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Mining under the early metal in the context of Kartamysh ore occurrence of Ukrainian Donbas

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Abstract

Purpose is to identify process engineering of mining under the Late Bronze age (18th-13th centuries BCE) in the context of copper deposits in the Eastern Ukraine. Among other things, it concerns analysis of manufacturing artifacts (i.e. ore production and preparation) in Kartamysh archeological area within the copper-ore territory of Bakhmut basin of Donbas.

Methods. Following methods have been applied: a comparative historical method supported by typological archaeological approach; statistical procedures; engineering and geological methods to determine extraction volumes and evaluate copper ore extraction from the mines in Kartamysh archaeological area as well as structural and technologic analysis; functional and typological analysis; traceological analysis; experimental modelling; and carbon dating.

Findings. Analysis of the specialized mining artifacts in Kartamysh archaeological area as well as mining artifacts within other copper-ore deposits in Bakhmut basin, extracted actively under the Late Bronze age, has made it possible to consider newly a number of important issues connected with process engineering of mining, specialization and labour division of ancient miners as well as evaluate significance of Donbas copper mines for the system of metal production development in the Eastern Europe of the second millennium BCE.

Originality. Analysis of Kartamysh archaeological area, where the majority of business performance objects are connected with mining, has helped the authors consider specialization of the industrial systems (i.e. different-purpose mine workings, various mining tools, and areas to prepare ore) right from the viewpoint of the production method. Since similar situation is typical for other Donets complex artifacts, being involved in scientific terminology as the mining and smelting one, it would be more reasonable to represent it as Donets ore mining system owing to its specialization in the integrated copper ore extraction and preparation.

Practical implications. The research results develop the history of mining science and engineering inclusive of ancient mining history in the Eastern Ukraine. They may be applied to train mining experts and in the process of creation of museum exhibitions (looking ahead, creation of Kartamysh skansen) while synthesizing technical and humanitarian aspects of engineering activities.

Keywords: *Donbas, archeological metallurgy, ancient mines, Kartamysh, stopes, copper ore, preparation, cultural heritage*

1. Introduction

Traditionally, the heighten interest of mining experts in the mining art origins and in cultural heritage of past eras is native to mining science and practice [1]-[7]. In Ukraine, the interest is intensified by the fact that within our territory, minerals have been extracted and processed since high antiquity. Unique surviving artifacts of mining and smelting activities, being of great scientific and cultural value, support the idea [8], [9]. For a long time, numerous studies of the mining and smelting activities of early metal period of the Eastern European steppe and forest steppe were focused on the analysis of metal-working manufacturing (5th-2nd millenniums BCE). First of all, it concerned typology of metal goods [10]-[13] and their production techniques [14]. The earliest mining and smelting artifacts (in many cases, they were parts of the unified system) were beyond heart and soul of research topics still remaining understudied by archeology. Issues of industrial engineering and ancient mining and smelting techniques during the paleometallic era continue to be areas of concern. Neither analysis nor importance of one of rare copper ore Eastern European territories being Bakhmut basin in Donbas, bearing authentic evidence to the ancient mining art of the Late Bronze Age (i.e. 18th-13th centuries BCE) has found out its proper place in the history of early facilities and educational material.

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As for the world scientific sources, territory of the modern left-bank Ukraine looks practically like a "gap" in the map of ancient mining artifacts [15] despite the availability of representative base of sources of mining and smelting artifacts accumulated during last decades. It depends heavily upon the lack of adequate international communication as well as scarce opportunities preventing Ukraine from influencing the global information processes (inclusive of the opportunity to make it through scientific papers in authoritative international publications). The paper, generalizing archaeological and engineering achievements of Kartamysh archaeological area studies (Popasna District of Luhansk Region) in addition to more than ten open seasons by the authors, is a step to turn thing around.

Field seasons of last decades (with the exclusion of occupation period of certain parts of Luhansk and Donetsk Regions) within the Dnipro-Don territory have helped found out numerous and expressive manufacturing units making it possible to reconstruct development of metal production inclusive of mining art by human population during Eneolithic-Bronze age within the Eastern European steppe and forest steppe area (5^{th}-2^{nd} millenniums BCE). Studies of mining by Timber-Grave Culture community (18/17^{th}-13^{th} centuries BCE) turned out to be particularly effective in light of excavation of production activity artifacts within Bakhmut basin copper-ore occurrence in Donbas. The initial period of small-area excavations within certain ore occurrences performed by S.I. Tatarinov in the last quarter of the 20^{th} century [16] gave information on the early not numerous mining and smelting sources of the Late Bronze age. A stage of systematic integrated studies of Kartamysh archaeological area studies (Popasna District of Luhansk Region) started at the outset of the 21^{st} century [8]. The stage turned out to be a watershed in the studies of mining, melting, and metalwork processes during the Late Bronze age within the Siverskyi Donets River basin as well as within the whole Dnipro-Don region.

2. Methods

Studies of Kartamysh system of mining and smelting artifacts involved the integrated approach based on the synthesis of archeological, strictly scientific, and engineering research methods.

Large-scale field analysis of ancient production activities within Kartamysh ore occurrence in Ukrainian Donbas were carried out from 2001 till 2010 by research groups of Donbas State Technical University and NASU Institute of Archaeology under supervision of Yu.M. Brovender. The archeological excavations were implemented step by step involving three underground stopes of Chervone Ozero-IV mine; three open pits of Chervone Ozero-I, Chervone Ozero-II, and Chervone Ozero-III mines; technogenic (preparation) site of Chervone Ozero-I mine; and two settlements of ancient miners Chervone Ozero-I and Chervone Ozero-III. The excavated ancient mine workings, other archaeological objects, and the obtained material created conditions for their scientific understanding.

Approaches of geological research were applied to determine extraction volumes and evaluate copper ore extraction from the mines in Kartamysh archaeological area [17]. The abovementioned took into consideration waste dump volume from the ancient level; the mined-out area within underground workings and surface workings; shape and conditions of the ore body occurrence; and copper content in ore.

The applied traceological analysis, being a study of wear traces (i.e. microwear of tool surfaces), has made it possible to identify their functional use [18]-[20]. In this context such optical facilities as microscopes and digital cameras were applied. The conclusions, drawn by tracers, were verified by means of the results of experimental modelling (among other things, ore preparation cycle). Experiments to analyze processes of dry concentration and wet concentration, participated by the authors, have been carried out [20], [21].

Formal and typological analysis has helped normalize and systemize the archaeological material as well as single out groups of typologically close production facilities and goods [21], [22]. Relying upon typologically close characteristics of the studied objects and articles and taking into consideration traceological data of the artifacts, functional and typological analysis has made it possible to identify features characterizing production specialization of the tools and, hence, an object within which the tools were found out.

Structural and technological analysis turned out to be important approach to study Kartamysh system. Its idea is identification of the area structure (i.e. specialization of the artifacts being components of the industrial area) as well as performance features of each of them [21].

Taking into consideration data of statistical processing of mining tools and other evidences of a smelting cycle of the industrial activities, structural and technological analysis has made it possible to identify product specialization of Kartamysh artifacts, their interconnection, and, finally, understand Kartamysh area of production artifacts as a system functioning within the single populated territory.

To date period, during which the mines were operated, radiocarbon analysis has been applied for bone tools of miners. The analysis was carried out by Kyiv radiocarbon laboratory of the Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine and Ministry for Emergency Situations of Ukraine (assayer N.N. Kovaliukh).

Use of the structural and technological analysis to compare Kartamysh with similar in time and culture mining and smelting systems within the Eastern-European territory has helped determine their common features as well as their differences.

3. Results and discussion

Analysis of the sources, representing metal production of the Early Metal Age (namely, mining, smelting, and metal working), of both ore-bearing territory of Bakhmut basin and the whole Dnipro-Don river valley makes it possible to achieve qualitatively new level of studying the problem of Donets mining and smelting point (DMSP) which successful solving is determined by means of a complex approach with the use of the current toolkit of natural-science and engineering research methods.

The sources of mining analysis during the Early Metal Age in the context of Kartamysh ore occurrence in Donbas like in the context of other Eurasian ore occurrences, mined in ancient times, differ in their nature. In total, they are divided into the two groups:

1) sources connected with a natural habitat of ancient nations;

2) archaeological sources connected directly with mining.

Having boundaries of their information potential, the source groups complement each other significantly.

Group one of the sources discloses features of mining origination and development within Bakhmut basin of Donbas during the Bronze Age relying upon geological conditions of the area. Being associated with the northern wing of Kartamysh syncline (i.e. the eastmost component of Bakhmut basin in the north-west end of Donets Ridge), Kartamysh ore occurrence is one of the largest and rich in low-melting deposit at the territory of the continuous synclinal structure. Archaeologically, its terrain is the most studied one.

Copper ore was extracted and prepared during the Bronze Age. The ore was developed from Kartamysh P1krt (Q) formation deposits of Lower Permian age characterized by the availability of cupriferous sandstone. The formation thickness is 500-900 m. It involves 6 "grey zones" being small (6-12 m) formations of grey or grey-green sandy and clay rocks standing out at a common red-brown background. Cupriferous mineralization is available within the "grey zones". Geologists suppose that Kartamysh mineralized target is the only one among all ore occurrences in Bakhmut basin having continuous mineralization within large areas [23]. Four ore levels with up to 0.8 m thickness and up to several km length have been prospected inside it. The levels are represented by lenticular bodies of solid and impregnated ore. Mineral composition of the ore is as follows: chalcosine Cu_2S; bornite Cu_5FeS_4 and chalcopyrite $CuFeS_2$ occur rarely. Malachite Cu Cu $(OH)_2$ $[CO_3]$ and azurite Cu_2 Cu $(OH)_2$ are well-developed within the oxidized zone [24]. Having up to 3 km outcrop, Kartamysh ore occurrence is characterized by the highest copper content: up to 3% of it is in ore bodies; and up to 60% is in solid ore. Numerous times, geologists mentioned its particular importance [23], [25].

Group two of the mining sources is represented by archaeological materials uniting evidence corresponding to extraction and ore preparation type of industrial activities. In terms of Kartamysh ore occurrence, extraction cycle involves mine workings and mining tools described in detail below.

3.1. Mine workings of Kartamysh ore occurrence

Four mines of Kartamysh ore occurrence are located along the upper share of cupriferous sandstone stretching west-to-east for almost 1 km (Fig. 1). Chervone Ozero-I is the last mine in the western part (2 km east from the village of Novozvanivka Popasna District Luhansk Region; Chervone Ozero-II is the last mine in the eastern part.

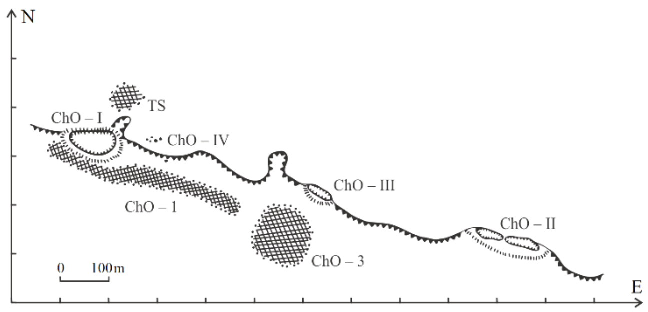

Figure 1. Surface plan of artifact location within Kartamysh archeological area: Ch – 1, 3 – settlements; ChO – mine workings; TS – technogenic site of Chervone Ozero-I mine

Copper ore within Kartamysh just like within other ore occurrences of Bakhmut basin, developed in the ancient times, has been extracted by means of two methods, i.e. using surface mining and underground one.

Researchers (especially geologists) explain different techniques of ore extraction depending upon the nature of an ore body occurrence. So, open pit mining is expedient to be applied for flat seams. In turn, underground mining is applicable for steep seams. Location of surface and underground mine workings within rather limited area (as it is observed in terms of Kartamysh ore occurrence) is not exclusive of geologist viewpoint. The geological cross sections, observed along outcrops of a ravine scouring the copper-ore kettleback as well as along walls of the excavated mine workings, demonstrate steep occurrence nature of the metalliferous seams. According to the data of geologists, Novozvanivsky thrust, located east of Kartamysh mineralization, affected the initial occurrence nature of ore-hosting rocks, varied its morphology, and resulted in the folded displacement as well as in faults [24]. Moreover, to some extent the availability of different ore mining procedures may involve efforts of ancient miners to make surface ore extraction less expensive but more complicated and dangerous, i.e. replace it with underground mining. However, the problem can be solved only after the analysis of the mine workings.

Marks of mine workings at the territory of copper ore occurrences of Bakhmut basin (which especially concerns the Late Bronze artifacts of Kartamysh area) are the marks of large scale ancient mining. Kartamysh relic open pits are particularly notable. They impress by their reasoning and expediency in the ore mining procedure selecting while speaking for excellence of ancient miners.

Open pit of Chervone Ozero-I mine is of elliptical shape. Its geometry is 100×70 m (Fig. 2). Thickness of the mined rocks is more than 6 m [22]. It has not been possible to determine occurrence level of the lithified Lower Permian deposits in its bottom share due to considerable hydraulic argillaceous depositions.

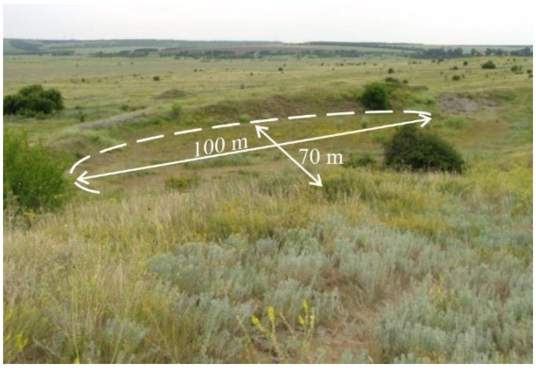

Figure 2. Open pit of Chervone Ozero-I mine

By estimation, based upon the results of complex geotechnological and archaeological studies, volume of the extracted rock mass in the open pit of Chervone Ozero-I mine is almost 6600 m^3; volume of the extracted high-grade ore is almost 400 m^3 [17].

Double open pit of Chervone Ozero-II mine, stretching west-to-east along a sand ridge edge, is the most extensive (Fig. 1). Geometry of its eastern pit is 138×12 m; its depth achieves 12 meters if depositions are involved. Geometry of its western pit is 62×18 m; its depth is down to 10 meters. Almost 3 meter width pillar (bulkhead) is established between the workings. Availability of the pillar may speak for ore body thinning there as well as for convenient arrangement of ore transportation through the open pit.

In terms of the open pit of Chervone Ozero-II mine, volume of the extracted rock was more than 20000 m^3; and volume of high-grade ore was more than 370 m^3 [17].

The third open mine working of Chervone Ozero-III mine is of the oval shape oriented north-easterly. Its geometry is 85×19 m in terms of 6 meter depth (Fig. 1). Volume of the extracted rock mass was more than 3000 m^3; and volume of the mined high-grade ore was almost 46 m^3 [17].

Underground mine workings of Chervone Ozero-IV mine, including 5 objects, were located in the ore-bearing sandy crest. At the surface, they were registered in terms of cone-shaped depressions with 2 to 8 diameter and down to 2 m depth (Fig. 3).

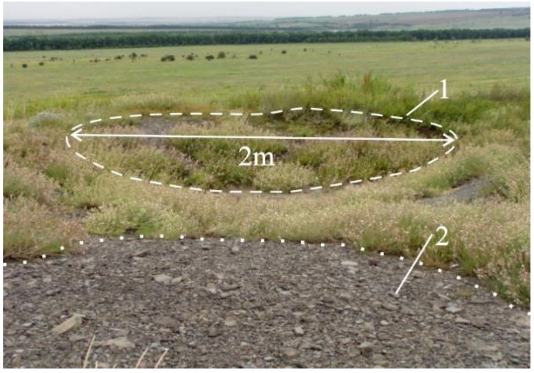

Figure 3. Chervone Ozero-IV mine. Marks of underground-type mine working (1) and waste dump (2)

Compactness of their location (Fig. 1) supports the idea that the extraction was performed by means of small mine workings in the form of mine shafts [26] interconnected with the help of horizontal roadways (mine workings *1* and *2*). The majority of researchers from different ore regions mention that density of the underground mine workings can be explained by prospecting and operational activities of ancient miners. Then, Ye.N. Chernykh and Ye.Yu. Lebedeva suppose that the accumulation of open mine workings as well as the underground ones within Kargaly ore field in the Southern Urals was first stipulated by dispersion and diversity of ore nests being typical for such a mineralization type as well as difficulties connected with prospecting of new ore deposits [27]. Moreover, the compactness of mine workings is considered by researchers as the expediency involving rational labour organization when the mined-out area was backfilled using rock from a new mine working [28]-[31]. The abovementioned is another example demonstrating that motivation of such reasonable practicality dominated when ancient miners were selecting a technique for copper ore extraction.

Availability of natural ventilation is important moment in the process of mining organization. Lack of aeration at the depth of ore body occurrence thins down its efficient mining. Ventilation was performed using breakthrough of two neighbouring day mine workings. Since ancient miners could not deal with underground water effectively, copper ore was extracted up to its level. In the context of Kartamysh, underground water level was recorded at almost 15 m depth from the day surface when its artifacts were excavated.

Within a mine shaft, and some distance from it ore was developed in the form of roadways which remove from the shaft made mining more dangerous. In turn, it stipulated the necessity to drive a new shaft and extract an ore-bearing seam with the help of short branching roadways.

Working *1* of Chervone Ozero-IV mine is the most studied one in the context of Kartamysh ore occurrence as well as in the context of the whole mineralization territory of Bakhmut basin in Donbas (Fig. 4).

Figure 4. Chervone Ozero-IV mine. Working 1

A shaft of the sloped collar deepening on the angle of strata inclination, being 50-55º, was located at the depth of 3.8 m from the surface. Partially, it was packed with red clay. Cavities, resulting from rainwater and melt water washing, were observed in some areas. Collar width of the inclined shaft corresponds to the width of southern wall of the shaft (almost 1.5 m); perhaps, it changes with the depth. Its height is almost 1 m. Early in the last century, similar geometry of a day drift with coal residuals and pottery fragments were found out within Kargaly. The day drift is the depth of 22 m; its length was 260 m [32]. A horizontal roadway, directed towards neighbouring mine working 2, is in the western wall of the working *1* of Chervone Ozero-IV mine. Maybe, copper ore was mined using several levels. However, the complex archaeological and engineering activities, carried out in Kartamysh, prevents from drawing such a conclusion.

The evidence weight suggests that the working *1* is the ancient one. The idea is supported by burial of an ancient miner [26] (Fig. 5). It has been found out in a peculiar "pocket" within the southern share of the plumb shaft deepened into the parent material by 2.7 m.

Figure 5. Chervone Ozero-IV mine. Burial place 1

Human skeleton was in a crouched position lying on its left side with the head southeast. Molded pottery vessel was behind the back near the skull. In the face of the buried man, animal rib has been found out which state prevented from making a traceological analysis. Pieces of the prepared copper ore as well as animal ribs looking much like bone tools, represented massively within the technogenic area of Chervone Ozero-I mine, call attention to themselves. The buried man lied under thick stone mass among which numerous animal bones of five domestic oxen and fragments of one more molded pottery vessel have been found out.

The obsequies and ceramics nature speak for the deceased person belonging to the members of the Late Bronze Age Berezhnovka-Mayovka Timber-Grave Culture. Bones of the buried person were subject to radiocarbon analysis. Average index is a value in the range of 1600-1562 BCE.

Thus, while generalizing the available geological, geotechnological, and archaeological data, one can mean rather high level of mining operations by ancient miners during the Late Bronze Age in the context of Donets Ridge. The idea is supported by the consideration of such specific geological features of the mined mineralization as: shapes and dimensions of ore body occurrence; ore grade; enclosing rock hardness; topographic features etc.

A plant site for the initial ore preparation and separation was located in the neighbourhood of the underground mine workings. Moreover, a waste dump (Fig. 3) was also placed there containing finely-fragmented rock mass inclusive of oxide-bearing ore and primary ore (i.e. chalcosine) pieces. The dump area is several tens of cubic meters.

Taken as a whole, total mining output of three open pits (i.e. Chervone Ozero-I-III*)* was no less than 30000 m^3; volume of the mined copper ore was almost 817 m^3. Taking into consideration underground extraction in Chervone Ozero-IV mine, ore output within Kartamysh basin achieved almost 1000 m^3.

It is clear that the necessity to keep secrets of mining mystique (supported by the Bible and more recent ethnographic evidence of the late XIX – early XX centuries) as well as sacral factors [33] (highlighted repeatedly by researchers [28], [29], [32]) may explain the tendency that miners, operated in open pits of Eurasian steppe, filled (covered) traces of their activities and daily life after they left the territories of ore development. In this context, lack of a cultural layer beyond the area of production structures, should be mentioned. The whole archaeological material has been revealed exclusively within the area of structures (workshops) or within the packing of neighbouring holes. Overburden operations, performed using test pitting procedure beyond the structures, were almost ineffectual from the viewpoint of archaeological material searching. It looks like we face again the rule when ancient miners should comply obligatory with the top secrecy requirements.

Working *2* of Chervone Ozero-IV mine and technogenic site of Chervone Ozero-I mine demonstrate complex system of production cult of ancient miners in terms of Kartamysh area. Accordingly, five burial places of skeletons of small cloven-hoofed animals have been found out; one skeleton has been found out in the upper layer of a cultural layer of the technogenic site. Definitely, the animals were sacrificed after intensive extraction and preparation stages were terminated. Nevertheless, animal sacrifices were common practice in the Kartamysh settlements of ancient miners during their lifetime. The sacrificial stone altars, found out in the neighbourhood of structures of Chervone Ozero-I settlement (Fig. 6) almost adjoining southern and southwest slopes of a waste dump of Chervone Ozero-I mine, afford ground to speak to the fact that the cults, connected with the mining operations by ancient Kartamysh miners, were worshiped near every production structure in virtue of their prime importance.

Figure 6. Chervone Ozero-I settlement: 1 – production structure with altar; 2 – sacrificial stone altar

The altars were made of large quartzitic sandstone; their weight was almost 150 kg. The upper share of each altar had a hollow transforming into a trough to the edge. Their geometry was 0.7×0.5×0.6 m. Externally, the sacrificial stone altars look like the hafted hammer being ancient mining tool.

Radiocarbon analysis of animal bones from working *2* packing material of Chervone Ozero-IV demonstrated average index in the range of 1645-1662 BCE.

3.2. Technogenic site of Chervone Ozero-I mine

After copper ore was prepared primarily and graded within the production sites, neighbouring mine workings, it was transported to a specific water-intake area for its further preparation to produce copper-ore concentrate being ready for metallurgical treatment (Fig. 1).

The technogenic site of Chervone Ozero-I mine is in the ravine fragmentation on the upland slopeside where melt water and rain water wash down by force of the landscape features. To use them for water treatment, a trench has been excavated at the territory of the production area (Fig. 7).

Figure 7. Technogenic site of Chervone Ozero-I mine: 1 – technological trench for water treatment (lower stratigraphic level)

Stratigraphically, it is the earliest one among the studied systems. The trench stretched southwest-northeast at more than 12 m length. It has been analyzed partially. Its width is 1.6-2.2 m; and its depth is 0.4-0.6 m. The trench is filled up with cupriferous sandstone sand, at the bottom of which sporadic fragments of stone and bone tools have been found out. The abovementioned can be considered as another evidence of the advanced achievements of ancient miners of Donets Ridge, i.e. use of water treatment to separate ore and waste rock.

Altogether, 210 square meters of the excavated area of the technogenic site have demonstrated three stratigraphic levels being complying with the production facilities: early level (i.e. technological trench); intermediary level (i.e. structures 2 and 4); and the late one (i.e. structures 1 and 3). The structures 1 and 3, studied partially, were recorded in the western wall profile of the excavation site occupying upper terrace share. Almost parallel arrangements of ditches of structures 2 and 4 have been found out within a lower terrace. Partially, 1 and 3 ditches bridged them over. Probably, the 2 and 4 structures are two chambers of one and the same production system.

Mainly, goods within the technogenic site of Chervone Ozero-I mine are represented by bone and stone tools. The set of stone tools, analyzed traceologically [18]-[20], consists of 184 items. Four groups are singled out from the viewpoint of functionality. Three of them are successive metal production cycles inclusive of tools for mining (23.6%), preparation (75.4%), and metal processing (1.2%) cycles. Group four consists of stone-working tools (2.1%).

According to expert traceological opinion, tools of a mining cycle are represented by pick axes (13 items); mining picks (8 items); and hammers (17 items) (Fig. 8). Practically, each of them is made of hard quartzitic sandstone and has approximate signs of wear. Pick axes, differing in wide end of the sharpened work surface, were applied for overburden operations. Roundly oblate or almost rectangular mining picks, differing in narrow wedge-like working surface, were used to loosen compact rocky ground. Solid hammers of trapezoidal or almost rectangular forms were applied while mining, separating prills from solid mass, and their primary disintegration.

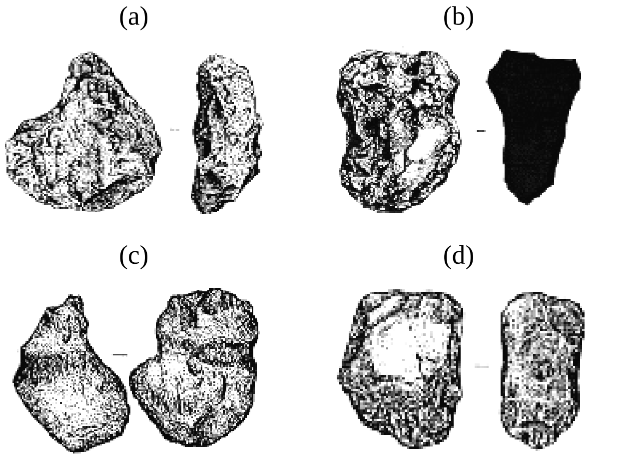

Figure 8. Kartamysh archaeological area (mining cycle tools): (a) pick axe; (b) mining pick; (c), (d) hammers; (a), (c), (d) tools from technogenic site of Chervone Ozero-I mine; (b) tool from Chervone Ozero-I settlement

There is the evidence to suggest that metal tools were used for mining cycle of industrial activities in Kartamysh. The idea is supported by the rock, bearing the marks of metal tool impacts, excavated within the technogenic site. Moreover, the traces, being in open view, have both wide and narrow hollows. Within the Donets mining and metallurgical territory, a fragment of a mould of the socketed end has been excavated. The fragment bears a direct relation to the mining cycle at the territory of Chervone Ozero-III settlement belonging to Kartamysh area. Similar tool is also known within Pylypchatyno-I settlement of Kysly Bugor ore occurrence [16].

The three functional types are singled out among the tools, applied for preparation cycle at a technogenic site of Chervone Ozero-I mine: ore breaking/ore grinding plate (20 items), grinding tamper (100 items), and fastened tamper (1 item) (Fig. 9). Mainly, ore braking/ore grinding plates are made of cupriferous sandstone. The only tool (5%) is made of quartzite. The tools are of various forms. Their feature is availability of a hollow, i.e. a niche with 3 to 6 cm diameter and 0.6 to 1.7 cm depth. The considered tools have one- and two-sided work surfaces. Mainly, grinding tampers, being tools of active manual actions, are made of cupriferous sandstone; only 9% of tools of the functional type are made of quartzite. Their characteristic feature is represented by one or several grinded down sides. The fastened tamper is a quartzite tool of active operation. It is of oval shape; it has a flattened place for a haft as well as shallow flutes for lashing belts.

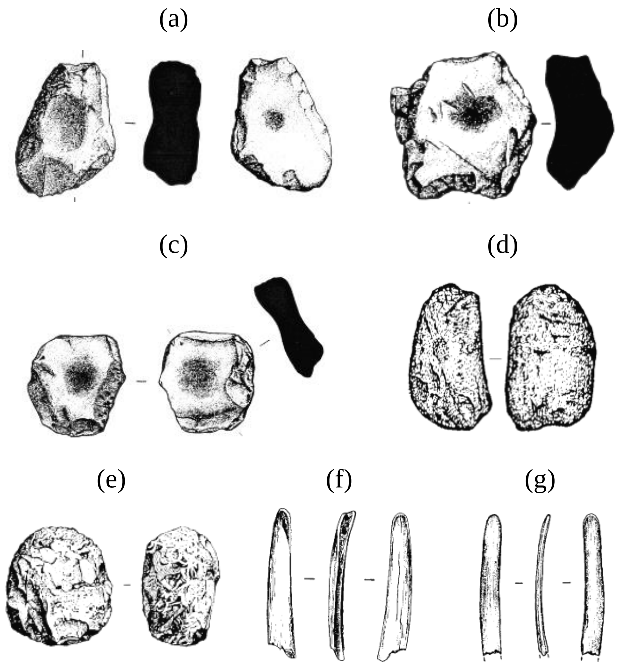

Figure 9. Kartamysh archaeological area (tools of a preparation cycle): (a), (b), (c) ore breaking/ore grinding plates; (d), (e) grinding tampers; (f), (g) bone separators; (a), (b), (c) tools from Chervone Ozero-I settlement; (d), (e), (f), (g) tools from technogenic site of Chervone Ozero-I mine

Tools of metal-processing cycle are the smallest group within the technogenic site of Chervone Ozero-I mine (2 items). Thus group is represented by two functional types: abrasives and hammer anvil. Stone-processing tools are quartzite hummer stones. Being not numerous (1%), their collection at the technogenic site speaks for operative tool repair in case of failure rather than for mining tool manufacturing in the context of the site.

Bone tools are the most numerous ones at the technogenic site of Chervone Ozero-I mine (Fig. 9). Their total number is 399 items. Tools, engaged in ore separation, are the largest group. Mainly, they are made of animal ribs (319 items). They were applied to mix the grinded and rubbed ore with the use of animal skins (97.9%). Traceological analysis of the bone tools with specific polished edges, carried out by O.N. Zagorodnia [20], and simulation of water treatment has supported suggestions of I.V. Gorashchiuk and V.B. Pankovski on the functional use of animal ribs as tools in the process of copper ore water treatment.

Piercings (4 items) and pricker (1 item) are one-piece bone products within the technogenic site. Their availability speaks for repair of leather bags or sacks being important tools required for ore transportation. Such a leather 52-40 cm bag, holding up to 20 kg of copper ore, was found out in one of the workings of Gumelnitski mine in the Urals [34].

Bony chip in the materials of technogenic site of Chervone Ozero-I mine can be considered as an oracle bone. Broad range of such goods has been found out within Gornyi settlement of Kargaly mining and smelting area [35]. Dangerous and risky everyday working life of an ancient miner was closely connected with goetic rituals. The oracle bone is one of such cultic attributes.

Melting proofs have also been found out among the materials of the technogenic site of Chervone Ozero-I mine. Their total number is 43 items. Skulls (17.3%), matte plates (62.8%), blocks of scorified stone (6.8%), and fragments of the scorified ceramics (i.e. melting pots) (3.15%) are among them.

The tools as well as the evidence, representing the basic cycles of ancient metal fabrication (i.e. extraction, preparation, and metallurgical) in the context of one production (technogenic) site, speak for high potential of metal fabrication of Kartamysh area inhabitants under the Late Bronze Age. Similar facility, complemented by metal processing signs, has been found out in the settlement of Chervone Ozero-III and inside other significant sites within the copper ore occurrences of Bakhmut basin (i.e. Vyskrivka, Klynove, and Pylypchatyno-1,2) [16]. It is understandable that miners of the Donets mining and metallurgical site under the Late Bronze Age could operate as melters, moulders, and iron forgers. Beyond Donets site, similar specializations are demonstrated by the inhabitants of Usove Ozero settlement on the Siverskyi Donets River [36] and Mosolovske settlement on the Bityug River [37] where foundry men lived and worked.

Hence, the technogenic site of Chervone Ozero-I mine represents evidence of each metal fabrication cycle. However, their total number (92.5%) is connected with ore treatment (i.e. preparation). Such specialization of the significant site is supported by concentration of small fragments of cupriferous sandstone used as rubbing stones, technological trench, and of course, significant volume of the rubbed sand of the cupriferous sandstone being waste of production operations. Technogenic site location was selected with the focus on the extraction and preparation specialization. Ancient miners used landscape features to accumulate melt water and rainwater for water treatment of copper ore mined in the neighbouring workings.

Calculation of the high-grade copper ore, extracted from an open pit of Chervone Ozero-I mine speaks for almost 400 m^3 of the ore, prepared within the technogenic site. If the amount is added by 200 m^3 of ore, extracted in the neighbouring Chervone Ozero-IV mine, the volume becomes more impressive since it achieves just about 600 m^3 [17]. From our viewpoint, technogenic sites neighboured each Kartamysh mine as well as other mines of Donets facility. To some extent, the suggestion is supported by analysis of a mine working-1 within Midna Ruda ore occurrence near which extensive in length technogenic layer of the rubbed cupriferous sandstone has also been found.

While generalizing the range of sources, coming from the industrial sites neighbouring mine workings of Chervone Ozero-IV mine, it is possible to state that in terms of the technogenic site of Chervone Ozero-I mine in Kartamysh area, ancient miners of Donets mining and metallurgical field performed several technological operations as for the ore preparation under the Late Bronze Age. Ore separation from waste rock in the area of mine workings and ore grinding down to small grains as well as water treatment within the technogenic site are among them. Copper ore, being ready for melting raw material, was the finished product. The technological operations with copper ore, identified within Kartamysh, support earlier observations obtained by researchers in different copper ore Eurasian regions.

Totality of the data, resulting from the research, makes it possible to associate the technogenic site of Chervone Ozero-I mine with population of Berezhnovka-Mayovka Timber-Grave Culture. Animal bones from the technogenic site of Chervone Ozero-I mine helped obtain seven radiocarbon dates. Their average index is 1675-1663 BCE.

Taking into consideration the features of Kartamysh ore occurrence as well as the level of processing capabilities of ancient metal makers under the Late Bronze Age, the copper amount, melted using Kartamysh ore, could achieve up to 160 tons in terms of complete extraction [17]. Even if one may assume that only five ore occurrences (i.e. Vyskrivka, Klynove, Kartamysh, Kyslyi Bugor, and Midna Ruda) were involved in extraction operations within Bakhmut basin, consideration of the data, obtained in terms of Kartamysh, helps conclude that the total output of Donets metal, melted under the Late Bronze Age, could be 700 tons [21]. Taking into consideration almost 500-year period of copper extraction in Bakhmut basin of Donbas by population of Berezhnovka-Mayovka Timber-Grave Culture (18/16th-13th centuries BCE), it becomes possible to evaluate approximately the total copper ore extraction output under the Late Bronze Age. Equivalently, it could correspond to 1.5-2.0 tons of copper a year on the average; moreover, more active copper ore extraction accounted for the first period of Berezhnovka-Mayovka Timber-Grave Culture (i.e. 18/17th-15th centuries BCE).

Yu.S. Grishin provides statistics being quite important for the research. The figures make our calculations on Donets area close to actual ones. Thus, in ancient Egypt, average annual amount of copper, melted under the Bronze Age, was 7 tons; it was 16.5 tons in the Western Europe and several tons in the Eastern Kazakhstan [34].

Hence, relying upon the Late Bronze Age data, copper production output within Kartamysh was rather significant.

4. Conclusions

Analysis of mining artifacts in terms of Bakhmut basin of Donbas (firstly, ancient Kartamysh mines) makes it possible to consider the Eastern Ukraine territory as not numerous global ore extraction areas under the Early Metal Age. Nature of surface mine workings as well as the underground ones and extraction tools as well as preparation ones speak for immensity and high (for its time) level of mining and ore preparation methods. It seems that metallurgy with its little evidence played a supporting role to provide ancient miners with metal mining tools or perform experimental melting in the process of ore grade evaluation. Major part of the prepared ore was transported to the special-purpose settlements of moulders located within a territory rich in firewood (like Usovo Ozero settlement on the Siverskyi Donets River).

Sacral organizational and motivational components of mining activities in the stable isolated groups of miners and metallurgists of Timber-Grave Culture community are rather high. The viewpoint is supported by numerous sacral artifacts at the territory of Kartamysh area.

Comprehensive analysis of the evidence of production activities of both Kartamysh system and other ancient industrial complexes of the region makes it possible to reconsider the approach as for the industrial structure functioning within the copper ore territory of Bakhmut basin in Donbas under the Bronze Age. In the scientific community, the structure is known as Donets mining and smelting area of the Bronze Era. Nevertheless, Donets mining area is more correct name since it focuses on the integrated extraction and preparation of copper ore. Basically, metal was smelted beyond it.

Unluckily, currently territory of the mines is in a “grey zone”, i.e. area of the armed conflict in the east of Ukraine. Hence, access to the artifacts as well as projects to establish “Kartamysh” skansen are put off indefinitely.

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Гірничий промисел в епоху раннього металу на Картамиському рудопрояві українського Донбасу

Ю. Бровендер, Г. Гайко, О. Бровендер

Мета. Виявлення особливостей технології та організації гірничого промислу в епоху пізньої бронзи (XVIII-XIII ст. до н.е.) на мідних родовищах Східної України, зокрема – аналіз пам’яток виробничої діяльності (видобутку і збагачення мідної руди) Картамиського археологічного мікрорайону на міднорудній території Бахмутської улоговини Донбасу.

Методика. Використовувались наступні методи дослідження: порівняльно-історичний метод, підсилений типологічним методом археології, статистичні методи, інженерно-геологічні методи визначення обсягів гірничих робіт і оцінки видобутку мідних руд в копальнях Картамиського археологічного мікрорайону, а також методи структурно-технологічного й функціонально-типологічного аналізу, трасологічного аналізу, експериментального моделювання та радіовуглецевого датування

Результати. Вивчення спеціалізованих пам’яток гірничого промислу Картамиського археологічного мікрорайону, а також пам’яток гірничодобувної діяльності на інших мідних родовищах Бахмутської улоговини, що активно розроблялися в епоху пізньої бронзи, дозволило по-новому розглянути низку важливих питань, пов’язаних з організацією і технологією гірничого промислу, спеціалізацією і розподілом праці давніх гірників, оцінити значення мідних копалень Донбасу в системі металовиробництва Східної Європи ІІ тис. до н.е.

Наукова новизна. Дослідження пам’яток Картамиського археологічного мікрорайону, де основна кількість об’єктів виробничої діяльності пов’язана з гірничим промислом, дозволило розглянути спеціалізацію давніх виробничих комплексів (гірничих виробок різного призначення, різноманітних гірничодобувних знарядь, технологічних майданчиків збагачення руд). Оскільки аналогічна ситуація простежується і на інших пам’ятках Донецького центру, що увійшов до наукового обігу як гірничо-металургійний, коректнішим представляється назвати його Донецьким гірничорудним центром пізньої бронзи, оскільки він спеціалізувався переважно на видобутку й переробці мідних руд.

Практична значимість. Результати роботи розвивають історію гірничої науки і техніки, зокрема давню історію гірництва на Сході України. Вони можуть бути використані для підготовки фахівців гірничого профілю, для створення музейних експозицій (у перспективі – створення скансена Картамиш) і синтезуватимуть технічні та гуманітарні аспекти інженерної діяльності.

Ключові слова: *Донбас, археометалургія, давні копальні, Картамиш, гірничі виробки, мідні руди, збагачення, культурна спадщина*

Горный промысел в эпоху раннего металла на Картамышском рудопроявлении украинского Донбасса

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Цель. Выявление особенностей технологии и организации горного промысла в эпоху поздней бронзы (XVIII-XIII вв. до н.э.) на медных месторождениях Восточной Украины, в частности – анализ памятников производственной деятельности (добычи и обогащения медной руды) Картамышского археологического микрорайона на меднорудной территории Бахмутской котловины Донбасса.

Методика. Использовались следующие методы исследований: сравнительно-исторический метод, подкрепленный типологическим методом археологии, статистические методы, инженерно-геологические методы определения объема горных работ и оценки добычи медных руд в рудниках Картамышского археологического микрорайона, а также методы структурно-технологического и функционально-типологического анализа, трасологического анализа, экспериментального моделирования и радиоуглеродного датирования.

Результаты. Изучение специализированных памятников горного промысла Картамышского археологического микрорайона, а также памятников горнодобывающей деятельности на других медных месторождениях Бахмутской котловины, активно разрабатываемых в эпоху поздней бронзы, позволило по-новому рассмотреть ряд важных вопросов, связанных с организацией и технологией горного промысла, специализацией и разделением труда древних горняков, оценить значение медных рудников Донбасса в системе развития металлопроизводства Восточной Европы II тыс. до н.э.

Научная новизна. Исследование памятников Картамышского археологического микрорайона, где основное количество объектов производственной деятельности связаны с горным промыслом, позволило авторам именно в этом виде производства рассматривать специализацию производственных комплексов (горных выработок различного назначения, разнообразных горнодобывающих орудий, технологических площадок обогащения руд). Поскольку аналогичная ситуация прослеживается и на других памятниках Донецкого центра, вошедшим в научный оборот как горно-металлургический, более корректным представляется называть его Донецким горнорудным центром, поскольку он специализировался на комплексном производстве по добыче и переработке медных руд.

Практическая значимость. Результаты роботы развивают историю горной науки и техники, в частности древнюю историю горного дела на Востоке Украины. Они могут быть использованы для подготовки специалистов горного профиля, использованы при создании музейных экспозиций (в перспективе – создания скансена Картамыш) и будут синтезировать технические и гуманитарные аспекты инженерной деятельности.

Ключевые слова: *Донбасс, археометаллургия, древние рудники, Картамыш, горные выработки, медные руды, обогащение, культурное наследие*