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the Mikhailo-Ovsyanka I complex in the Middle Volga region, the Chervone Ozero complexes, and other sites associated with the Donbas mining and metallurgical center (Chernykh et al. 2002; Matveeva et al. 2004; Tatarynov 2018; Shishlina et al. 2020; Brovender et al. 2021). In addition to mine workings, building structures were found at these sites, which cultural layers included evidence of a full cycle of metal production, from ore mining to the smelting and melting of copper and bronze tools.

The Alakul copper mining is less studied: only two southern Trans-Ural mines in this period have been confirmed by radiocarbon dating and a set of the corresponding artifact set in the respective cultural layers (Ankusheva et al. 2022). This work is devoted to one of these – the Vorovskaya Yama Mine. Here, for the first time in the area associated with the Alakul assemblage, the remains of miners' buildings located directly on the copper deposit were found. The research sets out to compare these structures to determine their possible purpose. This will bring us closer to reconstructing the production processes that occurred at the deposit in the Late Bronze Age and revealing new details of the life of the Alakul miners and metallurgists.

2 Materials and Methods

The Vorovskaya Yama ore occurrence is located in the Kizil District of the Chelyabinsk region, 60 km southeast of the City of Magnitogorsk (Russia) (53°02′ N 59°35′ E). This area is included in the modern landscape steppe zone. The occurrence of copper ore is confined to the dunite-clinopyroxene-gabbro massif. Serpentinites, talc-carbonate, and chlorite-carbonate-epidote metasomatites represent the ore-bearing rocks. The ore zone has a lenticular shape with a thickness of up to 8 m and a length of up to 25 m. Copper mineralization is represented by a complex of supergene secondary minerals, including malachite and, less commonly, azurite and cuprite. The central structure of the site is represented by a rounded open pit mine having a diameter of 35–40 m, while its depth reaches 5 m. This open pit mine is surrounded by a ring of dumps crept and turfed with steppe vegetation; the height of the dumps is 0.8–1.5 m from the modern surface (Zaykov et al. 2005).

The archaeological excavation on which we report was started in 2021 on the outer field of the north-eastern dump extending to an area of 64 sq. m (Fig. 1A). The remains of two structures (No. 1 and No. 2) were found under the dump (Fig. 1B). They included rectangular depressions in the buried soil, a series of postholes within them, evidence of hearths, along with a filling of these structures that differed from the adjacent soil. Alakul pottery was found both on the floor of the structures and in their filling (Ankusheva et al. 2022). According to radiocarbon dating, the period of functioning of the structures refers to the interval 1738–1514 cal BCE (95.4%) (Ankusheva et al. 2022, 2023, in prep.).

This paper includes a comparative description of the two structures according to the following parameters:

1) Their construction and soil filling;
2) Traces of metal in the hearths located within the structures;
3) Density of mass material (animal bones and ceramic fragments) in the cultural layer;
4) Function of the stone and ceramic tools found inside the structures.

Analytical methods include planographic and stratigraphic analysis of layers, structures, and finds in the excavation area; X-ray fluorescence analysis of soil from hearths; use-wear analysis of stone tools; and mineralogical analysis of crushed material. The use-wear analysis of stone tools was performed in the South Ural State Humanitarian Pedagogical University archaeological laboratory using an MBS-2 optical microscope (oblique illumination – up to 40x magnification; analyst Ivan V. Molchanov). Photographing of use-wear on the artifact surface was carried out using an MC-2-Zoom TD-2 stereomicroscope with a TOUPCAM 10M video ocular. X-ray fluorescence analysis was performed on a portable device INNOV-X α 400 in soil mode with an exposure time of 30 s (SU FRC MG UB RAS, analyst Maksim N. Ankushev). Crushed rodingite material was studied by Anatoly M. Yuminov at the South Urals Federal Research Center of Mineralogy and Geoecology UB RAS by concentrate analysis and optical and scanning electron microscopy (Tescan Vega 3 SBU; analyst Ivan A. Blinov). The assay analysis of the concentrate was carried out in the "Chelyabinskgeos'emka" complex laboratory.

3 Results and Discussion

1) *Design features of structures and their ground fill*

Structure 1[1], occupying the area in the north part of the excavation area 2021, is subrectangular and oriented with its long axis along the NE–SW or latitudinal direction (Fig. 1B). The structure penetrates the buried soil to a depth of 20 cm; its floor is located at the sterile layer of the adjacent zone. A line of post pits outlines the southern boundary of the structure; an additional accumulation of pits and a depression near the western boundary possibly indicates the presence of an entrance tambour. The dimensions of the investigated area of the structure are 6 m × 4 m.

The boundaries of Structure 1 are quite clearly defined by the filling, which includes two layers (Fig. 2). The lower layer, which is 15–20 cm thick and overlies the sterile layer, probably marks the building floor. It comprises gray-brown variegated loam abundantly saturated with copper oxides and charcoal inclusions. The upper layer of structural filling, having a thickness of 20–30 cm, is represented by a yellow, relatively homogeneous sandy loam consisting of crushed rodingites with copper mineralization (Fig. 2A). The material is represented by a crushed stone–perlite fraction with a predominance of fine crushed stone (45–50% of the total weight) and gravel (15–20%). The amount of sand and loam in this layer is about 20% and up to 10%, respectively.

[1] Here and below, the numbering of structures and hearths is given according to the Report on archaeological excavations (Ankusheva 2021) in order to avoid confusion in further work with materials.

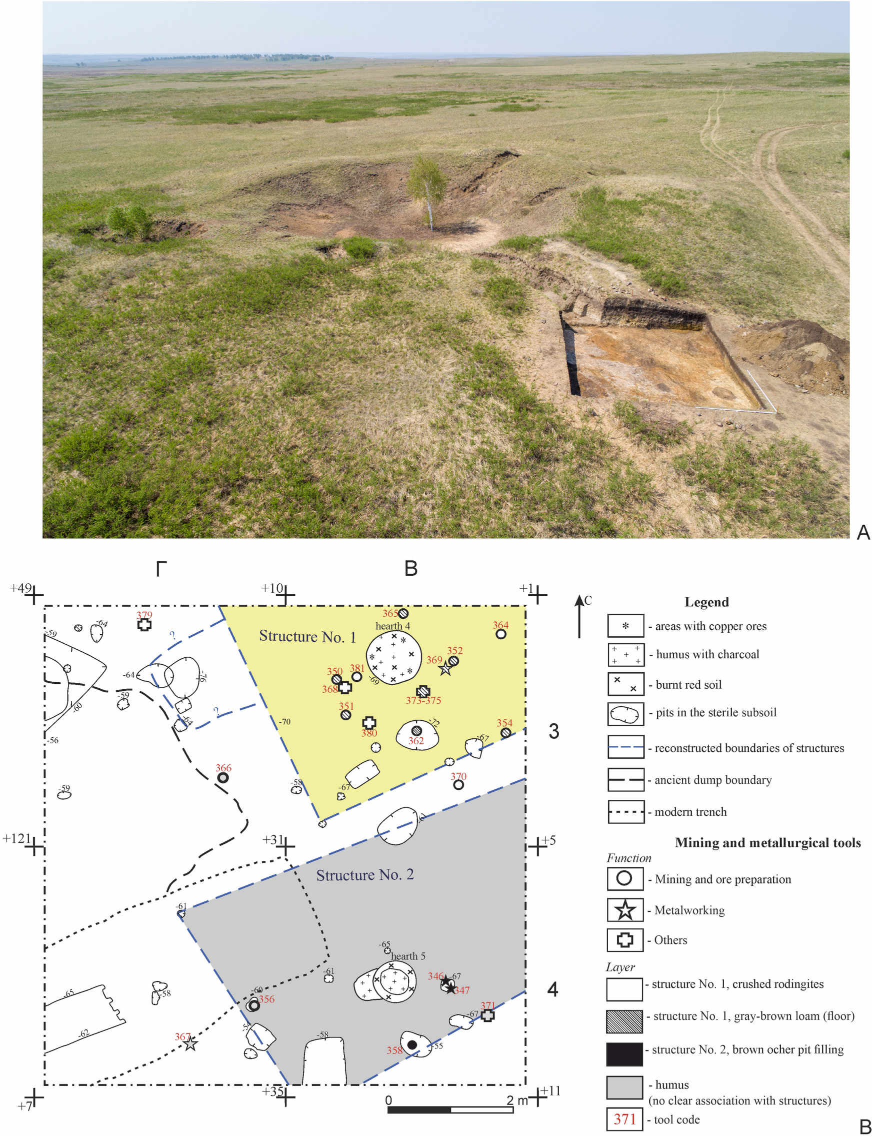

Fig. 1. The Vorovskaya Yama mine. A – A general view of the site with the excavation area of 2021; B – A plan of structures in the 2021 excavation

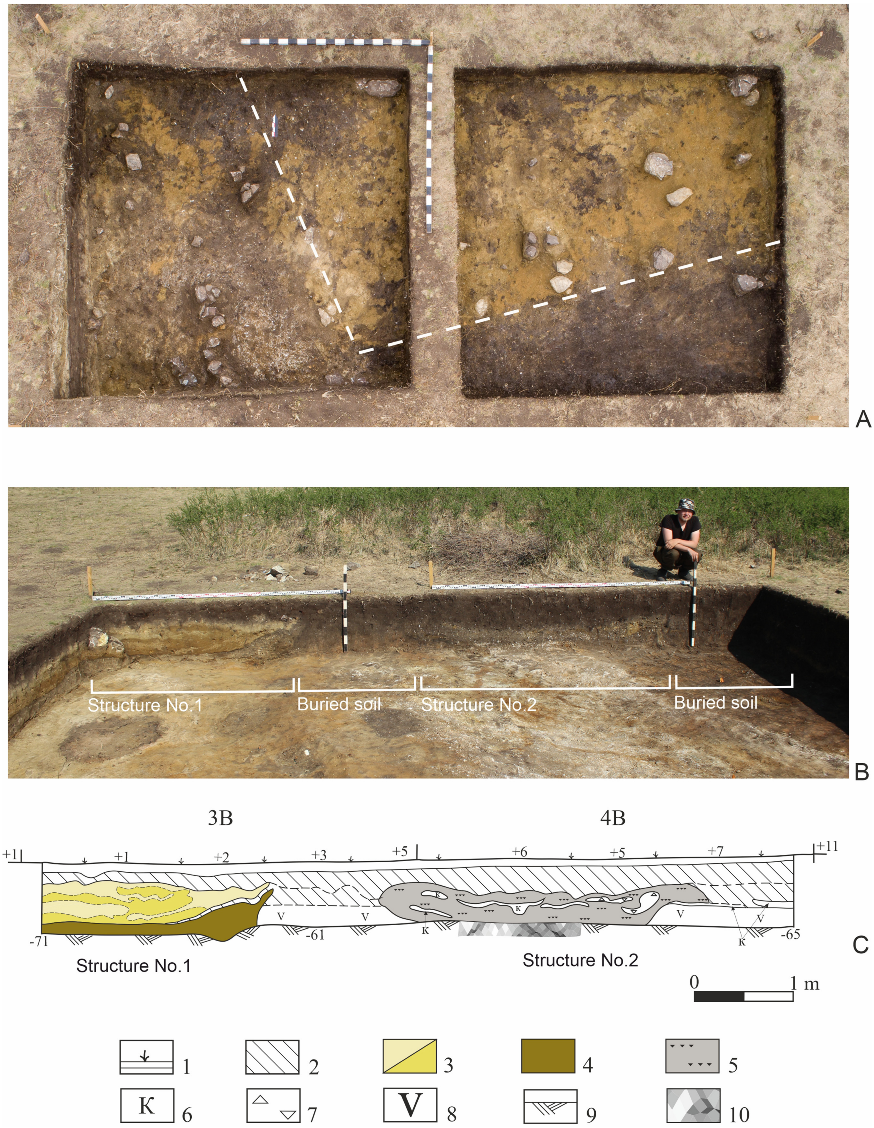

Fig. 2. The Alakul structures in the 2021 excavation area. A – Upper filling of Structure No. 1 (dotted lines indicate possible boundaries); B–C – The eastern profile of the excavation: photo (B) and scheme (C). 1 – turf; 2 – dark gray humus soil; 3 – sandy loam of crushed rodingites with copper mineralization (lighter/darker); 4 – gray-brown variegated loam with copper oxides and charcoal inclusions; 5 – gray humus with fine serpentinite gruss; 6 – brown sandy loam; 7 – crushed stone with sand; 8 – buried soil; 9 – sterile layer (yellow-orange dense loam); 10 – sterile layer (weathered serpentinites).

We assume that the upper layer of the filling of Structure No. 1 is the result of the storage and crushing of the mined ore followed by enrichment using manual selection methods. The average copper content in the crushed material reaches 3%; in individual samples, the corresponding proportion is 7–10%. Ore mineralization is mainly represented by malachite. In addition, relic grains of sulfides were found in the crushed ore: chalcopyrite, sphalerite, covellite, pyrrhotite, and acanthite; sometimes extremely small segregations (1–10 μm) of native gold and copper were recorded. According to the assay analysis, the gold content in rodingites reaches 0.5 ppm, while the silver content is up to 19 ppm. Accessory mineralization in the material is poorly represented. Magnetite, Cr-rich spinel, cuprite, albite, amphibole, epidote, barite, opal, and iodargyrite were found in the concentrate. Cr-rich spinels are the most important distinguishing feature of Vorovskaya Yama ores. These minerals mark the ores of copper deposits associated with serpentinite massifs. Andradite is the main mineral of crushed rodingites. It is characterized by clear zoning, expressed by the presence of the mineral in separate areas enriched in manganese.

Hearth No. 4 was found in the central part of the excavated area of Structure No. 1 on its floor, partially penetrating the sterile layer. This represents a round depression with a diameter of 85–90 cm and depth of 15 cm, filled with gray-brown ash soil abundantly saturated with charcoal, fine calcined rubble and gruss of serpentinites, rodingites, iron ores, and small fragments of oxidized copper ores. Along with individual large fragments (up to 10 cm) of weathered rodingites, multiple crushed burnt 0.5–2 cm bones are in the filling of the hearth.

Structure 2 is parallel to Structure No. 1 in the southern part of the excavation area and penetrates the buried soil. The dimensions of the investigated area of the structure are 6 × 3.5 m (Fig. 1B). The boundaries of this structure are less clear because its main filling consists of gray humus with fine serpentinite gruss. Separate lenses of brown loose sandy loam with gruss and small rubble of host rocks with brown iron ore and copper ores were recorded in the humus filling of the structure as well as at the level of its floor (Fig. 2B–C).

Hearth No. 5 was found in the central part of the excavated area of Structure No. 2 on its floor. It comprised a depression consisting of two parts: the main part being rounded, 70 cm in diameter, and filled with reddish calcined humus soil with inclusions of charcoal; a second subrectangular part, about 30 × 40 cm in size, filled with black ash and charcoal-enriched humus soil, adjoins it from the west side. In this section, the hearth has a plate-like shape and the reddish humus filling with inclusions of charcoal. The total depth was 10 cm.

Summarizing, we consider the common features of structures No. 1 and No. 2. Both buildings had a rectangular post-frame construction, penetrating the buried soil by 10–20 cm and with long sides of NE–SW or latitudinal orientation. The investigated parts of the structures appear to have similar dimensions (6 × 3.5–4 m); however, it is too early to talk about the total area of the structures due to the small size of the excavation. A hearth was found in the central part of each of the structures.

The filling of the structures constitutes the main difference between them. The floor level of structure No. 1 is more saturated with charcoal and copper minerals. This structure is also distinguished by a technological layer of crushed rodingites. This layer is the result of copper ore enrichment processes that occurred either in the building itself or its depression, sometimes following the cessation of its habitation. Conversely, the predominant filling of structure No. 2 is dark gray humus sandy loam, which is "standard" for the Late Bronze Age settlements in the Trans-Urals steppe. This loam is characterized by inclusions of gruss of talcated serpentinites and thin lenses of brown ocher soil. While the serpentinites are probably derived from the weathering crust underlying the structure, the origin of the second impurity cannot yet be established.

2) *Traces of metal in the hearths*

X-ray fluorescence analysis revealed a very high (from 15,000 to 20,000 ppm) concentration of copper in the hearth of Structure No. 1. Tin absent from local ores was found in the hearth filling (170 ppm). At the same time, the absence of slags in the hearth and the adjacent zone suggests its use in metallurgy for melting ingots and remelting finished copper- and tin-containing products or scrap.

The concentration of copper in the hearth of Structure No. 2 is also quite high (from 4,800 to 5,500 ppm). However, similar values (up to 6,500 ppm) typical for the cultural layer of the mine are generally due to the presence of copper-bearing dumps. Therefore, we cannot unequivocally state the use of this hearth in metallurgy. Its use for cooking, heating, or multifunctional purpose cannot be ruled out.

3) *Mass material (bones, ceramics) in the structures*

Six hundred ninety-eight fragments of bones and teeth of domestic ungulates with a total weight of 4.4 kg were found in the excavation area. While almost half of these (305 fragments weighing 2.1 kg) cannot be unambiguously associated with the filling of one structure or another, 265 fragments weighing 1.2 kg were found in the layers of the dump. Approximately the same number of bone remains was found in the lower layers of the structure filling: 58 fragments weighing 345 g in structure No. 1 and 84 fragments weighing 354 g in structure No. 2.

Three hundred ninety-eight fragments from at least 25 different vessels were found in the excavation area. However, only 13 ceramic fragments from at least two vessels were found at the floor level of Structure No. 1, much lower than in Structure No. 2 (231 fragments from 10 vessels). In addition to the floor of the structures, 57 fragments are associated with the layers of the ancient dump; from these fragments, at least four separate vessels have been identified. Further, 95 ceramic fragments come from layers that are difficult to associate with the filling of buildings or layers of dumps.

Thus, with relatively equal saturation of bone remains, the amount of ceramics significantly predominates on the floor of structure No. 2. This may indirectly indicate its household purpose.

4) *Tool functionality*

Twenty items related to metalworking were found. This sample includes a ceramic crucible with a slagged surface and nineteen stone tools. We have identified three functional categories of artifacts employing use-wear analysis (Fig. 1B):

Mining and ore-preparing tools (counterweights for lifting ore, hammers, picks): $n = 11$;

Metalworking tools (pestles, blacksmith hammers, as well as the crucible): n = 4;
Other items (bases, unfinished items, indefinite function): n = 5.

Thirteen tools were found inside Structure No. 1. Eight were found on the floor, and the rest were found on the top of the crushed rodingite layer. Most of these tools (n = 8) were used for mining and ore preparation (Fig. 3). In addition, two bases with a ground surface were found, as well as two tools with a ground surface and groove, whose function remains unclear. The only tool from Structure No. 1, presumably associated with metalworking, is a small hammer with a groove (Fig. 4). This was found in the central part of the structure and is possibly associated with the hearth.

Only three artifacts come from Structure No. 2. Two of these, comprising a crucible and stone pestle, were found in the pit near the hearth. Possibly, they constituted a certain "set" for metal processing, left for a utilitarian or sacred purpose in the deepening of the building. The third tool representing some kind of counterweight was also found in another pit within the structure.

Thus, most tools, predominantly associated with mine working, were found in Structure No. 1. This is in good agreement with the nature of its filling, represented by crushed rodingites. Regarding this comparison, Structure No. 2 is distinguished from the first by a smaller number of tools, their localization in pits, and the predominance of metalworking objects.

Consider the common and different features of the two structures. First, they probably had a similar design in terms of dimensions, depth in the buried soil, orientation to cardinal points, the use of a framework of posts in constructing the roof and walls, and the hearths inside the buildings. Second, approximately the same amount of bone remains was found in both structures. However, both criteria are quite vulnerable to criticism: the excavation area is too small for a detailed reconstruction of buildings, while most of the bone remains lack a clear stratigraphy.

The differences between the structures are more significant. Structure No. 1 has clear signs of production purpose. Along with the layer of crushed rodingites, findings of hammers, picks, counterweights, and bases illustrate the processes of mining and enrichment of copper ore occurring here. In addition, the production of bronze items within Structure No. 1 is confirmed by traces of tin in the hearth and the discovery of a metalworking stone hammer.

Structure No. 2 has signs of a dwelling structure. While a much larger number of ceramic fragments were found here, thick technological layers were not present in the filling. Finds associated with metalworking (crucible and pestle) also suggest bronze casting operations within the building. Note that all these artifacts were found in pits. They could have got there by accident or had been involved in some ritual actions with postholes, evidence of which is widely presented at the Late Bronze Age settlements of Northern Eurasia (Podobed et al. 2013).

These results find their parallels in the mining and metallurgical complexes of the Srubnaya culture, which are characterized by division into different functional zones. In particular, Complex 1 of the subphase B1 of the Gorny 1 settlement at the Kargaly ore field comprises a combination of dwellings and specialized metallurgical structures: a living placement, smelter and ore yards, a sacred pit and a waste pit; the analysis of Complex 2 similarly assumes a different purpose of its structures and objects (Chernykh

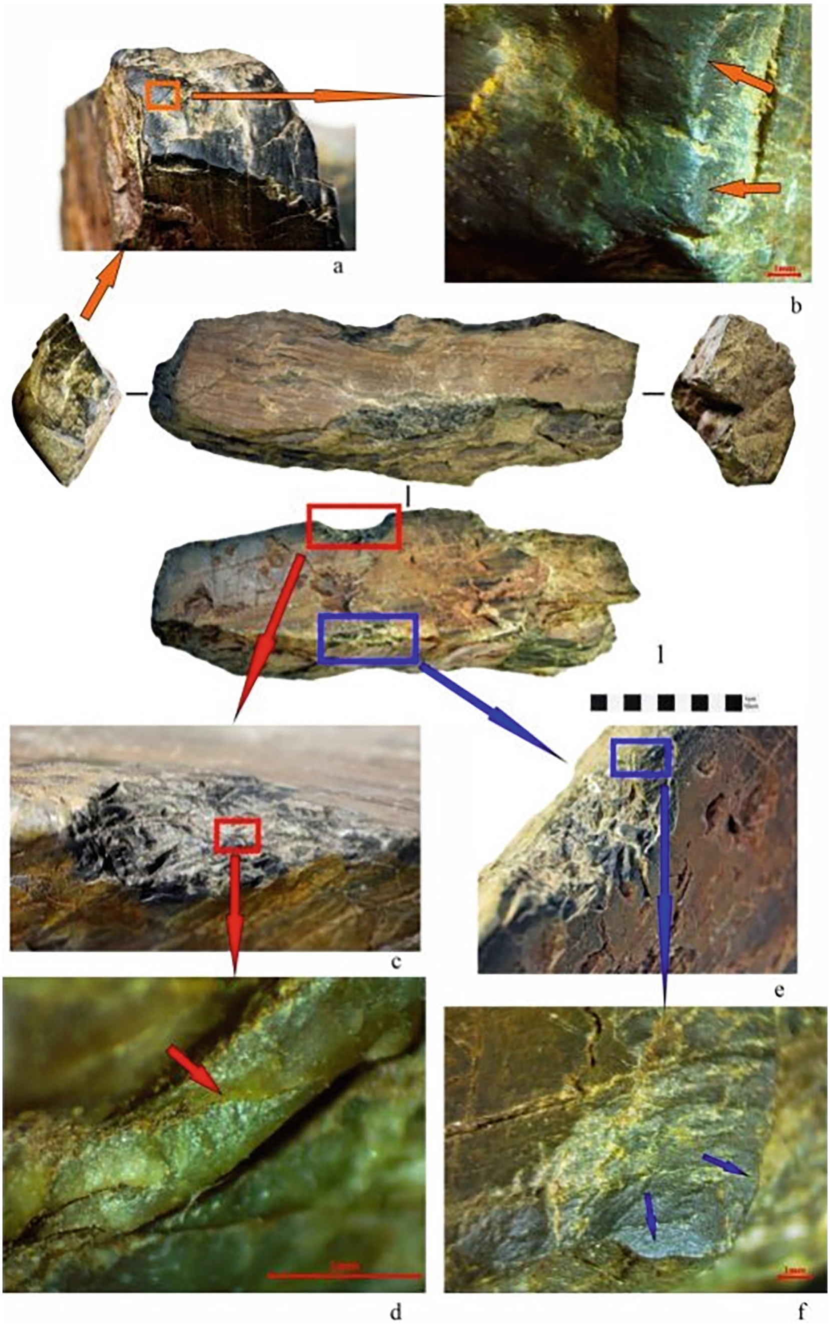

Fig. 3. A pick (#364). 1. Photos of the tool: a – macrophotography of end of tool; b – microphotograph of rounded edge (magnification *10); c – macrophotography of notch 1 on edge; d – microphotography of linear traces (magnification *40); e – macrophotography of notch 2 on edge; f – microphotography of rounded edge

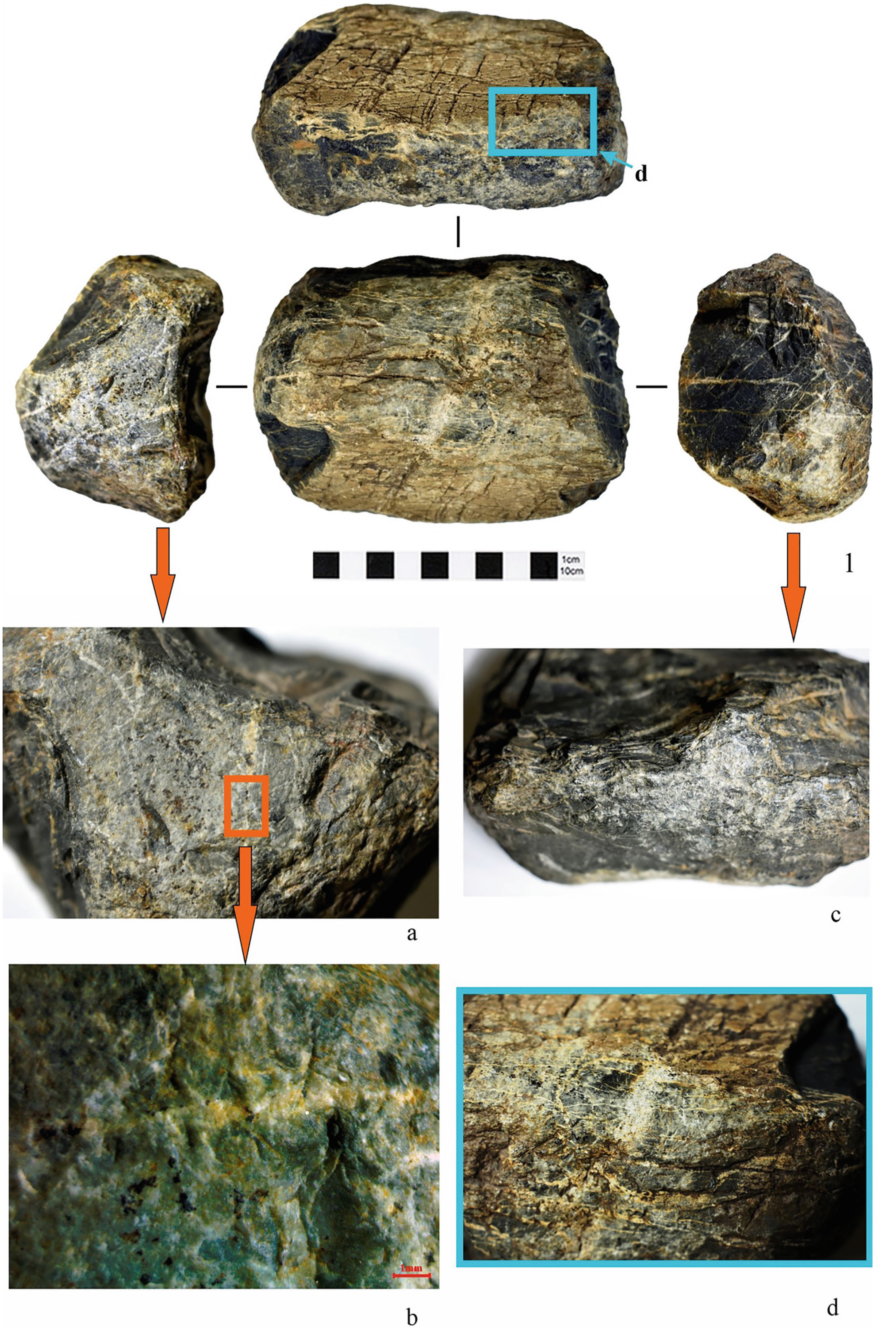

Fig. 4. A small hammer (#369). 1. Photos of the tool: a – macrophotography of the abrasion end of the tool; b – microphotograph of linear traces (magnification *10); c – macrophotography of end damage of the tool; d – macrophotography of edge damage

et al. 2002, p. 71–109). The researchers also suggest the division of the Excavation III of the Mikhailo-Ovsyanka I complex into the productive (mining and metallurgical) and household components. However, in this case, a chronological gap between the periods of their operation cannot be excluded (Matveeva et al. 2004, p. 76).

4 Conclusions

Mining and ore preparation processes and metalworking occurred in the Alakul settlement at the Vorovskaya Yama mine. We assume a different function of the two structures explored in the 2021 excavation: the mining and metallurgical specialization of Structure No. 1 and possible residence and household activities in Structure No. 2. The conclusions are preliminary because the area of the excavation is small, and the buildings have only been partially studied. Our hypothesis can be refined if the excavation area at the Alakul settlement of the Vorovskaya Yama mine is expanded.

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