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GLASSMAKING IN MEDIEVAL KAZAKHSTAN: RESULTS OF X-RAY SPECTRAL MICROANALYSIS OF GLASS FROM SOUTH AND SOUTHEAST KAZAKHSTAN

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Abstract. *Introduction*. The study of medieval glass and glassmaking in Kazakhstan holds significant importance archaeological scholarship of Central Asia as a whole. *Goals and objectives*. This paper presents the results of X-ray spectral microanalysis of eight glass fragments from six archaeological sites in Southern and Southeastern Kazakhstan. The analysis revealed a chemical diversity in the glass composition, including elevated concentrations of certain elements and the use of manganese and copper by local glassmakers as coloring agents. The analysis also identified minor impurities, linked to the composition of the original glass batch (frit). *Results*. The outcomes of the X-ray microanalysis show numerous parallels with glass assemblages from medieval sites in Central Asia and Kazakhstan, as well as with materials from sites of the Golden Horde period located in the territory of the Russian Federation. *Conclusion*. The research is ongoing, and further investigations may substantially reshape our understanding of the cultural phenomenon of medieval glass in Kazakhstan, as well as the broader interregional interactions across the Eurasian continent.
Keywords: Archaeology, medieval period, Southern Kazakhstan, glass, glassmaking, monument, site, Tortkul, X-ray spectroscopic microanalysis
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ОРТА ҒАСЫРЛАРДАҒЫ ҚАЗАҚСТАНДАҒЫ ШЫНЫ ӨНДІРІСІ ТУРАЛЫ: ОҢТҮСТІК ЖӘНЕ ОҢТҮСТІК-ШЫҒЫС ҚАЗАҚСТАН ШЫНЫЛАРЫНЫҢ РЕНТГЕН-СПЕКТРЛІК МИКРОТАЛДАУЫНЫҢ НӘТИЖЕЛЕРІ

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Андатпа. *Кіріспе.* Ортағасырлық шыны және шыны өндірісін зерттеу Қазақстанның археология ғылымы үшін, сондай-ақ Орталық Азияның археология ғылымы үшін маңызы зор. *Мақсаты мен міндеттері.* Мақалада Оңтүстік және Оңтүстік-шығыс Қазақстандағы алты археологиялық ескерткіштен алынған сегіз шыны сынықтарына жүргізілген рентген-спектрлік микроталдау нәтижелері беріледі. Талдау шыны құрамының химиялық әртүрлілігін, оның ішінде кейбір элементтердің жоғары концентрациясын және жергілікті шыны өндірушілердің бояу ретінде марганец пен мыс қолданғанын анықтады. Сонымен қатар, талдау кезінде бастапқы шыны массасының (партиясының) құрамына байланысты аз мөлшерде қоспалар анықталды. *Нәтижелер.* Шыныларға жүргізілген рентген-спектрлік микроталдау нәтижелері Орталық Азия мен Қазақстандағы орта ғасырлардағы ескерткіштердегі шынымен, сондай-ақ Ресей Федерациясының аумағында орналасқан Алтын Орда кезеңінің ескерткіштерінің материалдарымен көптеген ұқсастықтарды көрсетеді. Зерттеулер жалғасуда және одан әрі зерттеулер ортағасырлық Қазақстандағы шыны өндірісінің орны мен құрлық шеңберіндегі өндіріс орталықтарының өзара байланысын жаңа қырынан ашуы мүмкін.
Түйін сөздер: Археология, орта ғасыр, Қазақстан, шыны, шыны өндірісі, ескерткіш, қала орны, сауда, рентген-спектрлік микроталдау
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О СТЕКЛОДЕЛИИ В СРЕДНЕВЕКОВОМ КАЗАХСТАНЕ: РЕЗУЛЬТАТЫ РЕНТГЕНОСПЕКТРАЛЬНОГО МИКРОАНАЛИЗА СТЕКЛА ИЗ ЮЖНОГО И ЮГО-ВОСТОЧНОГО КАЗАХСТАНА

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Аннотация. *Введение.* Исследование средневекового стекла и стеклоделия Казахстана представляют важное значение для археологической науки Центральной Азии в целом. *Цель и задачи.* В работе представлены результаты рентгеноспектрального микроанализа восьми фрагментов стекла из шести археологических памятников Южного и Юго-Восточного Казахстана. Анализ показал химическое разнообразие состава стекла, включая повышенное содержание некоторых элементов и использование местными стекловарами марганца и меди в качестве красителей. Анализ также выявил незначительное содержание примесей, что обусловлено составом начальной стекломассы (шихты). *Результаты* рентгеноспектрального микроанализа средневековых стекол Казахстана демонстрируют многочисленные параллели со стеклами из средневековых памятников Средней Азии и Казахстана, а так же с материалами из памятников золотоордынского периода, расположенных на территории Российской Федерации. *Заключение.* Исследования продолжаются, и дальнейшие изыскания могут существенно изменить понимание культурного феномена стекла в рамках средневекового Казахстана, а также взаимосвязей между различными регионами евразийского континента.
Ключевые слова: Археология, Средневековье, Казахстан, стекло, стеклоделие, памятник, городище, торговля, рентгеноспектральный микроанализ
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Introduction

Glass is originally a plastic material that can only be obtained artificially. The components of the raw mixture – the batch (vitreous mass), which is the first stage of glass production – are primarily determined by their availability and reflect the traditions and technologies characteristic of specific geographical regions. These components include sand, natural soda, plant ash, potash, and lead. The concentration of these components also determines the chemical type of the glass. Alongside ceramics and numismatics, fragments of glass and glassware represent a common category of material culture frequently found during excavations of medieval towns and settlements, and less often at nomadic sites such as barrows and burial grounds.

Before the development of techniques for producing artificial glass, people used naturally occurring glass. Most often, shapeless, opaque pieces of glassy material were used to make ornaments and amulets. In the territory of Kazakhstan, the earliest glass-like items – beads dated to the Bronze Age – were discovered during excavations of the Tau-Tary, Borovskoe 2, Bylkildak I and II, Begazy, and Atasu cemeteries, as well as at the Kamai settlement (Ageeva, 1970: 7).

Modern science identifies two main origins of glassmaking. The first is as a byproduct of pottery production. As craftsmanship improved and the pace of ceramic production increased, and as kiln design advanced for final firing, an interesting phenomenon occurred – the formation of a thin vitreous layer, or glaze, which is literally considered the progenitor of glass. Burnt fuel (ash), combined with sand subjected to high temperatures, also led to the formation of fused “clumps” of glassy mass, which can be attributed to the earliest unintentional attempts at producing artificial glass.

The second origin of glassmaking is directly associated with metal and the development of metallurgy. During the smelting of metal ores in clay crucibles, slag was formed, which either intentionally or accidentally coated the crucible with a glaze or vitreous layer.

Items coated with ash-based or slag-based glaze had clear advantages over other products. The glaze rendered the ceramic surfaces waterproof, which naturally increased the lifespan of the vessel and created a consistent production demand.

Each of these two origins of glassmaking most likely developed in parallel. However, it is important to note that at this stage, people were constrained by the technological capabilities of their time. Although glaze and surface coatings represented a significant technical breakthrough, glassmaking as a craft was only beginning its gradual path of formation and development.

Over the centuries, the technology of producing vitreous mass, along with the methods of manufacturing glass products, spread extensively across trade and migration routes deep into Eurasia. Based on the study of the composition of glass masses and melting recipes, researchers suggest that glassmaking as a craft emerged in Central Asia as early as the 5th century CE (Abdurazakov, Bezborodov, 1966: 17). The continuity of technologies, as well as the relatively close proximity to the urban centers of Southern Kazakhstan, supports the hypothesis that glassmaking appeared in this region within the above-mentioned timeframe. However, one important clarification must be made: to date, no glassmaking workshops have been found during regular archaeological research at major medieval urban centers in Kazakhstan. Field reports and scholarly publications from the Soviet period to the present have recorded references to kilns of unusual construction uncovered at sites in southern Kazakhstan and Zhetysu. However, it was later established that these “unusual” kilns were used by craftsmen for firing ceramic ware (Patsevich, 1956: 79). The existence of glassmaking on the territory of medieval Kazakhstan is indirectly indicated by the numerous finds of glass products, semi-finished pieces, cullet (glass waste), and production rejects

During the Soviet period, the study of glass and glassmaking in medieval Kazakhstan received some scholarly attention, but was largely limited to describing morphological features such as color, thickness, and transparency. The dating of glass artifacts and fragments was based, first and foremost, on associated materials such as ceramics and coins, and secondly on parallels with better-studied medieval glass from Central Asia. The scholarly works and field reports of researchers such as E.I. Ageeva, T.N. Senigova, G.I. Patsevich, and others laid the foundation for the further, more detailed study of glass artifacts. This stage marked the beginning of the classification and typology of glass fragments and products from medieval Kazakhstan.

Later, glass fragments and objects were grouped into collections according to various aspects of their usage. Of particular importance are the collections of glass artifacts from the urban settlements of Taraz, Otrar, and Kuyruk-Tobe. Taking into account the preservation state of the items, these collections were divided into several functional categories: domestic and household, sanitary and hygienic, perfumery and pharmaceutical, chemical, as well as lamps and window glass (Baipakov, 2013: 352). This phase of medieval glass research in Kazakhstan is closely associated with the work of K.M. Baipakov, T.S. Doshchanova, T.V. Saveleva, and others.

As a result of these studies, typological characteristics of medieval Kazakhstani glass and its production techniques were identified. Numerous finds of glass artifacts in Southern Kazakhstan and Zhetysu, made using techniques such as free blowing, mold-blowing with rotation, and mold-casting, are dated to the 10th century. Scholars also noted a specific pattern: the forms and types of glass items from Kazakhstan remained largely unchanged up to the Mongol invasion and bear some resemblance to similar glass products from Central Asia (Baipakov, 1986: 163).

Since the late 18th century, the foundations for the study of ancient and medieval glass using specialized analytical methods began to take shape(Abdurazakov, Bezborodov, 1966). By the early 20th century, the number of chemical analyses conducted on ancient and medieval glass exceeded one hundred. These studies revealed that the composition of all examined glass artifacts included a series of chemical compounds–such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, PbO, SO_3, Na_2O, and

K_2O–which were later identified as the main glass-forming oxides, along with oxides of copper, manganese, cobalt, cuprous oxide, and tin. The quantitative content of these compounds became the basis for reconstructing the specific recipes used to produce the original glass batch. The study of artifacts in combination with the chemical properties of glass components represented a major breakthrough in archaeological research.

To date, glass and glassmaking specialists have accumulated a vast body of chemical and spectroscopic analytical results from glass samples originating in regions ranging from the Middle East, Central Asia, and China to Kievan Rus and various countries in the European part of Eurasia. Of particular importance to this work are studies conducted in Central Asia and Russia. Specifically, the research of A.A. Abdurazakov, M.A. Bezborodov, Yu.L. Shchapova, G.D. Belov, N.N. Kachalov, O.S. Rumyantseva, S.I. Valiulina, and others laid significant groundwork. These scholars based their investigations not only on the typological and morphological characteristics of glass artifacts, but also supported their findings with cross-referenced chemical, spectroscopic, and radiocarbon analyses. The primary aim of each study was to trace the origin and development of glassmaking within the local context of specific production schools and glassmaking recipes. This research direction remains highly relevant today for the archaeology of Kazakhstan and its neighboring regions.

The systematic study of medieval glass from Kazakhstan using specialized analytical methods began in 1966. Four samples of glass from the medieval site of Taraz were subjected to quantitative (wet) chemical analysis. The results of this study suggested that this location was likely a regional center for glass smelting and production in Southern Kazakhstan during the medieval period (Abdurazakov, Bezborodov, 1966: 17).

Materials and Methods

In 2009, researchers from the A.Kh. Margulan Institute of Archaeology initiated a program of quantitative chemical analysis of glass samples from Southern Kazakhstan and the Semirechye (Zhetysu) region to identify characteristics of local glass production. This study continues prior research on medieval glass and glassmaking in Kazakhstan and introduces new results into academic discourse.

The study employed X-ray spectral microanalysis, which yielded reliable results characterizing the composition of the glass. The analyses covered a range of elements from boron to uranium. The margin of error for the analysis was ±5 % in relation to the concentration of elements (n) across the range from 100 % to 0 %.

The X-ray spectral microanalysis method offers several advantages, most notably the ability for precise targeting. However, for accurate interpretation, the surface area of the glass must be clean. Otherwise, “the analysis may not detect components of the batch that did not dissolve into the glass phase during the melting process” (Sedykh, Frenkel 2012: 84), which may in turn affect the accuracy of the results. Another advantage of X-ray spectral analysis is its high sensitivity, up to 0.00001 % (10^{-5}), which exceeds that of conventional chemical analysis.

The interpretation of the obtained results is based on the chemical correlation system developed by V.A. Galibin, who conducted over 9,000 determinations of glass composition (Galibin, 2001; Egorkov, 2014: 286), and on interpretations of glass chemical analyses by A.A. Abdurazakov and M.A. Bezborodov from Central Asia (Abdurazakov, Bezborodov, 1966). Percentage comparisons were based on a conventional threshold of 1 %, with values exceeding this threshold considered intentional additives.

Eight glass fragments from six archaeological sites of medieval Kazakhstan were subjected to X-ray spectral microanalysis (Tables 1 and 2). Two samples were taken from the sites of Kuyruk-Tobe and Taraz, and one sample each from Otyrar, Kayalyk, and the Talas Valley tortkuls of Talapty and Zhargul-2.

Sample No. 1 – A fragment of the body of a thin-walled vessel made of transparent blue glass with a small number of oxygen bubbles. Found in Trench No. 1, Room No. 2 (TAE-83) during excavations at the Taraz city-site in 1983. The fragment is “clean”, with no patina or carbonate layers (Fig. 1: 1).

Sample No. 2 – A fragment of the body (possibly the lower part) of a vessel made of opaque dark brown glass with minor oxygen bubbling. The color intensity fades in places. Found in Trench No. 1, Room No. 2 (TAE-83) at the Taraz city-site in 1983. The fragment is "clean", with no patina or carbonate deposits (Fig. 1: 2).

Sample No. 3 – A fragment of the body (possibly a lid) of a thin-walled vessel made of transparent yellow glass. Oxygen bubbles are visible in the glass, some large enough to be seen with the naked eye. The fragment is decorated with circular lines. Found at the Kuyruk-Tobe city-site in the Otyrar Oasis in 1983. The fragment is "clean", with no patina or carbonate layers (Fig. 1: 3).

Sample No. 4 – A fragment of the body of a glass object made of opaque dark brown glass, with visible oxygen bubbles. Found at the Kuyruk-Tobe city-site in the Otyrar Oasis in 1983. The fragment is covered by a thin layer of carbonates (Fig. 1: 4).

Sample No. 5 – A rim fragment of a thin-walled vessel made of semi-transparent blue glass. Oxygen bubbles are visible. Found at the Otyrar city-site in 2012. The fragment is "clean". with no patina or carbonates (Fig. 1: 5).

Sample No. 6 – A body fragment (possibly window glass) of a thin-walled vessel made of transparent blue glass. Oxygen bubbles are visible. Found at the Antonovka (Kayalyk) city-site in 2012. The fragment is "clean", with no patina or carbonates (Fig. 1: 6).

Sample No. 7 – A body fragment made of opaque, thick-walled blue glass. Found at the Talapty tortkul site in 2021. The fragment is covered with a thin layer of patina (Fig. 1: 7).

Sample No. 8 – A body fragment of opaque blue glass. Found 1 at the Zhargul-2 tortkul site in 2021. The fragment is covered by a significant layer of patina (Fig. 1: 8).

Table 1. Results of X-ray spectral microanalysis (average compound content in %)
Таблица 1. Результаты рентгеноспектрального микроанализа (среднее значение соединений в %)

Archaeological Site	**Sample No.**	**Glass Color**	Results of X-ray Spectral Microanalysis (Average Compound Content in %)												
			Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	MnO	FeO	TiO_2	CuO
Taraz (TAE-83)	1	Transparent blue	12,64	3,82	3,56	64,05	0,44	0,38	0,39	4,93	8,27	0,43	1,08	-	-
Taraz (TAE-83)	2	Opaque dark brown	12,68	3,36	3,95	63,94	0,26	0,35	0,41	4,52	8,85	0,27	1,26	-	-
Kuyruk-Tobe (K-R-T-83)	3	Transparent yellow	11,80	4,26	6,13	60,13	0,34	0,49	0,52	3,82	9,07	1,34	1,71	-	-
Kuyruk-Tobe (K-R-T-83)	4	Opaque dark brown	14,00	3,98	5,79	60,47	0,32	0,59	0,78	3,13	9,08	0,16	1,49	-	-
Otyrar (OT-2012)	5	Semi-transparent blue	12,89	3,44	4,33	63,06	0,40	0,58	0,27	5,20	6,99	-	1,10	0,27	1,47
Antonovka (Kayalyk-2007)	6	Transparent blue	8,10	3,85	5,78	65,00	0,63	0,33	0,52	6,93	7,69	0,03	0,81	0,33	-
Talapty (2021)	7	Blue glass	8,36	5,87	10,83	61,62	0,99	1,29	2,08	4,47	3,38	-	1,10	-	-

Zhargul-2 (2021)	8	Opaque blue	1,92	5,01	8,12	49,54	0,86	1,22	0,93	4,84	22,92	0,29	3,97	0,37	-

Table 2. Results of X-ray spectral microanalysis (average element content in %)
Таблица 2. Результаты рентгеноспектрального микроанализа (среднее значение компонентов в %)

Archaeological Site	**Sample No.**	**Glass Color**	Results of X-ray Spectral Microanalysis (Average Compound Content in %)													
			O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Mn	Fe	Ti	Cu
Taraz (TAE-83)	1	Transparent blue	43,95	9,45	2,32	1,91	30,28	0,20	0,16	0,40	8,27	4,15	0,34	0,85	-	-
Taraz (TAE-83)	2	Opaque dark brown	44,58	9,41	2,03	2,09	29,88	0,11	0,14	0,41	3,76	6,33	0,21	0,96	0,09	-
Kuyruk-Tobe (K-R-T-83)	3	Transparent yellow	43,16	8,86	2,61	3,30	28,66	0,15	0,20	0,54	3,24	6,63	1,06	1,36	0,23	-
Kuyruk-Tobe (K-R-T-83)	4	Opaque dark brown	45,73	10,21	2,35	2,98	27,46	0,14	0,23	0,75	2,51	6,29	0,12	1,12	0,11	-
Otyrar (OT-2012)	5	Semi-transparent	44,71	9,52	2,06	2,28	29,32	0,18	0,23	0,26	4,29	4,97	-	0,85	0,16	1,17
Antonovka (Kayalyk-2007)	6	Transparent blue	50,64	5,61	2,13	2,78	27,34	0,24	0,12	0,45	5,08	4,85	0,02	0,56	0,18	-
Talapty (2021)	7	Blue glass	65,42	4,57	2,43	3,76	17,98	0,24	0,29	1,18	2,18	1,42	-	0,53	-	-
Zhargul-2 (2021)	8	Opaque blue	51,79	1,25	2,62	3,67	19,46	0,30	0,40	0,76	3,32	13,50	0,19	2,57	-	-

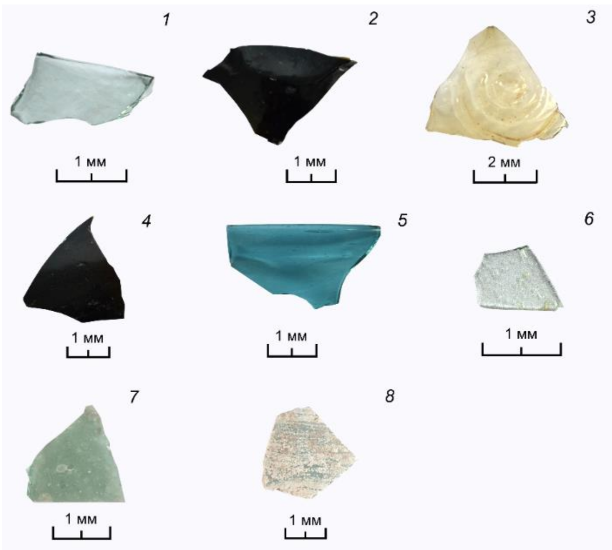

Figure 1. Glass fragments selected for X-ray spectral analysis: 1 – Glass fragment. Taraz city-site, 1983; 2 – Glass fragment. Taraz city-site, 1983, 3 – Glass fragment. Kuyruk-Tobe city-site, 1983; 4 – Glass fragment. Kuyruk-Tobe city-site, 1983; 5 – Glass fragment. Otyrar city-site, 2012; 6 – Glass fragment. Kayalyk (Antonovka) city-site, 2007; 7 – Glass fragment. Talapty Tortkul, 2021; 8 – Glass fragment. Zhargul-2 Tortkul, 2021
Рис 1. Фрагменты стекол, отобранные для рентгеноспектрального анализа: 1 – Фрагмент стекла. Городище Тараз. 1983 год; 2 – Фрагмент стекла. Городище Тараз. 1983 год; 3 – Фрагмент стекла. Городище Куйрук-тобе. 1983 год; 4 – Фрагмент стекла. Городище Куйрук-тобе. 1983 год; 5 – Фрагмент стекла. Городище Отырар. 2012 год; 6 – Фрагмент стекла. Городище Каялык (Антоновка). 2007 год; 7 – Фрагмент стекла. Торткуль Талапты. 2021 год; 8 – Фрагмент стекла. Торткуль Жаргуль-2. 2021 год

Discussion

According to V.A. Galibin, the chemical process that leads to the formation of glass mass is based on the reaction between silica and the carbonates of alkali and alkaline earth metals. The chemical composition of any glass object typically includes three fundamental groups of elements, each contributing to specific functions in glass formation: glass formers, colorants/decolorants/opacifiers, and additives/impurities.

The *glass-forming* elements include silicon, sodium, aluminum, potassium, calcium, magnesium, lead, barium, and boron. The glass samples selected for this study contain almost all of these elements, with the exception of boron, barium, and lead. Nearly all fragments exhibit high concentrations of silicon and sodium compounds, which corresponds to the raw batch composition characteristic of the "Eastern" glassmaking school (sand + plant ash). The concentration of these compounds reflects the specific chemical makeup of the raw materials –namely, the sand and the plant ash used.

The situation with aluminum and its oxide is more complex. While many researchers consider aluminum a glass-forming element, Galibin–one of the pioneers in using chemical composition of glass as an archaeological source–suggests that aluminum may have entered the glass mass unintentionally. During the initial melting phase in ceramic crucibles, the clay could have reacted with the batch materials. Since clay minerals are aluminosilicates, they may have "contaminated" the mixture with aluminum (Galibin, 2001: 48). At the same time, aluminum could have also been present in the plant ash or sand. The presence of aluminum in glass has long raised questions regarding its origin. In the analyzed samples, aluminum concentrations range from 1.91 % to 3.67 %, with the highest value (3.76 %) found in the sample from the Talapty tortkul (2021).

The concentration of the primary glass-forming compound–silicon dioxide (SiO_2) – in the analyzed samples ranges from 17.98 % to 30.28 %, which is determined by the composition of the sand used in the glass batch. The lowest silica concentration was recorded in the sample from the Zhargul tortkul site (2021).

Phosphorus, sulfur, and chlorine–whether in combination with each other or with other elements may have acted as *colorants, decolorants, clarifiers, or opacifiers*. These elements can influence properties such as color, transparency, or saturation of the glass, or they may simply be unintentional impurities. Therefore, the interpretation of their presence in the samples should be based not only on the fact of their inclusion, but primarily on their chemical behavior. The phosphorus content in the samples does not exceed 1 %. Since phosphorus is a component of plants, its presence further supports the sand-and-plant-ash composition of the batch. During glass melting, most phosphorus volatilizes under high temperatures, but as part of the initial batch, it may remain in trace concentrations.

Iron and its oxide play a different role. Iron tends to impart a greenish hue to glass. To neutralize this coloring effect, decolorants were intentionally added to the batch. For example, in the sample from the Kuyruk-tobe settlement, iron is present at 1.36 %, while the manganese content exceeds 1 %. In this case, manganese oxide likely acted as a decolorizing agent, giving the glass a yellow tint.

In the medieval period, the color of glass primarily depended on the presence and chemical properties of the glass-forming components. In the sample from Otyrar city-site, the copper content exceeds 1 %, while manganese oxide is absent. Given the levels of silicon and sodium in this specimen, it can also be classified as a sand-and-plant-ash glass. Since cobalt is not present in the composition, it is safe to conclude that copper acted as the main colorant, imparting a rich blue color to the glass.

Overall, based on the presence of coloring agents, the analyzed samples can be divided into two groups. The first includes samples from the sites of Taraz, Kuyruk-tobe, Kayalyk, and the tortkuls of Talapty and Zhargul-2, whose glass is colored with manganese. The second group includes the sample from Otyrar, which was colored using copper oxide.

Results

The results of the X-ray spectroscopic microanalysis reveal a relatively homogeneous pattern. All samples are classified as sodium–plant ash alkali glasses of the Na_2O–K_2O–CaO–MgO–Al_2O_3–SiO_2 type (Valiulina, 2013: 26). The relative content of magnesium oxide indicates that dolomites were the primary source of alkaline earth materials in the glass batch.

An exception is the blue glass fragment from the Zhargul-2 tortkul site, which shows a minimal Na_2O concentration (1.92 %). Given the elevated calcium content, the alkaline earth source in this batch was likely dolomitic limestone. A close analogy to this sample can be found in the rim fragment of a light green vessel from the Samosdelka settlement, which was made of K-Ca-Si glass. According to widely recognized chemical classifications and subtypes, the Zhargul-2 sample corresponds to Western European glassmaking traditions (Valiulina, Zilivinskaya, 2010: 71).

The relative concentrations of elements that do not exceed the conventional threshold of 1 %–such as phosphorus, titanium, and chlorine–indicate their initial presence in the glass batch and classify them as unintentional impurities. The presence of these impurities in the glass compositions directly suggests that medieval glassmakers may have used locally available raw materials in the production process–such as quartz sand naturally containing titanium oxides and elevated levels of alumina, as well as plant ash, which "contaminated" the batch with trace amounts of phosphorus and chlorine. No detectable levels of cobalt, antimony, or lead were found in the analyzed samples.

As previously noted, a significant body of analytical data on ancient and medieval glass has now been accumulated by researchers across nearly the entire continent. Each of these studies has enabled the identification of chemical types of glass and the recipes (or technological traditions) used by ancient artisans.

The most widespread chemical type of ancient glass is soda glass, which is characteristic of Egyptian and Phoenician production schools (Galibin 1983: 98). This type is distinguished by a high Na_2O content and a low K_2O concentration (up to 1–1.5 %) (Rumyantseva, 2015: 22). Soda glass produced according to the Phoenician or Egyptian recipes was widely used during the Roman and Early Byzantine periods (Yegorykov, Plokhov 2019: 93), although this recipe continued to be used in some regions during the medieval era. According to V.A. Galibin, Chinese glass up until the early 3rd century CE is characterized by a high barium content, while medieval Chinese glass often contains lead.

The results of the X-ray spectroscopic microanalysis conducted by the authors clearly show that the analyzed samples do not correspond to soda glass types, nor to traditions where lead was employed as a primary glass-forming component. The compositions of the medieval Kazakhstani samples most closely align with those from Central Asia.

During the medieval period, glassmaking workshops in Central Asia followed the so-called "Eastern" glassmaking tradition, which utilized a mixture of sand and unrefined plant ash as the primary glass-forming raw materials. The availability of certain ingredients for the glass batch not only reflects the production school and the chemical types and subtypes of the glass but also highlights regional variations in the composition of the batch materials themselves.

Table 3 presents the results of quantitative chemical analyses of glass samples from major urban centers in Central Asia dating from the 8th to the 13th centuries. In the mid-20th century, quantitative (wet) chemical analysis was considered the most accurate method for determining the concentrations of various compounds and elements in glass compositions. The compositional parallels revealed between glasses analyzed by both methods may raise some questions; however, comparisons remain valid due to the fact that average values of compounds and elements tend to exhibit only minimal deviations.

Table 3. Average chemical composition of medieval glasses by historical-geographical regions (Based on the correlation of wet chemical analysis by A.A. Abdurazakov and M.A. Bezborodov, and the X-ray spectral analysis by the authors)

Таблица 3. Средние значение химических составов средневековых стекол по историко-географическим областям (количественных химический анализ согласно корреляции Абдрузакова А.А. и Безбородова М.А. и рентгеноспектрального анализ авторов)

	Results of quantitative (wet) chemical analysis (Average values in %)				Results of X-ray spectral analysis (Average values in %)	
Oxides	**Southern Tajikistan**	**Bukhara Oasis**	**Ferghana**	**Khorezm**	**Otyrar Oasis**	**Talas Valley**
Oxides						
Na_2O	14.89	18.25	18.02	16.79	13.02	9.08
MgO	4.85	5.64	4.74	4.84	4.0	4.01
Al_2O_3	1.48	4.75	4.20	1.95	5.30	7.01
SiO_2	67.47	59.22	63.50	68.44	60.37	63.94
K_2O	2.42	4.41	2.35	12.85	4.02	4.52
CaO	7.52	8.18	6.73	6.78	7.02	7.5
SO_3	0.06	0.39	-	0.17	0.58	1.05
TiO_2	-	0.08	0.14	-	0.27	0.37

Conclusion

Preliminary results based on the X-ray spectroscopic microanalysis of eight glass samples suggest that medieval glass production in Kazakhstan was comparable to that of the major urban centers of Central Asia. The proportion of the primary glass-forming component, SiO_2, is generally similar across the samples, with only slight variations in concentration. This indicates a comparable glassmaking recipe while also reflecting chemical differences in the sand used as a raw material.

The Na_2O content is comparable to that found in glass from southern Tajikistan, particularly from Panjakent, as well as to the average values observed in the samples from the Kuyruk-Tobe and Otyrar city-sites. However, the sodium oxide concentration is higher than that of samples from the Talas Valley archaeological sites.

The analyzed samples also exhibit an elevated alumina (Al_2O_3) content in comparison with glass samples from Central Asia. The difference in Al_2O_3 levels exceeds 1 %, suggesting the possible existence of a local glassmaking industry that utilized raw materials with a higher alumina content.

The K_2O content in glasses from the Otyrar Oasis and Talas Valley sites ranges between 4.0–4.6 %, aligning with the average potassium oxide concentration observed in glass from the Bukhara Oasis and exceeding that of glasses from Tajikistan, Ferghana, and Khwarezm.

An elevated SiO_2 content was recorded in the sample from the Kayalyk city-site. Notably, this result contrasts with the data from the quantitative chemical analysis conducted in 2009, which showed SiO_2 levels in two Kayalyk samples not exceeding 55 % (Doszhanova 2009: 166). X-ray spectral microanalysis, which in some respects surpasses traditional wet chemical analysis, has not revealed such critical discrepancies when compared with similar analyses of glass from Central Asian sites. Therefore, it would be reasonable to conduct additional research on the Kayalyk glass to obtain more accurate conclusions.

In the context of the 21st century, given the continuous and dynamic development of analytical technologies, it is essential to incorporate results from cross-method analyses–such as spectral, spectroscopic, X-ray structural, and chemical durability tests–into research. However, according to early researchers of glass artifacts, each analytical method solves a number of specific issues while failing to address others. Yulia L. Shchapova, a pioneer in the study of ancient and medieval glasses of Central Eurasia, noted that "... despite the high value and potential of technical methods in the study of the history of glass, the successes achieved thus far should be considered more practical and local than general and theoretical…" (Shchapova 1977: 95). According to Shchapova, the primary task in glass research is to identify the technological features and glassmaking principles of particular production schools. It would be erroneous to localize any given fragment to a single workshop, considering the advanced level of trade from antiquity to the late Middle Ages and the high likelihood that glass found at one archaeological site may have been produced in a completely different region. Moreover, there are known cases where raw glass or cullet was transported from one geographic area to another due to its advantages over local glass materials. Nevertheless, the identification of specific glassmaking principles and recipes using specialized analyses, including X-ray spectral techniques, may serve as a reliable basis for determining the place of manufacture, taking into account the chemical properties of the batch components.

The presence of specific components in the composition of glass samples, based on the results of analyses of medieval glass artifacts from sites in southern and southeastern Kazakhstan, makes it possible not only to distinguish them from Central Asian glass but also to date them to the 12th–13th centuries. This conclusion is supported by the absence in the glass composition of several key ingredients: natural soda, which was a primary component of glass in the ancient period; antimony, used as a decolorizing agent until the 4th century CE; and lead, commonly used as a primary glass-forming agent. Moreover, the manufacturing methods also support this chronological framework. Most of the analyzed samples–except for the fragment from the Talapty tortkul–are thin-walled and contain a noticeable number of air bubbles, indicating the use of a glassblowing pipe in their production. The dating of the analyzed samples is based on typological parallels with artifacts from Central Asia and Golden Horde period sites in Russia and will require further refinement.

The preliminary results of this study of medieval glass artifacts suggest that there were at least two distinct glassmaking schools on the territory of Kazakhstan during the medieval period–one at the Taraz settlement and another at the Otrar settlement–each employing similar glassmaking recipes but using different raw material combinations in the batch formulation.

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МАЗМҰНЫ

ТАРИХНАМА ЖӘНЕ ДЕРЕКТАНУ

ТАРИХ

ЭТНОЛОГИЯ/АНТРОПОЛОГИЯ

СОДЕРЖАНИЕ

ИСТОРИОГРАФИЯ И ИСТОЧНИКОВЕДЕНИЕ

ИСТОРИЯ

ЭТНОЛОГИЯ/АНТРОПОЛОГИЯ

CONTENTS

HISTORIOGRAPHY AND SOURCE STUDIES

HISTORY

ETHNOLOGY/ANTHROPOLOGY

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