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Interdisciplinary study of 13th century silver coins of the Juchid (based on the materials of the Burundukovsky hoard, Tatarstan, Russia)

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ABSTRACT
This work represents an interdisciplinary study of archaeological silver coins discovered in the territory of Burunduki village located in the Tatarstan Republic (Russia). The coins were minted in the 13th century in Bolgar (Volga Bolgaria) during the rule of the Juchid dynasty (the Golden Horde). The silver-containing numismatic material was studied using three analytical methods: X-ray fluorescence analysis, emission spectroscopy and scanning electron and optical microscopy. Surfaces of coin fractures were studied in order to determine the inner structure. The results of this study demonstrated that fracture mapping corresponds to physical processes occurring during pressure processing. As a result, local material was clearly classified into two groups in terms of the chemical composition and manufacturing technique.

Section: RESEARCH PAPER

Keywords: archaeological silver coins; Golden Horde; Volga Bulgaria; 13th century; chemical composition; structure; embossing technology; X-ray fluorescence analysis; emission spectral analysis; scanning electron microscopy; optical microscopy

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1. INTRODUCTION

In May of 1987 a hoard was discovered at the edge of a forest near Burunduki village in the Tatarstan Republic (Figure 1). It was inside a red clay ceramic vessel with a silver cover [1]. The hoard consisted of 906 coins: with the name of An-Nasir li-din Allah (2 pcs.), Mongke (609 pcs.), Ariq Boke (291 pcs.), and unattributable (4 pcs). All coins were minted at a mint in the the capital of Volga Bolgaria – the town of Bolgar. The hoard was deposited in the first half of the 1260s.

It is presently deposited in the Museum of Archaeology under the Academy of Sciences of the Tatarstan Republic (Kazan, Russia).

Since its discovery the hoard has only been studied fragmentarily using classical techniques of numismatics: attribution according to the stamp and metrology. In order to study the dynamics of economic development and handicraft traditions of this area in the 13th century, it is very important to restore the formulation and technology of coin minting. A complex approach with the use of interdisciplinary research methods allows to establish a pattern of the quality variation of silver coins in the course of time on the basis of objective analytical data.

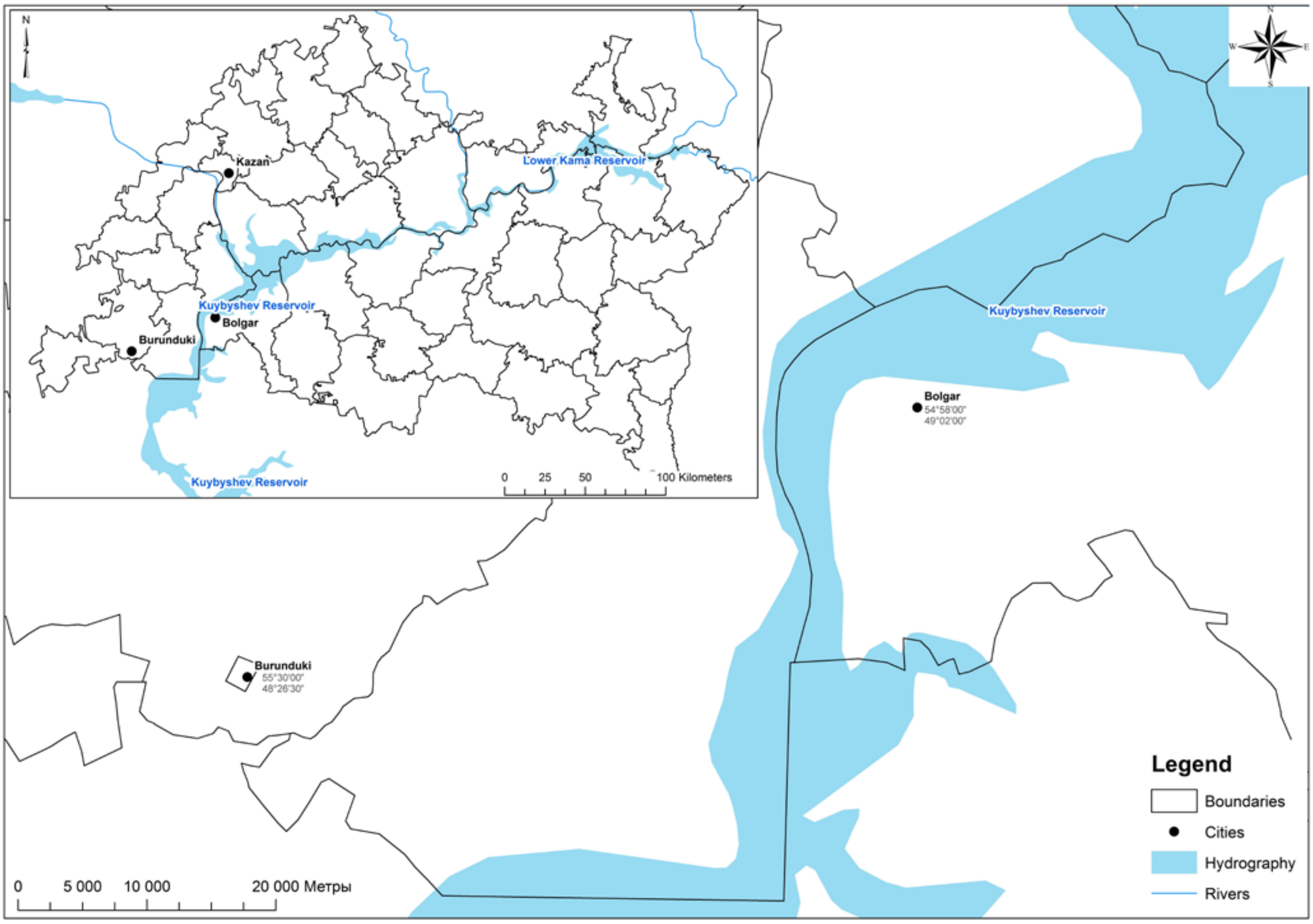


Figure 1. Burunduki village with respect to Bolgar, Kazan and Moscow (the map was compiled using an information system for archaeological research registration "ArchGIS" (Tatarstan, Russia [2]).

Presently, there are several methods of research of chemical composition and structure of materials. A classical method of research of chemical composition of coins is the emission-spectral method (ESA), which most accurately determines the composition of materials, including microcomponents [3], [4]. A disadvantage of this analysis method is the destruction of 20-30 mg of the sample during analysis and the infeasibility of elemental mapping.

Another popular non-destructive method of numismatic material research is the X-ray fluorescence analysis (XRF). This method allows to analyze the surface layer of coins. ESA and XRF do not allow to determine the inner structure [3]-[9]. However, XRF falls into the category of non-destructive analytical technologies, and can provide a rather accurate distribution pattern of chemical elements across the lateral area of the coin during the research of sample fractures.

The experience of using scanning electron microscopy (SEM) [5] demonstrated good results during the research of the inner structure of coins, and can provide layer-by-layer research of chemical composition, but the accuracy of its impurity analysis is rather low. The method is also destructive, which is related to the small volume of the working chamber and the requirement of studying a fresh fracture in order to obtain an adequate pattern.

Double-pulse laser atomic-emission spectroscopy described in [6] which is used for layer-by-layer determination of chemical composition also requires damaging of the coin. A disadvantage of this method lies in the unknown location of the structural layers of a coin, which results in that the layers are randomly determined. Besides, an inevitable evaporation of crater walls blurrs the pattern of each subsequent layer.

Various types of cleaning and special preparation of coins, as described in [10], [11], may provide blurring of the pattern of elemental distribution inside the coin. It is clearly demonstrated in [5], where a "blurred" lateral fracture leads to a several percent increase of silver content in the centre of the coin.

2. NUMISMATIC MATERIALS

The composition of the hoard allows to conclude that by the moment of its deposition in the early 1260s the monetary circulation of the Bolgar region still contained dinars: the name of a deceased Baghdad caliph An-Nasir li-Din-Allah (died in 622 A.H./1225 A.D.) [1]. The dinars were minted at a Bolgar mint in the mid-1240s (a more accurate dating is not possible, as there is no minting date on the coins). Two-thirds of the hoard are silver coins with the name of Mongke Khan (son of Tului, grandson of Genghis Khan) who began to rule the Mongol Empire in 1251. Since that period in the course of almost 10 years Bolgar wilayah (province)minted coins bearing his name and tamga (stamp) [12]-[14]. In the very beginning of the 1250s minted coins had a mandatory weight of 1.20 g. After several weight reductions in the course of almost 10 years the mandatory weight amounted to 0.71 g.

The majority of coins have a weight of 0.71±0.02 g (10.6 %). Besides, other two weight ranges are observed: 0.98±0.02 g and 0.89±0.01 g. The average weight is 0.80 g. Coins weighing 0.62–0.80 g constitute a half (51.4 %) of all Mongke coins from this hoard. Minting was carried out in accordance with several "mandatory norms".

After Mongke's death the throne was supposed to be rightfully taken by Ariq Boke, another son of Tului. However, the third son of Tului by the name of Kublai did not acknowledge the rights of his older brother Ariq Boke and also went after the hereditary throne of Genghis Khan. A war between brothers began in 1260 [12]-[14]. In the Middle Volga region far away from Central Mongolia the mints of Bolgar's land began to issue coins with the name of the rightful heir Ariq Boke.

The maximum weight range is 0.79±0.02 g (21 %). The second weight range is 0.70±0.02 g. The average weight is 0.76 g. Coins weighing 0.73-0.85 g constitute over half (65.2 %) of all Ariq Boke coins from the hoard. Notably, the weight range of Mongke coins amounting to 0.71 g is 0.08 g lower than that of the Ariq Boke coins, amounting to 0.79 g. This is most probably accounted for by the loss of weight in the process of circulation due to a long circulation period of Mongke coins compared to those of Ariq Boke.

There were notable technical specifications given to mints for coin issuance. Early coin issues (with the name of the deceased Baghdad caliph An-Nasir li-Din-Allah) were carried out in accordance with an *el-marco* system. However, when the throne was taken by Mongke Khan the situation changed – the mint began to issue coins in accordance with a "mandatory" norm, i.e. with identical weight for each allowable weight standard. Subsequently, this production characteristic never changed. Notably, the *el-marco* system was used by numerous mints of the Mongol Empire in the early period of establishment of proprietary silver and gold minting. A peculiar feature of the circulation of such coins is that their value was determined by weighing, and in retail trade it led to chipping of coins if their buyer did not have a coin with a corresponding weight. The inconveniences of circulation of such coins are evident, and therefore in a certain while effectively all mints of the Mongol Empire (including the ones in the Bolgar wilayah) made a transition to issuing coins with a uniform "mandatory" weight (within specified ranges).

As it is known, "Kublai who prevailed over Ariq Boke in the power struggle spared his brother's life for about two years, letting him make use of the former rights and privleges, althoug keeping him under special supervision" [12]. Ariq Boke died in 664 A.H. (October 13th, 1265 – October 1st, 1266). The minting of coins with his name most probably continued in the region through 1266. After Ariq Boke's death power in the Ulus of Jochi was taken over by Mengu-Timur. He refused to obey to Kublai considering him an usurper, and proclaimed the establishment of his own state which is presently referred to as the Golden Horde. It took place in 665 A.H./1266-1267 A.D. Since that period a new tamga of Mengu-Timur (frequently referred to as the "Batu House Tamga") appeared on silver and copper coins of Khwarezm, Bolgar, Crimea, Jand, Sarai and other regions of the newly established state [12]-[14].

3. CHEMICAL COMPOSITION

The present work is dedicated to a study of 7 silver monetary artefacts from the Burundukovsky hoard. The analytical selection includes two coins minted by each of the rulers: 2 coins emitted by An-Nisir (Figure 2*a*, *b*), 2 coins emitted by Mongke Khan (Figure 2*c*, *d*), and 2 coins minted by Ariq Boke (Figure 2*e*, *f*). A coin-shaped silver coin discovered in the same hoard was used as a reference standard (Figure 2*g*).

The technique of silver-containing material sampling for coin research providing adequate results is described in paper [5]. The proposed procedure of sample preparation for analysis provided correlation between the results obtained using various research methods (ESA, XRF, SEM).

A system of stage-by-stage studying of samples aimed at the reduction of research costs and the optimization of the correctness of analytical data was implemented within the scope of this work. All 7 coins were studied using OM and XRF, chemicals of 5 coins were determined using ESA, and three coins were analyzed using SEM.

The research of coins with the optical microscopy technique was carried out in the Institute of Archaeology of the Tatarstan Academy of Sciences using a Levenhuk DTX 90 digital microscope. It provides a 10 to 300-fold magnification and is equipped with a 5-megapixel camera.

XRF was conducted by a Tornado X-ray phase analysis spectrometer manufactured by Bruker in Kazan (Volga Region) Federal University (Kazan, Russia). SEM was performed using an AURIGA CrossBeam digital microscope and an INCA X-MAX energy-dispersive spectrometer at Kazan National Research Technical University, named after A.N. Tupolev (Kazan, Russia). The research techniques are specified in [15].

The ESA technique is as follows: 10-15 mg of the sample are incinerated until complete evaporation from a carbon electrode crater in an AC arc. The exposure time for highly volatile elements is 30 s at a current of 8 A, after which the spectrum is overlapped and the sample is further incinerated at a current of 18 A. The spectrum obtained using a DFS-458 diffraction spectrograph was registered on PFS-03 photographic plates. The working lattice of the spectrograph is No.3 with 1800 pcs./mm. The obtained spectrograms were formed on a MF-2 spectrophotometer. The researched samples were analyzed using a classical method of 3 reference standards represented by jewellery silver grades 875 and 925, and a silver coin grade 500 of 1927. State reference standards of bronze alloys were used in order to assess lead, tin, zinc and other impurities.

Chemical composition data is given in Table 1. The results of XRF and SEM analyses were recalculated for a "pure" composition with no consideration of silicon, calcium and aluminium. Despite certain differences in the elemental content, the results of the analyses provide rather comparable data. Significant variations in terms of concentration can be accounted for by two factors.

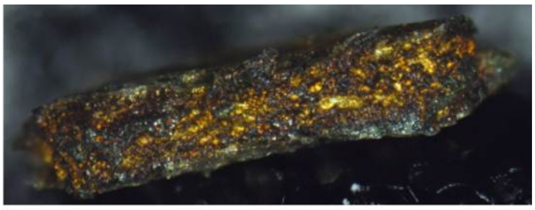
The first one is accounted for by the characteristic features of the methods: XRF and SEM only analyze the surface layer, whereas ESA provides an overall composition of the entire sample. Surface polishing during research of silver coins leads to distortion of chemical composition data [5]. However, the relief surface of fractures also introduces a measurement error upon addition of data across the area. SEM energy-dispersive analysis failed to provide determination of gold content in the samples, discovered by ESA and SEM. Lead sensitivity for SEM was limited to 1 %.

Irregularity in the distribution of elements in the matrix may constitute the second factor. Figure 3 shows photographs of a fracture obtained using an optical microscope. Areas with different compositions are visible in the fractures, which signifies a non-uniform distribution of elements in the coin matrix.

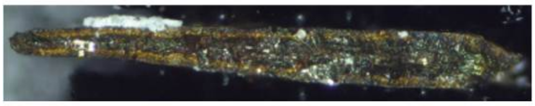
Figure 2. Analyzed coins of the Juchid dynasty.

Table 1. Chemical composition of silver coins obtained using three independent methods (weight, %).

№	*Method*	*Ag*	*As*	*Au*	*Bi*	*Co*	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*	*Sn*	*Sb*	*Zn*
1	ESA	96.13	0.0056	0.15	0.024	0.0008	1.51	0.79	0.004	0.0004	1.36	0.0008	0.006	0.009
	XRF	96.03		0.6			2.92				0.37			
	SEM	95.06					3.48	0.16			1.3			
2	ESA	95.33	0.0067	0.28	0.057	0.0006	2.38	0.13	0.002	0.0006	1.77	0.02	0.007	0.005
	XRF	95.16		0.86			3.16	0.18			0.63			
3	ESA	82.43	0.001	4.67	0.4	0.0008	10.16	0.11	0.008	0.0002	2.09	0.0016	0.007	0.005
	XRF	93.88		0.54			4.99				0.52			
	SEM	94.98					5.02							
4	XRF	98.37		0.2			0.98				0.16			
5	ESA	85.95	0.0047	2.96	0.17	0.0009	8.66	0.11	0.005	0.0003	2.12	0.0049	0.005	0.003
	XRF	93.78		0.46			4.95				0.79			
6	ESA	95.57	0.0008	0.44	0.099	0.0004	3.22	0.021	0.006	0.0008	0.61	0.0008	0.006	0.004
	XRF	93.6		0.55			5.18				0.66			
	SEM	94.06					5.94							
7	XRF	94.9		0.32			3.35	0.06			0.77			



a



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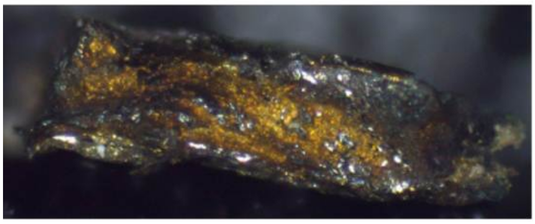
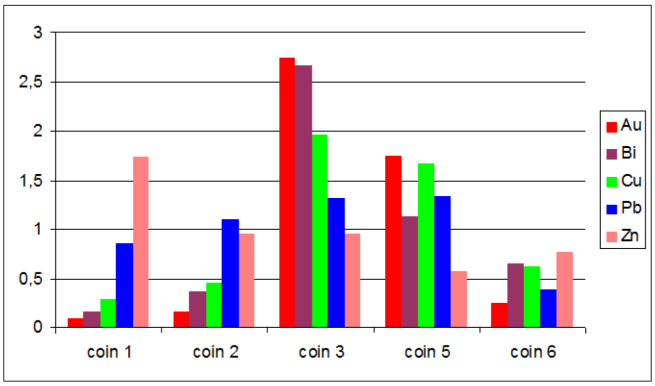


c

Figure 3. Photographs of SEM optical microscopy of coin fractures: *a* - *No.1*, *b* - *No.3*, *c* - *No.6*.

Research of correlation dependencies between the elements allows to make a conclusion regarding the raw material used during coin minting. Figure 4 shows diagrams of relative concentration values (with respect to the average value). As seen from the diagrams, coins of various rulers are characterized by certain chemical compositions. Diagram "a" (Figure 4*a*) demonstrated a correlation between gold, copper and bismuth, whereas the other group is formed by lead and zinc. Diagram "b" (Figure 4*b*) for four coins demonstrates a direct dependence between arsenic, tin and nickel, with the exception of tin in coin *No.1* and nickel in coin *No.6*. A linear dependence between lead, cobalt and stibium is observed in all coins except coin *No.6*. Despite the presence of dependencies, practically all identical regularities are characteristic for coins *No.1* and *No.2; No.3, No.4 and No.5*, which signifies the use of certain sources of the gold, copper and lead components during the reign of different rulers.. Coin *No.6* is distinguished by its special composition.

An evidence of the existence of correlation between copper and gold content in coins *No.1* and *No.3* is provided by XRF elemental distribution maps (Figure 5*a, b*). For coins *No.5* and



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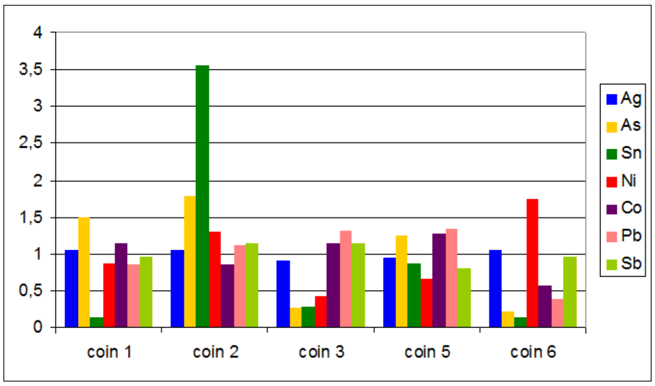
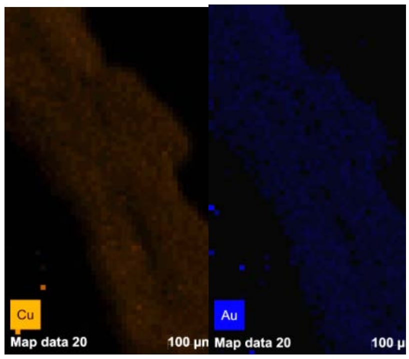


b

Figure 4. Diagrams of relative concentrations: *a* – Au, Bi, Cu, Pb, Zn; *b* – Ag, As, Sn, Ni, Co, Pb, Sb.



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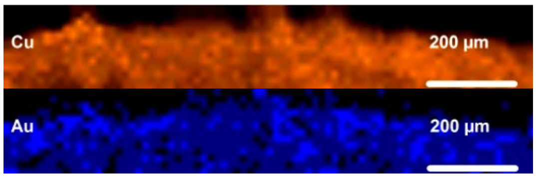

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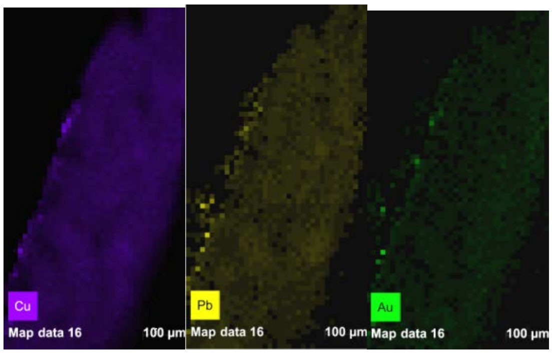

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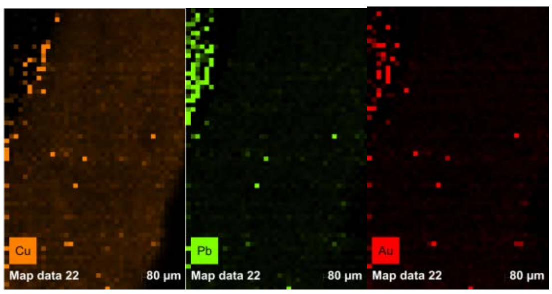

d

Figure 5. Elemental distribution across coin fractures: *a* – coin *No.1* Cu and Au; *b* – coin *No.3* Cu and Au; *c* – coin *No.5* Cu, Au and Pb; *d* – coin *No.6* Cu, Au and Pb.

No.6 elemental mapping confirms the identical location of copper, gold and lead (Figure 5*c, d*), proving a special source of raw material from which Ariq Boke's coins were minted.

4. STRUCTURE AND TECHNOLOGY

Below is the description of the peculiar features of chemical composition, structure and technology of coin manufacturing.

Coin No.1 (An-Nasir, Bolgar, 13th c.) was crafted from silver of a high grade. It features a three-layer structure with very thin outer layers (approximately 60 μm). The thickness of the coin varies from 255 to 325 μm depending on the die pattern.

The round shape of coin *No.1* signifies that its blank features a similar shape (Figure 2*a*). The edge of the coin still contains S-shaped grooves (Figure 6) characteristic for free pressing between two parallel surfaces.

Copper concentration in the outer layer is significantly less than in the inner layer. Colour mapping demonstrates the absence of lead components in the outer layers. The distribution of this element across the area of the inner layer is uniform (Figure 5*a*). The metal matrix is composed of silver with trace impurities of Pb-Cu-Ag (Figure 7, Table 2).

The structure of the coin clearly demonstrated recrystallization processes as a result of minting (Figure 3*c*).

A correlation is noticeable between copper and gold content, which signifies a certain source of raw material. The inner layer features traces of cold hammering indicating the use of high pressure in coin minting.

Coin *No.2* (An-Nasir, Bolgar, 13th c.) was crafted from silver of a high grade. The distribution of elements across the area of the fracture is uniform, with the exception of a thin surface layer in which the content of impurities is lower than that inside the coin. No clear correlation between the elements is observed. Inside the coin, likewise coin *No.1*, there was a highly deformed layer with a recrystallized structure. The thickness of the inner layer is approximately 360 μm, and outer layers 20 to 45 μm.

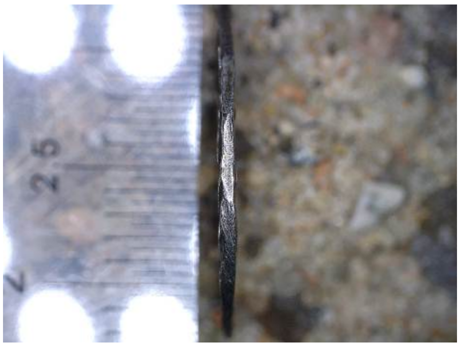

Figure 6. Photographs of coin *No.1*.

Table 2. Chemical composition of trace impurities, coin *No.1*.

Element	Weight %	Element	Weight %
C K	6.08	C K	9.14
O K	14.05	O K	2.01
Cu K	23.59	Al K	0.35
Ag L	18.25	Cu K	2.05
Pb M	38.03	Ag L	49.39
		Pb M	37.06

The minting technology of coin *No.2* matches that of coin *No.1*.

Coin *No.3* (Mongke Khan, Bolgar, 13th c.) was crafted from silver of a high grade. The coin is very thin (approximately 240 μm) and has a clear laminar structure, which may signify extension of the silver base of the coin material.

Presumably, coin *No.3* was crafted using an extended silver wire. This is confirmed by the extended oval shape with a characteristic thickening and a trace of cutting from a continuous extended blank (Figure 2*c*).

The thin outer layer (30 to 45 μm) does not contain lead. Uneven distribution of lead and gold (Figure 5*b*) in the inner layer may signify an insufficient melting temperature during crafting of the blank, as a result of which these elements did not dissolve in the alloy matrix.

A colour photograph clearly indicated the presence of a yellow outer layer (Figure 3*b*) which was not registered during elemental mapping. According to ESA results, this coin contains 4.67 % of gold, and according to XRF results 0.54 %. The structure of the coin bears traces of strong recrystallization processes accompanied by cold hammering in the middle of the central layer (Figure 8). Lamination of the outer layers is observed.

Coin *No.4* (Mongke Khan, Bolgar, 13 c.) is also characterized by a high grade of silver. The plasticity of coin material did not allow to obtain a brittle fracture, so the pattern of the distribution of elements did not reveal any characteristic

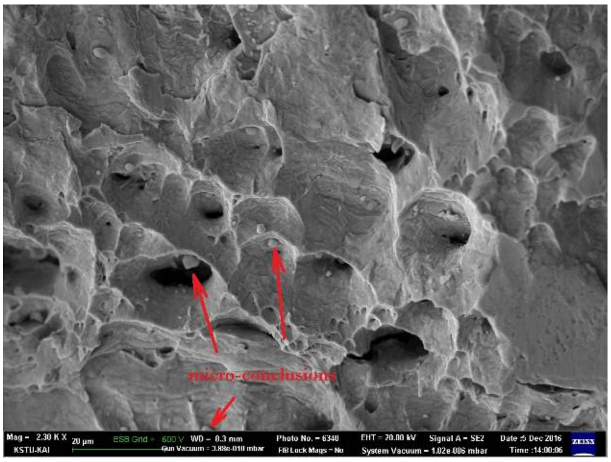

Figure 7. Structure of coin *No.1* with trace impurities.

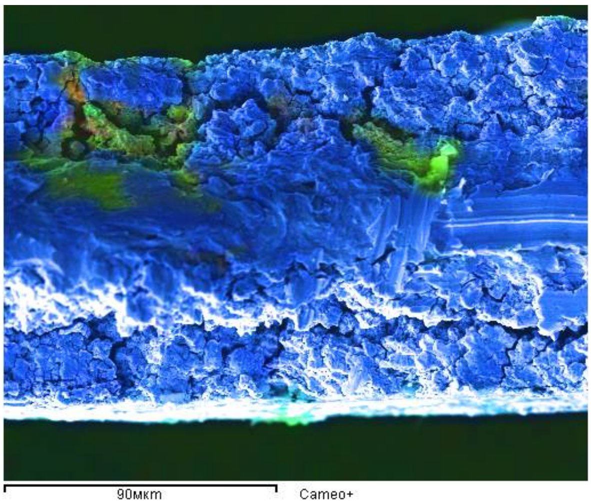

Figure 8. Structure of coin *No.3*.

features in the structure and distribution of chemical elements. However, it is highly probable that there is a gold overlap likewise coin *No.3*. Thickness of the coin is about 210 μm, and width of the fracture is 45 μm.

The coin has an oval shape, but is not elongated as *No.3*. However, traces of cutting have preserved on one of its sides.

Coin *No.5* (Ariq Bokea, Bolgar, 13th c.) has an oval shape and has been crafted using silver of a high grade. The distribution of elements across the mapping area is uniform. Like the case with coin *No.3* and *No.4*, a certain intensiveness of gold content is observed (Figure 5*c*). The thickness of the coin is about 190 μm, and the width of the fracture is 75 μm.

The external shape of the coin indicates that it was made of a plate, and angles in the form of a flare have preserved in the form of welding burrs along the edge of the coin (Figure 2*e*). No traces of cutting have preserved. One can assume that it was minted using a flattened wire.

The three-layer coin *No.6* (Ariq Bokea, Bolgar, 13th c.) has a high silver content and an oval shape. The distribution of elements across the scanning area is uniform. The inner layer contains inclusions of lead-copper conglomerates. Gold, like in coin *No.1*, correlated with copper, excluding the outer layers (Figure 5*d*) in which higher concentrations of Au are observed. The coin is approximately 290-310 μm thick depending on the die pattern, and the thickness of the outer layers is 45 μm.

The coin has an oval shape like coin *No.5*, and a slight trace of cutting has remained on one of its sides. Presumably, a black in the form of a wire was used during minting.

Despite the fact that in the optical microscopy image the areas marked with a yellow colour are clearly visible (Figure 3*c*), the distribution of copper and silver correlates with each other (Figure 5*d*). Therefore, this color was obtained due to the presence of gold in the sample, and a concentration of 0.45 % was recorded by XRF and ESA methods.

Analytical data obtained for the coin demonstrated that the total spectrum along the fracture does not register lead, while in the central part the concentration of this element is significant, amounting to 1.5 %. Microparticles of a lead-silver and silver-copper-nickel composition are registered in the structure of the metal matrix (Table 3, Figure 9). The results of the SEM analysis of chemical composition of trace impurities provided information on the feedstock used in minting of the central part of the coin. During minting, copper-nickel and lead-silver additives were included in the alloy, as a result of which the silver alloy grade decreased, although the weight index remained approximately the same as for pure silver. Thus, the technology of coin minting is similar to the technology used in crafting of the 10th-11th century coins of the Samanid dynasty [15].

Table 3. Chemical composition of inclusins in the metal matrix of coin *No.6*.

Element / **Inclusion 1**	Spectrum 3, weight %	Element / **Inclusion 2**	Spectrum 4, weight %
C K	5.58	C K	12.26
O K	13.77	Al K	2.25
Cu K	1.61	Ni K	4.31
Ag L	24.56	Cu K	10.96
Pb M	54.49	Ag L	70.23

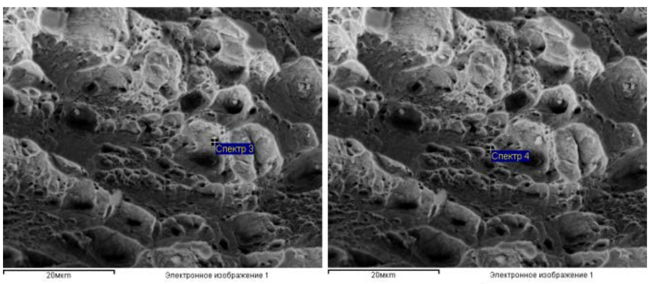

Figure 9. Microphotographs with analytical points of the structure of coin №6: A - lead-silver trace impurity, b - silver-copper inclusion.

Coin-shaped pendant *No.7* is made of high-grade silver.

Pendant *No.7* has a round shape, the die was unilateral, and a single hole was punched therein (Figure 2*g*). No traces of cutting are observed, and it is probable that the blank was circular in shape along the longitudinal section.

The artefact has a three-layer structure, similar to coin *No.6*. Unlike the first coins *No.1* and *No.2*, copper and gold contained in the pendent feature an inverse correlation, and the distribution of silver and gold on colour maps is the same. In outer layers, the concentration of these elements is higher. This circumstance indicated a source of silver different from the first coins. Coin thickness is about 270 μm, and outer layers 60 μm. Structural changes are observed under the influence of a high pressure applied during minting. This is confirmed by XRF results.

The distorted structure contains grains of silver of high grade with copper dissolved therein, lead-silver and lead-copper inclusions.

All coins and coin-shaped pendants have a faint coating of a gold colour (Figure 10).

5. CONCLUSIONS

Research of numismatic material involves a number of challenges. The major one in this case is the determination of a "golden mean" between the cost of ongoing research and the quality of the results, which allows to adequately assess the pattern of structural changes.

In this study, it was possible to maintain the effectiveness of the developed method [5], [16] by means of a successive parallel study of the mass coin material.

A study of microphotographs and maps of the distribution of elements obtained using XRF and SEM methods demonstrated that coins from this hoard have a strongly deformed structure with traces of etching, and a possible gold coating.

All coins are made of high-grade silver - over 90 %. Research of alloys carried out on the basis of three basic alloying elements: copper, lead and gold demonstrated that all

Figure 10. Gold coating on the coin-shaped pendant *No.7*.

researched coins from the Burundukovsky hoard were made using the same formulation. However, coins of different rulers are made of different raw materials, as evidenced by the varying correlation dependencies of copper, gold, lead and nickel impurities.

In general, despite the insufficient resolution of images in the case of fine-grained crystallization of metals, XRF proved to be an adequate and inexpensive method of coin fracturing. SEM confirmed the results of the XRF analysis. All coins feature obvious traces of metal processing using pressure and etching. The difference in the chemical composition of XRF, ESA and ESA, observed for some coins, can be explained both by the characteristic features of analytical technologies and the uneven distribution of elements in the coin matrix.

The structure of coins can be subdivided into two main groups:

Group 1. Coins have a strongly deformed structure with a subtle or evident cold hammering of the inner layer. This indicates the application of a strong pressure, as a result of which the metal layers in the centre were compacted so much that the material recoiled and recrystallized. Friction between the layers provoked a diffusion process. Movement of the layers of metal occurred through the centre of the coin along the longitudinal axis.

This group includes coins *No.1*, *No.2* and *No.7*.

Group 2. Coins made of a wire with a direct hammer blow, which may indicate a possible rush during minting. This circumstance can indicate a high mobility of mints. Such coins have an elongated oval shape with traces of an inaccurate cutting, and their thickness often radically varies, whereas holes are observed in certain samples. This group includes coins *No.3*, *No.4*, *No.5* and *No.6*.

Coin *No.4* made from a pre-flattened wire, appears more accurate in shape.

Coin *No.5*, made of a plate. It is likely that wire was also used as the initial blank, but in this case there was an intended preparation of the plate with uniform thickness.

For two coins and a single coin pendant, the original blank was a a metal blank with a regular circumferential shape: *No.1*, *No.2* and *No.7*.

All coins feature obvious traces of pressure treatment and have been subjected to active etching.

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