ISSN 2635-1676, Nanobiotechnology Reports, 2022, Vol. 17, No. 5, pp. 629–637. © Pleiades Publishing, Ltd., 2022.
Russian Text © The Author(s), 2022, published in Rossiiskie Nanotekhnologii, 2022, Vol. 17, No. 5, pp. 616–624.

METHODS OF NATURAL SCIENCES IN THE STUDY OF CULTURAL HERITAGE OBJECTS

Stone Artifacts of the Bronze Age: Analysis of the Mineral Composition and Determination of Resource Ranges

P. I. Kalinin[a,*] **(ORCID: 0000-0002-7252-2997), N. I. Shishlina**[b,c] **(ORCID: 0000-0001-9638-0156), A. Yu. Loboda**[d,e] **(ORCID: 0000-0003-4926-1140), I. N. Trunkin**[d]**, E. S. Kulikova**[d] **(ORCID: 0000-0003-1702-9435), R. D. Svetogorov**[d] **(ORCID: 0000-0003-0360-1023), A. M. Ismagulov**[e]**, E. Yu. Tereschenko**[d,e,f] **(ORCID: 0000-0001-5035-6978), and E. B. Yatsishina**[d,e] **(ORCID: 0000-0001-7652-7253)**

[a] *Institute of Physicochemical and Biological Problems in Soil Science, Russian Academy of Sciences, Pushchino, Moscow oblast, 142290 Russia*

[b] *State Historical Museum, Moscow, 109012 Russia*

[c] *Peter the Great Museum of Anthropology and Ethnography (the Kunstkamera), Russian Academy of Sciences, St. Petersburg, 199034 Russia*

[d] *National Research Center "Kurchatov Institute", Moscow, 123182 Russia*

[e] *Institute of Chemical Reagents and High-Purity Chemical Substances (IREA), National Research Center "Kurchatov Institute", Moscow, 107076 Russia*

[f] *Shubnikov Institute of Crystallography, Federal Scientific Research Center "Crystallography and Photonics," Russian Academy of Sciences, Moscow, 119333 Russia*

**e-mail: kalinin331@rambler.ru*

Received February 15, 2022; revised July 4, 2022; accepted July 4, 2022

Abstract—The mineral composition of stone artifacts from the collection of the Historical Museum from monuments of the Bronze Age in the North Caucasus and the adjacent steppe is determined by comprehensive instrumental analysis. It is found that three stone axes from the North Caucasus are made of serpentinite of local origin. A mace and straightener for arrow shafts found in the Republic of Kalmykia are made of Ergeninsky sandstone that is widespread on the territory of the Ergeninsky Upland. Two more items from sites of the Republic of Kalmykia (a mace and ax) are made of amphibolite that could have been mined in the deposits of the Ukrainian Shield in the Azov Lowland. The ancient population predominantly used for the manufacture of artifacts raw materials of local origin or from neighboring regions, where groups of mobile pastoralists could migrate as part of seasonal movements. It is probable that, at that time, Caucasian items did not find their way into the steppe as often as previously assumed.

DOI: 10.1134/S2635167622050056

INTRODUCTION

In the Bronze Age, the population of various regions widely used stone items, placing special emphasis on their color. Axes, maces, scepters, and other symbols of high social status and authority as well as labor tools were fabricated from them. The determination of the rock types and probable sources of raw-material resources makes it possible to find out the movement patterns of individual subgroups within the general population inside and outside developed territories, to identify trade routes, and to understand, where the raw materials could originate from, and the craftsmen of which cultures could fabricate certain items. This makes it possible to evaluate the system of relations among the population of different regions.

Both archeologists and museum staff often visually determine the rock type of a stone. For example, archeologists often use a common term serpentine to assess the rock type of an item based only on its green color [1] or limestone, based on the fact white it is white. There is yet no accurate scientific determination of the rock type of the stones, from which the famous axes from the Hoard L from Troy are fabricated. Notations such as *nephritoid* and *jadeitite* migrate from one book to another [3, 4]. Moreover, even the application of some methods, e.g., electron probe microanalysis and the calculation of microdiffraction patterns, turns out to be not always sufficient and leads to errors in rock-type determination. This happened with the identification of the rock type when studying axes from the Borodino Treasure of the

Table 1. Study objects

Sample	Museum number	Site	Item	Culture
North Caucasus				
1	GIM86417/1 A 1302/1	Nal'chik	Ax	North Caucasian
10	GIM509809/1 A 1302/1	Nal'chik	Ax	North Caucasian
11	GIM766990/215 A 1234/30	Pyatigorsk area	Ax	North Caucasian
Kalmykia, steppe regions of the Kuma–Manych Depression and Southern Ergeni				
6	GIM103500/125 A 1908/125	East Manych, left bank, III, burial mound 23, burial site 4	Macehead	Catacomb
2	GIM110078/101 A 2266/101	Mu-Sharet-4, burial mound 13, burial site 4	Ax	Pit Grave
6	GIM103500/125 A 1908/125	East Manych, left bank, III, burial mound 23, burial site 4	Macehead	Catacomb
7	GIM103500/372 A 1908/372	East Manych, left bank, 1965 burial mound 21, burial site 12	Straightener for arrow shafts	North Caucasian

II millennium BC from the collection of the Historical Museum. Based on the results of initial studies by scientific methods, a conclusion was obtained, according to which the axes are made of nephrite from the deposits of the Western Sayan Mountains [5]. Within this same study, the researchers came to the conclusion that the maces from the Borodino Treasure are fabricated from talc (ibid). The performed comprehensive study showed that the axes are made of serpentinite and jade, and the maces, from white antigorite, a silicate from the group of serpentine [6].

Because of this, accurate and well-reasoned determination of the rock types and their origin remains relevant. The specific tasks set in this study consist in carrying out a comprehensive analysis of stone items originating from the collection of the Historical Museum from sites of the Bronze Age in the North Caucasus and the adjacent steppe. This makes it possible to not only determine the rock type, from which the items are fabricated, but also to discuss which items could have been fabricated by steppe and North Caucasian groups from the local rock types and what could have probably been fabricated in different regions.

EXPERIMENTAL

Seven stone items of the Bronze Age kept in the collection of the Historical Museum were selected for the study (Fig. 1). These were axes, maces, and a so-called straightener for arrow shafts. All the burial sites, from where the items originate, belong to the middle–latter half of the III millennium BC (Table 1). Two regions were selected, namely, sites located in the foothills of the North Caucasus (Nalchik, Pyatigorsk area) and steppe regions of Kalmykia (Kuma–Manych Depression, Southern Ergeni) (Fig. 2).

The samples were collected using a metal tool from the internal side of the sleeve or from the surface of the item. A set of methods was applied for the study: X-ray diffraction analysis, scanning electron microscopy (SEM) with energy-dispersive X-ray microanalysis (EDXMA), inductively coupled plasma mass spectrometry (ICP-MS), and inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

The phase composition of the stone items was studied at room temperate on the X-ray diffraction analysis station of the Kurchatov synchrotron radiation source. A Rayonix SX165 position-sensitive detector located at a distance of 80 mm from the sample perpendicular to the incident X-ray beam was used for the recording of the two-dimensional diffraction patterns. The measurement time of one diffraction pattern was 2 min, the wavelength of the incident monochromatic radiation was 0.74 Å, and the size of the photon beam was 400 μm^2. The obtained two-dimensional patterns led to the standard form for powder diffraction patterns $I(2\theta)$ due to azimuthal integration in the Dionis program. The phase composition was determined using the PDF–4+ database by the method of corundum numbers.

The main elemental composition of the samples was determined by SEM-EDXMA. The measurements were performed on a VERSA 3D dual beam scanning electron–ion microscope (Thermo Fisher Scientific) with an annular backscattered-electron (BSE) detector combined with an EDX microanalyzer: a Si(Li) detector (EDAX). Recording was per-

Fig. 1. Stone items of the Bronze Age: (*1*) Nalchik, excavations by N.K. Kirillov, 1886; (*2*) Nal'chik, incidental find; (*3*) Pyatigorsk okrug, excavations by D.Ya. Samokvasov; (*4*) burial mounds of the East Manych, right bank, 1967, burial mound 11, burial site 27, excavations by I.V. Sinitsyn; (*5*) Mu-Sharet-4 burial ground, burial mound 13, burial site 4, excavations by N.I. Shishlina; (*6*) burial mounds of the East Manych-III, 1966, burial mound 23, burial site 4, excavations by I.V. Sinitsyn; and (*7*) burial mounds of the East Manych-I, 1965, burial mound 21, burial site 2.

formed at a low pressure (70 Pa) at an accelerating potential of 30 kV and a current of 45 nA.

The concentration of trace impurities was determined by ICP-MS and ICP-AES.

Sample preparation: a weighed amount of the sample (0.1–5 mg) was dissolved in a MARS 180°C microwave digestion system in a mixture of nitric and hydrofluoric acids with a ratio of 1 : 1. The obtained solution with a precipitate was quantitatively transferred into a glassy carbon crucible and 1 mL of H_2SO_4 was poured. It was evaporated to the vapors of sulfuric acid, 2 mL of HNO_3 was added, and it was diluted with water and heated. After this, the obtained solution was quantitatively transferred into a polypropylene tube, and the volume of the sample was adjusted to 50 mL.

The obtained solutions were analyzed by ICP-MS and ICP-AES:

(i) the ICP-MS measurements were conducted on an ElanDRC-e mass spectrometer (Perkin Elmer). The analysis was performed using an ICP-MS-3-10 multielement calibration reference standard (5% HNO_3) (High-Purity Standards) using the Total-Quant method;

(ii) the ICP-AES measurements were conducted on an iCAP6300 Duo atomic emission spectrometer (Thermo Fisher Scientific) using the iTEVA program (version 2.5.0.84). The analysis was performed using ICP-MS-68B-100 Solution A and B (2% HNO_3) multielement calibration reference standards (ICP-MS-68B-A-10, High-Purity Standards).

RESULTS

Phase Composition

The samples were divided into three groups with respect to the phase composition. Samples 1–3 found

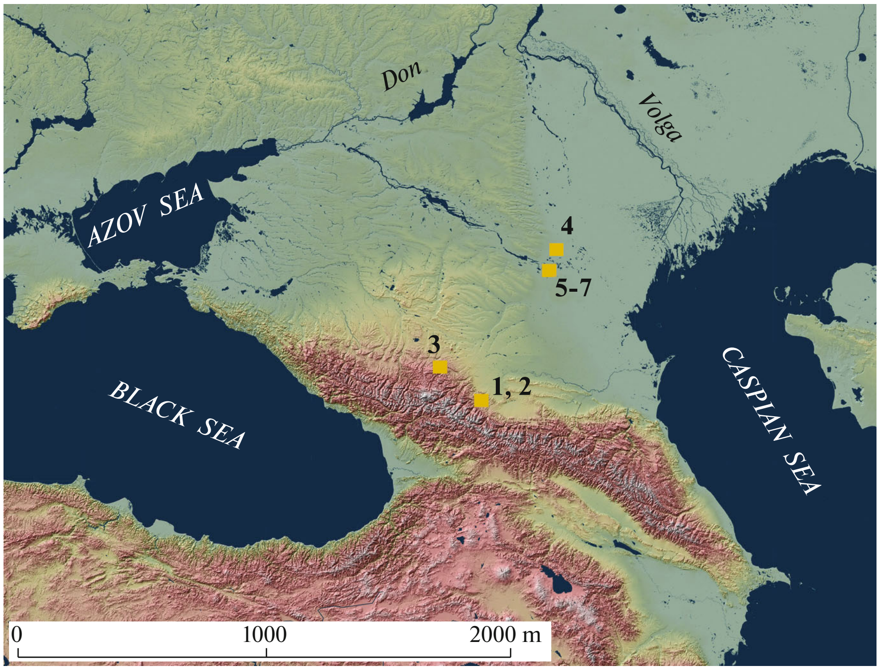


Fig. 2. Places of finds of stone items.

in the North Caucasus and Kabardino-Balkaria (samples 1, 2) and near Pyatigorsk (sample 3) belong to the first group. The data of the analysis show that they predominantly consist of minerals of the group of serpentine: antigorite and lizardite. Iron minerals, pyroxenes, and micas are present in small amounts (Table 2).

The second group includes samples 4 and 5 found in the Republic of Kalmykia in the territory of the Southern Ergeni and Kuma–Manych Depression. They consist of hornblende and albite as well as an admixture of mica, clinochlore, and quartz. The light-colored areas are albite (sample 4.1) and the dark-colored, hornblende (sample 4.2).

Table 2. Phase composition of the stone items

Mineral, %	1	2	3	4.1	4.2	5	6	7
Quartz	<1			6		5	11	98
Muscovite	3			15		2		
Clinochlore					13	1		
Albite				71		35		
Calcite	<1		<1				85	2
Magnetite	2	29	–					
Lizardite	94	30	48					
Hornblende					87	57		
Enstatite		7						
Hematite			3	<1				
Antigorite		34	45					

4.1 is white areas in sample 4 and 4.2 is dark areas.

The third group consists of samples 6 and 7 found in the Kuma–Manych Depression. They consist of quartz and calcite.

Chemical Composition

Table 3 shows the concentration of major elements and trace elements except for Si. Samples 1–3 predominantly consist of Mg (14–21%) and Fe (3–7%); samples 4 and 5, of Fe (3–13%), Ca (4–7%), Mg (0.4–8%), Al (4–11%), and Na (1–4%); and samples 6 and 7, of Ca (13–28%), Al (0.3–0.9%), and Fe (0.2–4%).

Micromorphology and Energy-Dispersive X-Ray Microanalysis (EDXMA)

The images obtained using a scanning electron microscope show that samples 1–3 consist of similar layered, parallel-scaled, and fibrous aggregates that build up dense continuous masses of crystals (Fig. 3).

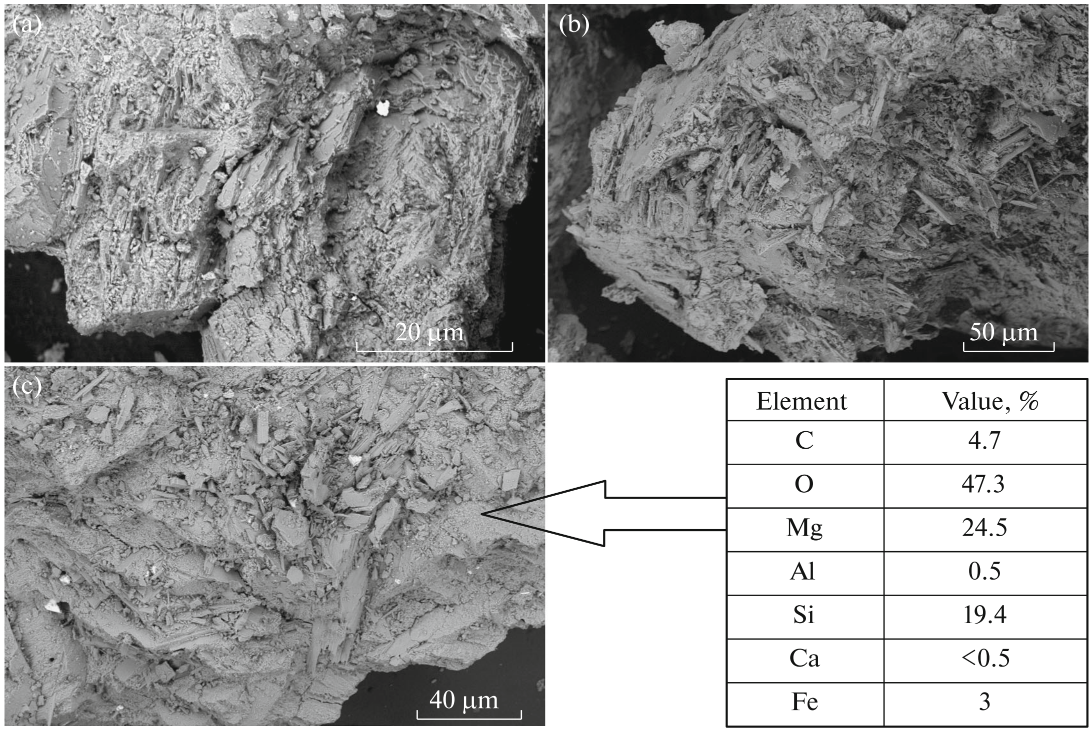
Samples 4 and 5 consist of long-prismatic and columnar forms of crystals composing dense masses of hornblende and tabular, lamellar, and sometimes rosette crystals of albite which form large aggregates (Figs. 4a, 4b).

The crystals in samples 6 and 7 are represented by round-shaped rolled grains of quartz as well as massive rhombohedral and scalenohedral forms of crystals of calcite which fill the pore space. The data of microprobe analysis indicate that the round-shaped grains consist of silicon 50% and of oxygen 39%, which corresponds to quartz (Figs. 4c, 4d).

Table 3. Data of ICP-AES and ICP-MS on the concentration of some elements in the studied samples

Element, %	1	2	3	4.1	4.2	5	6	7
Al	0.253	0.91	0.291	10.6	3.64	4.03	0.933	0.341
Mg	19.5	14.0	20.9	0.371	7.99	3.32	0.347	0.129
Ca	0.498	1.17	0.104	4.24	7.41	5.22	28.1	12.8
Cr	0.067	0.358	0.048	0.035	0.018	0.027	b/LOD	b/LOD
Cu	0.025	0.008	0.022	0.02	0.006	0.918	0.006	b/LOD
Fe	6.16	6.86	3.22	3.17	9.15	13.1	0.519	0.195
K	b/LOD	0.213	0.13	1.75	0.127	0.689	0.164	0.108
Na	b/LOD	0.186	b/LOD	3.52	0.845	1.27	0.497	b/LOD
Ni	0.202	0.127	0.118	b/LOD	0.018	0.223	0.004	b/LOD
P	b/LOD	0.771	b/LOD	b/LOD	b/LOD	b/LOD	0.183	b/LOD
Ti	0.004	0.014	b/LOD	0.09	1.014	0.446	0.021	0.024
Li	0.0002	0.0006	0.0007	b/LOD	b/LOD	b/LOD	0.0017	0.0002
B	b/LOD	b/LOD	0.0078	b/LOD	b/LOD	b/LOD	0.0032	b/LOD
Sc	0.0004	0.0009	0.0004	0.0167	0.0069	0.0147	0.0002	0.0001
Mn	0.0559	0.0601	0.0195	0.0189	0.112	0.121	0.0945	0.0026
Co	0.0077	0.0054	0.0042	0.0012	0.0049	0.0045	0.0005	0.0001
Ni	0.157	0.112	0.101	0.0178	0.0106	0.188	0.0013	b/LOD
Ga	b/LOD	0.0002	b/LOD	0.0018	b/LOD	b/LOD	0.0002	b/LOD
Ge	b/LOD	0.0003	0.0002	0.0018	b/LOD	0.0013	b/LOD	b/LOD
Rb	0.0002	0.0002	0.0002	0.0053	b/LOD	b/LOD	0.0007	0.0003
Sr	0.0028	0.0232	0.0022	0.0743	0.0022	0.0068	0.0665	0.0039
Y	b/LOD	0.0002	b/LOD	b/LOD	0.0031	0.0011	0.0012	0.0002
Zr	0.0002	0.0028	0.0006	0.0013	0.0044	0.0035	0.0026	0.0025
Nb	0.0002	b/LOD	b/LOD	b/LOD	b/LOD	0.006	b/LOD	b/LOD
Mo	b/LOD	0.0002	b/LOD	b/LOD	b/LOD	b/LOD	0.0001	b/LOD
Ag	0.0002	0.0002	0.0012	b/LOD	b/LOD	0.0069	b/LOD	b/LOD
Cd	b/LOD	0.0002	0.0005	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD
In	b/LOD	0.0001	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD
Sn	0.0003	0.0062	0.0038	0.0011	0.0076	0.0221	0.0013	b/LOD
Sb	b/LOD	0.0002	0.0007	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD
Ba	0.0037	0.143	0.0037	0.0558	0.0019	0.0076	0.0427	0.006
La	0.0001	0.0002	b/LOD	b/LOD	b/LOD	b/LOD	0.0013	0.0002
Ce	0.0002	0.0002	0.0002	b/LOD	0.0014	b/LOD	0.0021	0.0005
Pr	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	0.0003	b/LOD
Nd	0.0001	0.0003	b/LOD	b/LOD	0.0015	b/LOD	0.0011	0.0002
Sm	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	0.0002	b/LOD
Eu	b/LOD	0.0002	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD
Gd	b/LOD	b/LOD	b/LOD	b/LOD	0.0005	b/LOD	0.0002	b/LOD
Dy	b/LOD	b/LOD	b/LOD	b/LOD	0.0006	b/LOD	0.0002	b/LOD
W	0.0008	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	0.0003
Au	b/LOD	0.0004	0.0001	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD
Hg	b/LOD	b/LOD	0.0002	0.0015	b/LOD	b/LOD	b/LOD	b/LOD
Pb	0.0022	0.0229	0.0059	0.0093	b/LOD	0.488	0.0018	0.0001
Bi	b/LOD	b/LOD	b/LOD	0.0275	b/LOD	b/LOD	b/LOD	b/LOD
Th	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	0.0001	b/LOD
U	0.0002	b/LOD	b/LOD	b/LOD	b/LOD	b/LOD	0.0002	b/LOD

b/LOD is below limits of detection; 4.1 is white areas in sample 4 and 4.2 is dark areas.



Element	Value, %
C	4.7
O	47.3
Mg	24.5
Al	0.5
Si	19.4
Ca	<0.5
Fe	3

Fig. 3. SEM images of the micromorphology of the crystals of minerals of the group of serpentine and their chemical composition: (a) sample 1, (b) sample 2, and (c) sample 3.

DISCUSSION

Material Composition of the Stone Artifacts

Comprehensive instrumental analysis of the stone artifacts made it possible to distinguish three groups of items.

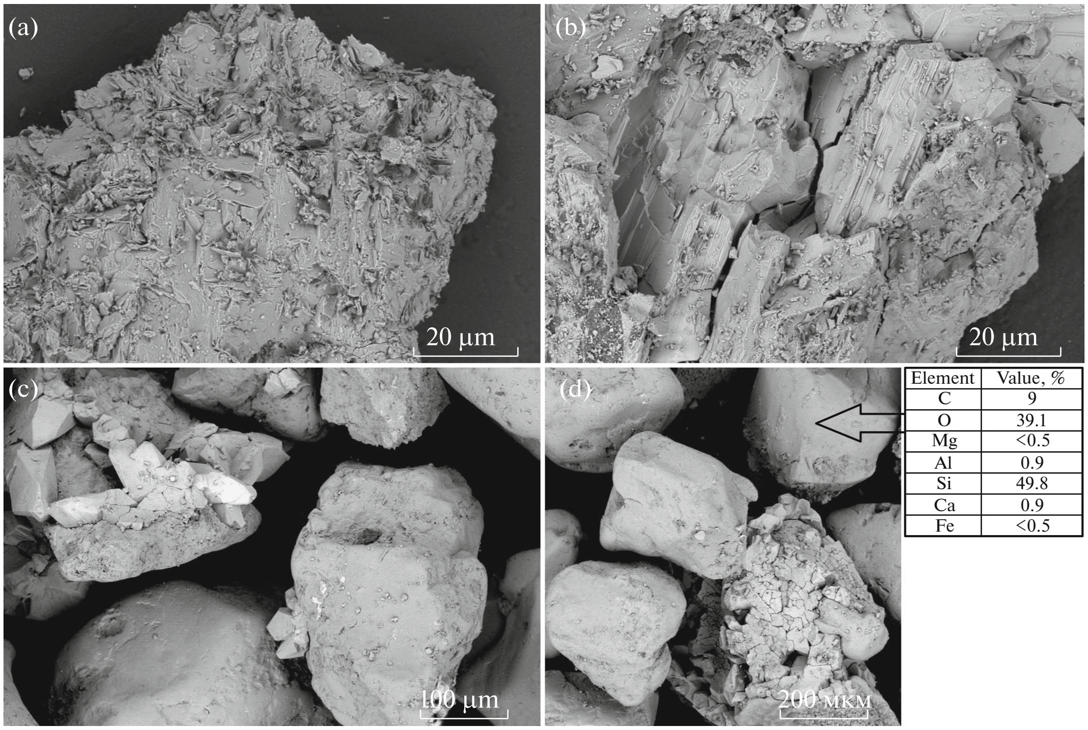
The first group includes the three stone axes found in the North Caucasus (samples 1–3). The phase analysis indicates their predominantly serpentine composition with an insignificant admixture of other minerals. The samples predominantly consist of Mg and Fe, which corresponds to the formulas of antigorite $(Mg,Fe)_3Si_2O_5(OH)_4$ and lizardite $Mg_3Si_2O_5(OH)_4$; these are minerals from the serpentine group. The crystal aggregates are layered, parallel-scaled forms that are characteristic for layered silicates, to which serpentines belong [6]. Therefore, the rock, from which the axes are fabricated, can be characterized as serpentinite.

The second group includes the mace (sample 4) and ax (sample 5) found in the Republic of Kalmykia. They consist of hornblende and albite. Dark-colored hornblende predominates in the ax, while albite is present in the form of white disseminations. The mace, on the contrary, predominantly consists of light-colored albite with often regular-shaped disseminations of dark-colored hornblende. The analysis of the chemical composition shows the highest concentration of Fe, Ca, Mg, Al, and Na, which corresponds to the formulae of hornblende $Ca_2(Mg, Fe, Al)_5(Al, Si)_8O_{22}(OH)_2$ and albite $Na[AlSi_3O_8]$. The micromorphology of the crystals also indicates a rock consisting of amphiboles and plagioclases. Elongated, long-prismatic aggregates are characteristic for hornblende, while columnar and lamellar forms are characteristic for albite. Such a composition makes it possible to classify the rocks, from which these items are fabricated, as amphibolites.

The third group unites samples 6 and 7 from the Republic of Kalmykia. They consist of quartz (SiO_2) and calcite ($CaCO_3$) and are calcareous sandstone.

Rock Sources

To determine the origin of the serpentinite items (samples 1–3), their chemical composition is important (Table 1). Since serpentinization greatly changes the protolith, typical impurity elements that enrich magmatic melts were studied to determine the genesis of serpentine. Impurities of Fe, Ni, Al, Mn, Cr, and Sr are characteristic for antigorite and lizardite. These elements are less mobile during serpentinization in comparison with other major elements and trace elements, which makes it possible to determine the nature of the protolith and possible type of the deposit [7]. Thus, the high concentration of Cr and Ni indicates the development of serpentinization by ultramafic rocks, while the increased values of Sr may sug-



Element	Value, %
C	9
O	39.1
Mg	<0.5
Al	0.9
Si	49.8
Ca	0.9
Fe	<0.5

Fig. 4. SEM images of the micromorphology of the crystals in the samples: (a) crystals of albite from sample 4; (b) crystals of hornblende from sample 5; (c) large round-shaped grains of quartz with crystals of calcite with the scalenohedral form on the surface, sample 6; and (d) grains of quartz and their chemical composition, sample 7.

gest the formation of serpentine in the zone of contact of silicate rocks with carbonates.

To assess the protolith, from which serpentinite was formed, the forsterite component in the olivine series was calculated by the formula $X\text{Mg} = \text{Mg}/(\text{Mg} + \text{Fe})$, and this value was compared to the concentration of Ni that often replaces Mg and Fe in olivine [7] (Fig. 5). Forsterite is a common mineral of ultramafic rocks, but it is also encountered in metamorphized dolomites and magnesium skarns, from which serpentinization can develop as well. The concentration of the forsterite component is quite high for all the samples [7]. The values of Ni fluctuate in a narrow range of 0.1 up to 0.2%. The samples are combined into one group based on this indicator, which suggests the similarity of their origin.

The type of rock, from which serpentinization developed, can be determined using the Sr/Cr ratio (Fig. 5). High values of strontium are characteristic for carbonate rocks, and of chromium, for ultramafic. In sample 2, the concentration of Sr is much higher in comparison with samples 1 and 3. The high concentration of Ca in this sample evidences the possible formation of serpentine from carbonate rocks (Table 3). The presence of a carbonate protolith is also indicated by the white color of the ax, which makes it similar to the stone maces from the Borodino Treasure which are also fabricated from light-colored serpentinite [6]. On the other hand, the high concentration of impurity elements such as Ni, Cr, Fe, and Al indicates the significant effect of rocks with ultramafic composition (Table 3). Apparently, the material for the ax, from which sample 2 was collected, was mined from serpentinized ultramafic rocks with a significant impurity of calcite or dolomite. Such deposits are widespread in the North Caucasus. Massifs of serpentinites and small lens-like masses are traced in parallel to the Caucasian Range from Mount Kazbek in the east to the Pshekha River in the west [8]. In geological publications, they are known under the name *Serpentinite Belt of the North Caucasus* [9]. The main part of the massifs is located in the territory of North Ossetia, Kabardino-Balkaria, Karachay-Cherkessia, Adygea, and Krasnodar area. Caucasian serpentinites are intensively dislocated [10]. Significant carbonization at areas of fractures is characteristic for them, which makes them a probable source of both green and light-colored serpentinite. Because of this, despite the fact that the appearance of the North Caucasian axes significantly differs from each other in both shape and color, their manufacture from serpentinites similar in composition gives a reason to suggest local sources of this material.

Samples 6 and 7 from the Republic of Kalmykia consist of medium- and coarse-grained calcareous sandstone. Such a sandstone is typical for Ergeninsky sediments widespread throughout the entire steppe region within the territory of Rostov and Volgograd

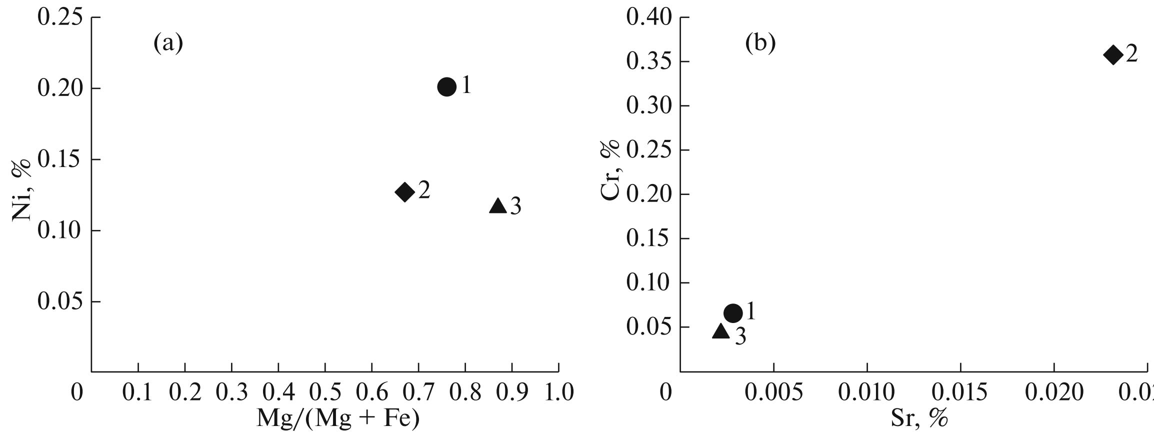


Fig. 5. (a) Ratio of Ni to Mg/(Mg + Fe) in the samples of serpentinite. The Mg/(Mg + Fe) ratio is the forsterite component in the olivine series [7]. (b) Diagram of the variations of Cr and Sr which demonstrates the contribution from ultramafic and carbonate protoliths. The deviation of the values to the right side of the graph indicates a carbonate protolith, and the deviation to the upper part, the formation of serpentine by ultramafic rocks.

oblasts and the Republic of Kalmykia. The Ergeninsky Formation of the Neogene Period is mainly represented by light-colored quartz sands and sandstones with interbedded shales. A characteristic feature of these sediments is the presence of specific coarse-grained alluvial sandstones encountered in the form of huge block masses or strata [11]. In the Ergeninsky Upland, such sandstone can often be found in the bottoms of balkas or ravines, where it crops out as a result of the erosion of Pleistocene sediments covering it. It is noted in some works that Ergeninsky sandstone was used by the ancient population and served as a material for megalithic structures of the Yamnaya culture time [12].

Therefore, the morphological characteristics and data of instrumental analysis make it possible to assign the material, from which samples 6 and 7 are fabricated, to alluvial sandstone of the Ergeninsky Formation widespread in the Ergeninsky Upland.

Samples 4 and 5 were also found in the Republic of Kalmykia within the territory of the Southern Ergeni and Kuma–Manych Depression. But, as opposed to the samples made of sandstone, they are made of metamorphic rock, amphibolite. It consists of dark-colored hornblende and white albite—sodium feldspar from the group of plagioclases. Such rocks are not encountered in the territory of the steppe area between the Volga and Don Rivers as well as in the Caucasus. The nearest place, where there are outcrops of plagioclase amphibolites, is the Oktyabrskoye ore field located in the southeastern part of the Ukrainian Shield [13]. For example, the Mazurovskoe Deposit located 45 km from Mariupol is formed by rocks of the gneiss–migmatite complex with tabular bodies of amphibolites [14]. There is not yet sufficient proof of the fabrication of samples 2 and 3 from Pryazovie rocks but the difference in the material of these artifacts from typical steppe sandy items suggests the significant diversity of the resource base of nomadic tribes.

Therefore, the obtained data indicate that the ancient population used most diverse resources. When fabricating artifacts, first of all local raw materials or raw materials from the neighboring regions, where mobile pastoralists could migrate as part of their seasonal movements, made their way to steppe workshops. The ax from the Yamnaya culture complex of the Mu-Sharet burial ground is made not of Caucasian serpentinite as it was initially supposed but of amphibolite, a rock originating from the region neighboring the Northwest Pre-Caspian area, relationships with which were developed from as early as the Neolithic Age [15]. A mace was left in the Catacomb culture cenotaph of the burial mounds of the East Manych which is also most likely fabricated from Eastern Ukrainian amphibolite rather than from Caucasian serpentine as it was supposed in [16].

Despite the fact that the stone axes found in the North Caucasus have different shapes and colors, they are fabricated from serpentinite similar in composition. This indicates that the proximity of the raw-material source was a more important factor in comparison with the design of the item.

CONCLUSIONS

Using comprehensive instrumental analysis of the stone items of the Bronze Age from the collection of the Historical Museum, it has turned out to be possible to determine the material composition and possible origin of raw materials for their manufacture.

Three stone axes from the North Caucasus are fabricated from serpentinite, most likely, of local origin. The items made of sandstone found in the Republic of Kalmykia are fabricated from alluvial sandstone widespread in the territory of the Ergeninsky Upland. The mace and ax, also from sites of the Republic of Kalmykia, are fabricated from a metamorphic rock, amphibolite. Such a material could have been mined in the deposits of the Ukrainian Shield in the Azov Lowland.

Therefore, during the fabrication of artifacts by the ancient population, local raw materials from the neighboring regions, where groups of mobile pastoralists could have migrated as part of seasonal movements, were predominantly used. Increasingly frequent finds of ancient items made of sandstone suggest the ability of the population of the Bronze Age to benefit from the scarce resources of the steppe, using all available materials. Probably, at that time, Caucasian items did not get into the steppe as often as was earlier supposed. The material from neighboring regions indicates a developed system of relationships of the nomadic population with other ethnic groups.

FUNDING

The studies of stone items from the collection of the Historical Museum were supported by the Russian Science Foundation (grant no. 21-18-00026).

CONFLICT OF INTEREST

We declare that we have no conflicts of interest.

REFERENCES

1. V. A. Safronov, Probl. Arkheol., No. 1, 75 (1968).
2. I. V. Sinitsyn and U. E. Erdniev, *Antiquities of East Manych* (Kalmyts. Knizh. Izdat., Elista, 1987) [in Russian].
3. M. Yu. Treister, *Treasures of Troy, Exhibition Catalog* (GMII im. Pushkina, Moscow, 1996) [in Russian].
4. *Bronze Age. Europe without Borders. Exhibition Catalog,* Ed. by Yu. Yu. Piotrovskii (Chist. List, St. Petersburg, 2013) [in Russian].
5. N. I. Shishlina, in *Bronze Age. Europe without Borders. Exhibition Catalog,* Ed. by Yu. Yu. Piotrovskii (Chist. List, St. Petersburg, 2013), p. 156 [in Russian].
6. P. I. Kalinin, A. A. Veligzhanin, N. N. Presnyakova, et al., *Borodino Treasure of the Heroic Era of the Bronze Age. Natural Science and Historical Context,* Ed. by N. I. Shishlin (GIM, Moscow, 2019), p. 42 [in Russian].
7. M. Menzel, C. Garrido, V. L. Sánchez-Vizcaíno, et al., Metamorph. Geol. **37**, 681 (2019). https://doi.org/10.1111/jmg.12481
8. V. M. Gazeev, A. G. Gurbanov, O. A. Gurbanova, and S. V. Popov, Vestn. Vladikavk. Nauch. Tsentra. **18** (2), 29 (2018). https://doi.org/10.23671/VNC.2018.2.23760
9. N. E. Efremov, Sov. Geol., No. 7, 7 (1938).
10. Yu. V. Popov, O. E. Pustovit, and A. Yu. Nikulin, Geol. Geofiz. Yuga Ross. **11** (1), 38 (2021). https://doi.org/10.46698/VNC.2021.91.98.004
11. M. V. Karandeeva, *Geomorphology of the European Part of the USSR* (Mosk. Gos. Univ. Moscow, 1957) [in Russian].
12. N. I. Shishlina, N. V. Leonova, P. I. Kalinin, et al., in *Proceedings of the 6th (22nd) All-Russian Archaeological Congress, Samara,* Ed. by A. P. Derevyanko (SGSPU, Samara, 2020), Vol. 1, p. 358 [in Russian].
13. A. N. Donskoy, *Nepheline Complex of the Oktyabrsky Alkaline Massif* (Naukova Dumka, Kiev, 1982) [in Russian].
14. T. P. Volkova and S. N. Strekozov, Tr. DonGTU, Ser. Gorno-Geol., No. 24, 120 (2001).
15. N. I. Shishlina, *Northwestern Caspian in the Bronze Age (V-III Millennium BC)* (GIM, Moscow, 2007) [in Russian].
16. U. E. Erdniev, *Archaeological Sites of Southern Ergeni* (Kalmyts. Knizh. Izdat., Elista, 1982) [in Russian].

Translated by E. Boltukhina