
**NATURAL SCIENTIFIC METHODS
IN STUDYING CULTURAL HERITAGE OBJECTS**

Comparative Analysis of the Elemental Composition of Antique Ceramics from Knidos and Kos: Clarification of Localization

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Abstract—The analysis of the main and micro-impurity elemental composition of fragments of antique amphorae with features and stamps of the Knidos and Kos centers of production has been carried out. Differences in the groups of samples from Kos and Knidos have been detected in terms of the Si and Fe content, which can be considered as evidence of different technological characteristics. Specifically, the high concentration of quartz/silica sand in the clay of the amphorae produced in Kos and the use of iron-rich clay in the products of Knidos should be noted. Statistical analysis indicated the stratification of the samples according to the main elements and impurities (Al, Si, Ca, Mg, Fe, K, Ti) into 3 groups Kos and two groups of Knidian samples typical for the island (Kos) and continental (Knidos) origin of the samples.

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INTRODUCTION

The existence of ceramic containers in the two famous winemaking centers of Knidos and Kos was known more than a hundred years ago. Back in the middle of the 19th century, stamps with the Knidian ethnicon began to be distinguished from the total mass of ceramic stamps, and at the beginning of the 20th century, double-barreled handles were proposed to be attributed to the amphorae of Kos. For a long time, it was believed that the large-scale production of wine and amphorae fell in the Hellenistic era. At present, thanks to archaeological research in the territory of colonies, it has been reliably established that winemaking and, accordingly, amphora production, existed here at an earlier time. However, as a result of these studies, including in the found amphora workshops, no whole vessels were found, which made it difficult to identify them.

Several years ago, based on materials from the northern Black Sea sites in [1, pp. 101–110; 2, p. 19], taking into account the morphological features and the presence of stamps, a typology of Koan and Knidian amphorae was proposed, including those for the 4th century. At the same time, some doubts remained about the belonging of individual amphorae included in the typological schemes to specific centers. This

refers to vessels, the morphological features of which are not quite typical for the bulk of amphorae. This applies equally to both centers. In addition, containers of the first three quarters of the 4th century raise considerable doubts, primarily due to the great rarity of the stamps at that time. Also, many questions were raised by the attribution of amphorae with single-barreled handles to the Koan containers.

The geographical proximity of the colonies also raises a fair question, how reliable is the localization of vessels carried out on the basis of morphological features.

Only a comparative analysis of a clay puddle, which was the objective of this paper, can help to understand this situation. When studying the composition of fragments of ancient amphorae, we used a combination of integral and local methods for analyzing the elemental, phase, and morphological composition, which had previously shown their effectiveness in the study of ceramic objects of cultural heritage [3–5].

MATERIALS AND METHODS

The objects of study were fragments of ancient amphorae, including those with stamps associated

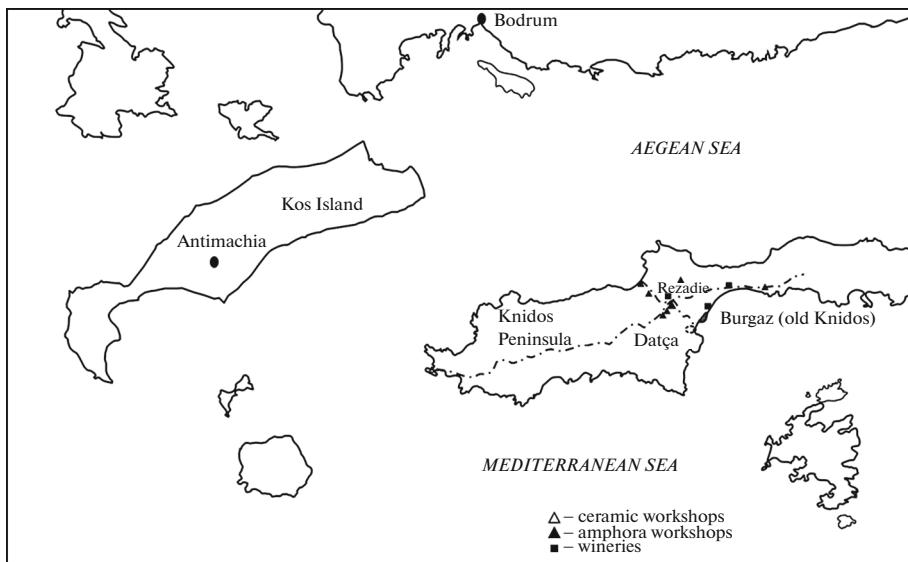


Fig. 1. Location of workshops on the Knidian Peninsula and Kos Island [6].

with the production centers of the Mediterranean basin of Kos and Knidos (Figs. 1–3, Tables 1, 2). From Knidos, 28 samples of vessels were selected (samples 17kn–20kn, 22kn, 22-bkn, 22-vkn, 55kn, 84kn, 90kn, 128kn–137kn, 143kn, 144kn, 157kn, 166kn, 168kn, 219kn–221kn), and 16 samples from amphorae identified as produced on the island of Kos (samples 23k, 24k, 24-b k, 25k, 62k, 89k, 139k, 140k–142k, 154k, 164k, 167k, 172k, 176k, 177k). The samples are dated to the second quarter of the 4th–2nd centuries BC.

Vessels of Knidian production. Whole and fragmented vessels and spalls from several stamps belong to Knidian production (Tables 1, 2, Fig. 2). The earliest in the sample list is an amphora of the so-called “Elizavetian” variant from burial no. 224 of the Pri-kubansky burial ground (sample 220kn) from 360–350 BC. [7]. Amphorae of the “Chersonesos” variant from burials no. 353 (sample 168kn) and 105 (sample 166kn) of the same burial ground are dated slightly later (340–330 BC). It is very important that the samples from the stamped specimens were analyzed. So, sample 55kn is the neck of an amphora of the same “Chersonesos” version [1, p. 103–104] with a monogram stamp ΠΑΘ or ΑΠΟ (Fig. 2). Another sample, 90kn, was taken from a fragment of a vessel with exactly the same stamp (Fig. 2), but with a different profile of the rim, which automatically assigns it to a different type of container [1, p. 104]. Two more samples were taken from the Knidian stamps: sample 22-v kn—from the stamp with the “hallmark” of the last quarter of the 4th—early 3rd centuries BC (Table 2), sample 22-b kn, from the stamp of the beginning of the 2nd century BC [8, p. 564], containing ethnicon (Table 2).

Of great interest is sample 221kn from a rather rare amphora, the manufacture of which in Knidos raises some questions. Despite the general morphological similarity with traditional Knidian specimens, the vessel is distinguished by the peculiar shape of the stem (Fig. 2). The body of the vessel is very large, the neck is short, and the rim is less massive. Such rims are known from excavations on the Knidian Peninsula and are characteristic of the vessels of the last third of the 4th century BC [9, p. 162]. However, in the materials of the Northern Black Sea region, such amphorae are extremely rare. Unfortunately, the museum has not preserved information about the place where this vessel was found.

Several exemplars of the sample list (17kn, 18kn, 19kn, 20kn, 219kn) belong to the vessels of the “pythoid” variant of the last third of the 4th to early 3rd centuries BC. Unfortunately, the sampling of 11 clay samples (129kn–137kn, 143kn, 144kn) was not entirely correct and all that we can say about them is that they were taken from the Knidian stamps containing the ethnicon and dating in a wide range of the 3rd century BC. At the same time, they can act as reference samples, since there is no doubt that they belong to Knidian production. The latest specimens are represented by stamped vessels from the middle of the 3rd century BC (sample 84kn) and the very beginning of the 2nd century BC (samples 22-bkn and 157 kn).

Amphorae of Kos. As for the clay samples from the Koan amphorae (Fig. 3), the earliest among them are amphorae of the early variant I–A of the second to third quarters of the 4th century BC from burials no. 402 (sample 167k) and no. 103 (sample 177k) of the Pri-kubansky necropolis, burial no. 37 of the western

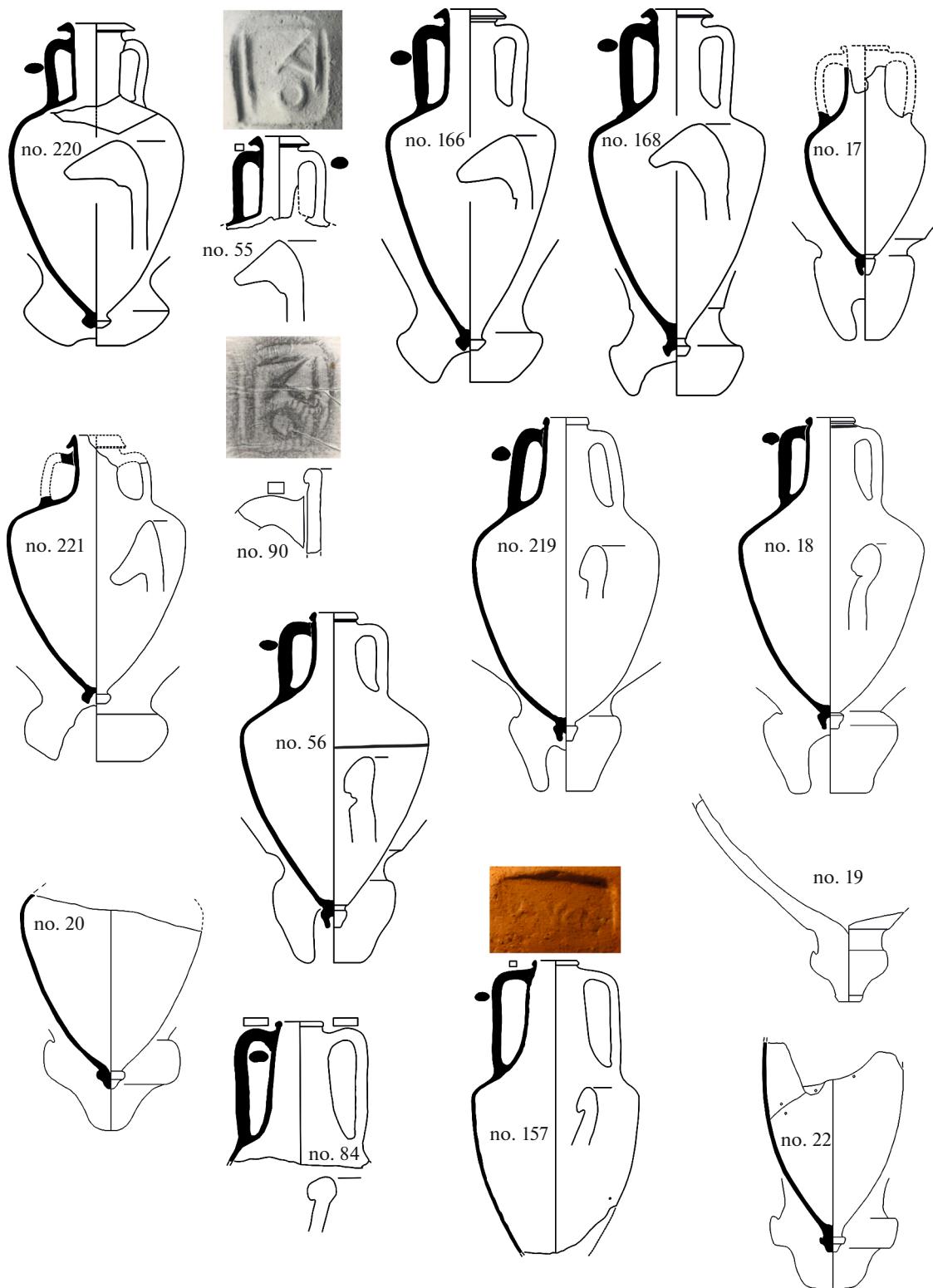


Fig. 2. Knidian amphorae nos. 17kn-20kn, 22kn, 55kn, 84kn, 90kn, 157kn, 166kn, 168kn, 219kn, 220kn.

burial ground of Starokorsunskoe settlement no. 2 (sample 176k). Samples 23k, 24k, 62k, 154k, 164k, and 172k belong to a later time (their detailed description is given in [2]). Two samples, 62k and 154k, have

morphological features that are not quite typical for the bulk of the vessels, which raises some doubts about the belonging of these amphorae to the production of Kos. The sample list contains two samples taken from

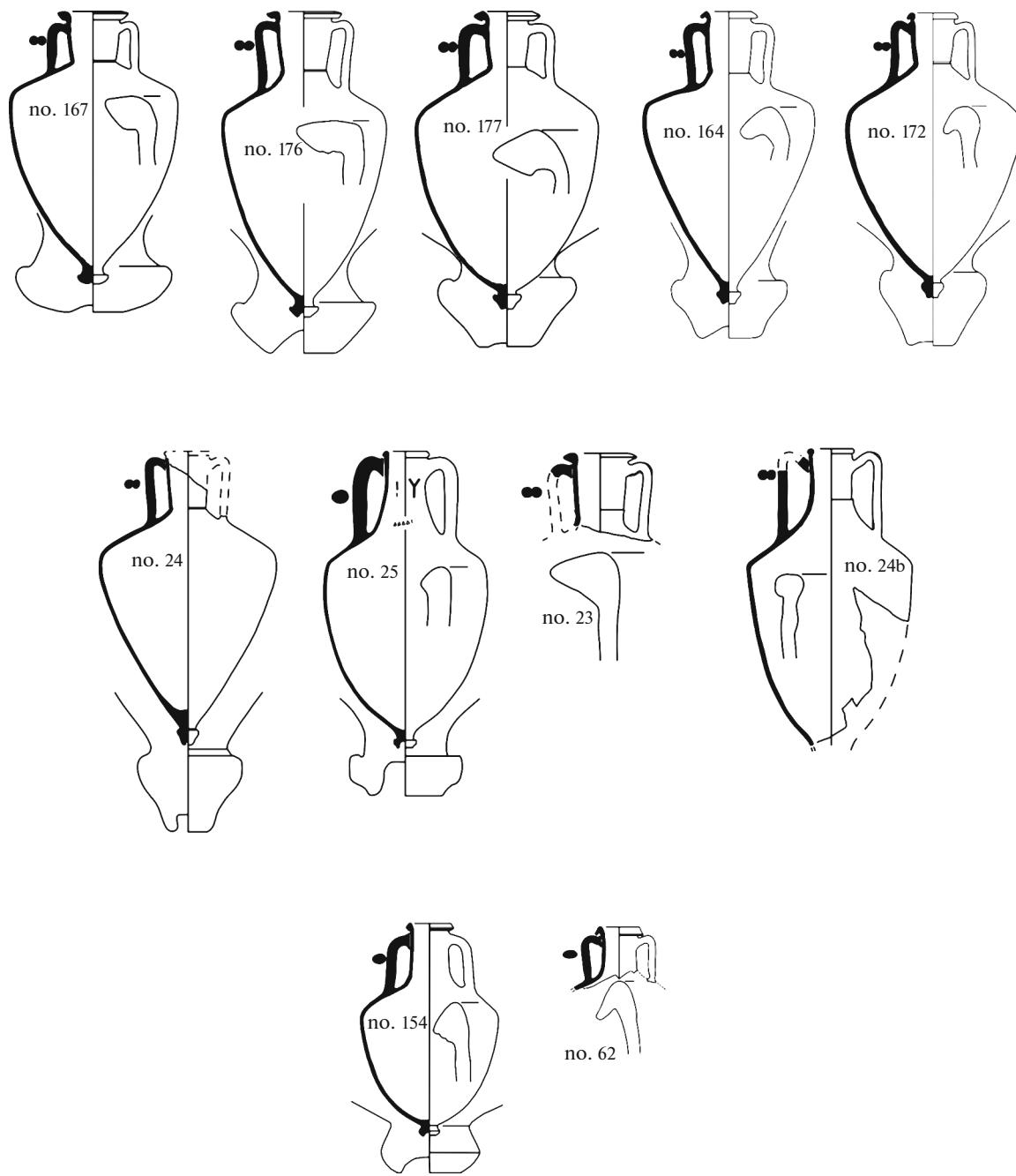


Fig. 3. Koan amphorae nos. 23k, 24k, 24bk, 25k, 62k, 154k, 164k, 167k, 172k, 176k, 177k.

the Koan stamps, 89k and 141k (Table 2). The chronology of the stamps of this center is rather poorly developed, and these specimens can be dated very widely 3rd–2nd centuries BC. Three more samples (139k, 140k, 142k) were taken from the stamped double-barreled handles of Koan amphorae. Unfortunately, we do not have any other information about them and we can widely date them to the 3rd century BC.

Elemental analysis of the basic composition of ceramics was carried out by scanning electron

microscopy with energy-dispersive X-ray analysis (SEM/EDX). The measurements were carried out on Versa 3D and Quanta 3D scanning electron microscopes (Thermo Fisher Scientific, USA) at an accelerating voltage of 30 kV in low vacuum (30–70 Pa) to exclude the accumulation of static electricity. Since the total content of detected elements is reduced to 100%, the results obtained are considered semi-quantitative. The sensitivity of the method is 0.1–0.5 wt %. To exclude the influence of numerous impurities on the data on the composi-

Table 1. Metric parameters of the amphorae from which the clay samples were taken, with the indication of the chronology

Sam- ple	Origin	Place of storage	Linear dimensions, mm						Date, BC	
			H	H ₀	H ₁	H ₃	D	d ₁		
Amphorae of Knidos (Fig. 2)										
220kn	Prikubanskiy burial ground, burial 224 (26)	KM No. 11600/810	~720	~645	~300	~170	~395	175	360–350	
55kn	Geroevka-86, field inventory f.i. 24	Kerch?				220		172	335–300	
166kn	Prikubanskiy burial ground, burial 105 (11)	KM No. 11570/734	806	760	320	~210	400	170	350–325	
168kn	Prikubanskiy burial ground, burial 353 (2)	KM No. 11600/1983	818	743	335	~200	413	168	350–325	
221kn	Possibly Lenin's farm	KM unnumbered	634	598	250	~145	420	~140	335–300	
17kn	Olbia, 1989	OR, Ol.89/134	pres. 493				282		335–300	
219kn	Prikubanskiy burial ground, burial 103 (11)	KM No. 11570/709	764	712	350	~175	440	108	335–300	
18kn	Gorgippia, 1981, burial 25	AAM No. 7065/8	734	680	315	~165	438	114	335–300	
20kn	Gorgippia, 1981, burial 25, in. 66	AAM, w/n	pres. 410				430		335–300	
84kn	Chersonesos	SHCMR TC	pres. 345					~113	250–225	
22kn	Tarkhankut expedition 1987, Bolshoi Kastel TE-87, BK/28		pres. 480				330		200–150	
157kn	Taman archaeological expedition TAE-96, Tuzla, necropolis, o. 8	KM No. 10565/28	pres. 690		330	~260	392	110	200–170	
Amphorae of Kos (Fig. 3)										
167k	Prikubanskiy burial ground, burial 402 (2)	KM No. 11600/2332	690	645	240	~125	422	176	375–345	
176k	Kuban archaeological expedition, Starokorsunskoe settlement No. 2, western burial ground, excavation V, burial 356z KAE-96, Starokors. settl. No. 2, west. burial, ex. V, b. 356z (1)	KM No. 10566/95	774	720	300	150	416	188	350–325	
177k	Prikubanskiy burial ground, burial 103 (12)	KM No. 11570/710	754	692	300	~140	466	168	350–325	
164k	Prikubanskiy burial ground, burial 335 (10)	KM No. 11600/1841a	740	686	280	~160	436	144	325–300	
172k	Prikubanskiy burial ground, burial 65 (68)	KM No. 11570/391	718	664	290	~124	444	128	320–280	
24k	Gorgippia-81, burial 25, in. 62	AAM No. 10933/62	pres. 713	~660		~185	446		325–300	
25k	Tarkhankut expedition, 1979, estate 7/2, inventory 2/80TE-79, U7/2, inventory 2/80		750	710	355	200	415	~118	300–275	
62k	Estate on allotment No. 26	SHCMR TC No. 5/36461	pres. 170			125		125	300–275	
23k	Gorgippia-79, West, b. 11, pit	AAM(?)	pres. 220			175		184	300–250	
24-bk	Tarkhankut expedition 1987, Bolshoi Kastel 21, inventory 109/2TE-87, BK/21, in. 109/2		pres. 750		300	165	422	118	200–150	
154k	Myrmekion, necropolis, burial 66	SH, MN.53-10	536	500	245	140	347	118	325–275	

KM—Krasnodar Museum, OR—Olbia Reserve, AAM—Anapa Archaeological Museum, SHCMR TC—State Historical and Cultural Museum-Reserve Chersonesos Tavricheskiy, SH—State Hermitage, MN—Myrmekion necropolis, KHM—Kiev Historical Museum, SSU—Saratov State University, IACH—Institute of Archeology and Cultural Heritage.

tion of the ceramic base, SEM/EDX measurements were performed in three to five regions of the clay base without impurities. The obtained data on the composition were averaged. Sample preparation for the correct elemental analysis by the SEM/EDX method involved the preparation of thin sections of the samples, since the presence of surface irregular-

ities leads to distortions in determining the concentration of elements.

The content of micro- and trace impurities in the composition of ceramics was determined by inductively coupled plasma mass spectrometry (ICP-MS). Sample preparation, dissolution to a base concentration of 0.1 g/L, was carried out according to the

Table 2. Legends of the stamps from which the clay samples were taken, with the indication of the chronology

Sample	Origin	Place of storage, inventory number	Stamp	Legend	Date, BC
Stamps of Knidos					
22v kn		SHCMR TC, no. 120/36466		“Snout of ship”, ΠΑΣΙΚΡΑ	3/3 4 century BC
128 kn		SHCMR TC, 134/36466		“Snout of ship”	3/3 4 century BC
55kn	Geroevka, 1986, field inventory f.i. 24			ΠΑΘ	3/3 4 century BC
90kn	Olbia	KHM, no. 63-1252, Ol. 36/190		ΠΑΘ	3/3 4 century BC
157kn	Taman archaeological expedition TAE-96, Cape Tuzla, necropolis, object o. 8	KM, no. 10565/28		manufacturer Nisius (restoration by N.V. Efremov)	beginning of 2nd century BC
22-b kn	Tarkhankut expedition, 1987, Bolshoi Kastel, Dvor 8 TE-87, BK/Dv 8			ΕΠΙ ΑΣΚΛΗΠΙΟΔΑΡΟΥ ΘΕΙΥΔΑΜΟΥ ΚΝΙΛΙΟΝ	beginning of 2nd century BC
Stamps of Kos					
89k	“Taman Tholos”	SSU, no. IACH A-4		ΑΠΙΟΛΛΑ	3rd–2nd centuries BC
141k		SHCMR TC, no. 40/36578		Round, “crab” emblem (?)	3rd–2nd centuries BC

KM—Krasnodar Museum, SHCMR TC—State Historical and Cultural Museum—Reserve Chersoneses Tavricheskiy, KHM—Kiev Historical Museum, SSU—Saratov State University.

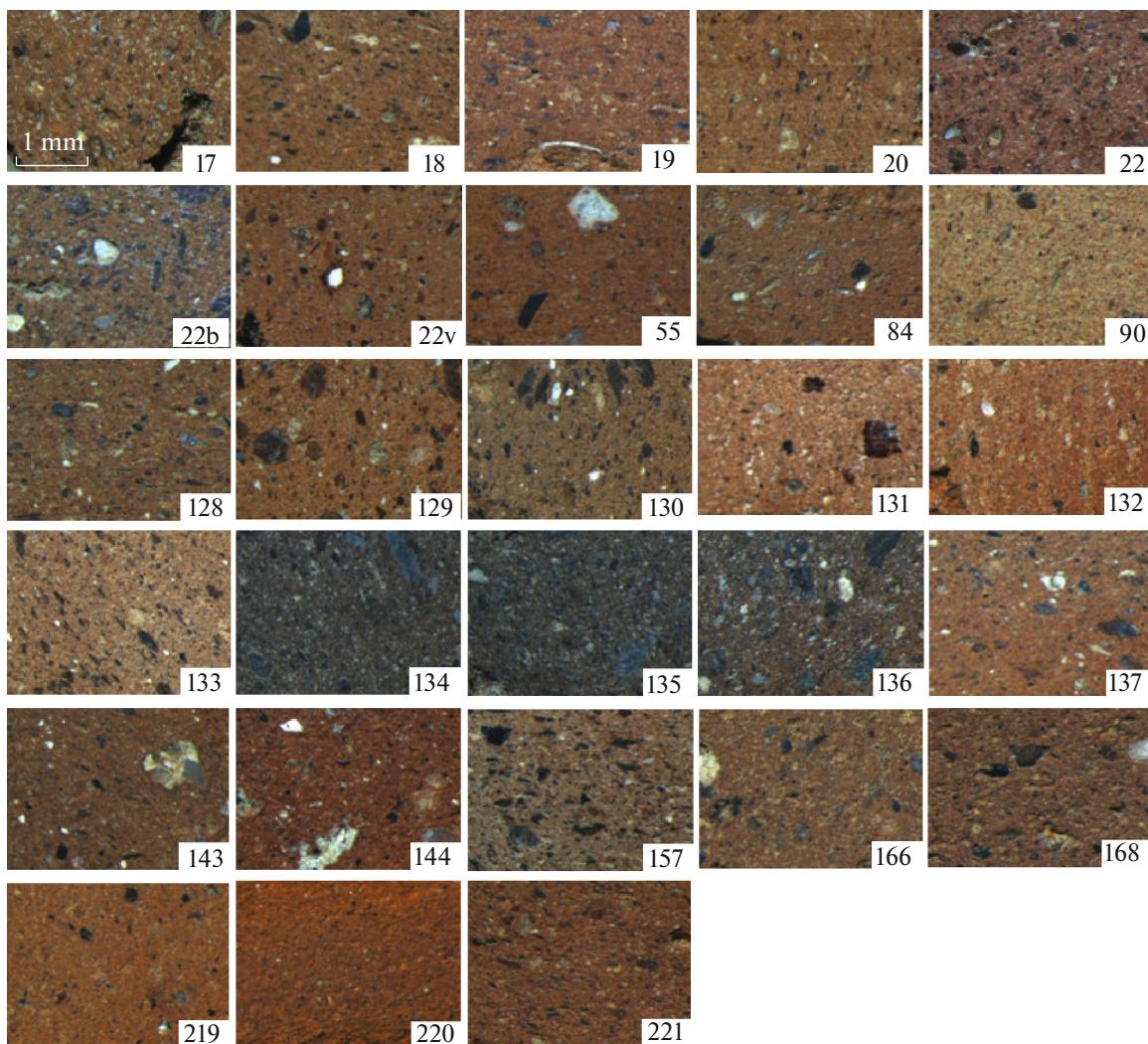


Fig. 4. Optical photographs of thin sections of Knidian samples.

protocol described in [4]. The measurements were performed on an iCapQ-c mass spectrometer (Thermo Fisher Scientific, USA), the content of elements was recorded using the most common isotopes of the determined elements, free from isobaric overlays. The use of multielement standards, High-Purity Standards A (48 elements) and B (13 elements), made it possible to determine the absolute values of the content of about 50 elements in a concentration of up to 10^{-10} – 10^{-12} wt %, excluding gassing elements. Correction of polyatomic overlays was performed using a reaction-collision cell (He/H). The reproducibility of the results was checked by double measurement of the working solutions. Calibration, elemental analysis, and correction of spectral overlays were performed using the QTegra software developed by Thermo Fisher Scientific.

Optical images of the polished surface of the samples (Figs. 4, 5) were obtained on an SMZ 1270 microscope (Nikon, Japan); the images were processed using the NIS-Elements program.

The generalized analysis of the data to systematize the results on the main composition of clay and trace impurities, to identify groups with the correlation of parameters included a principal component analysis (PCA) using the Statistica program, and binary diagrams of the content of various elements.

RESULTS AND DISCUSSION

According to the local SEM/EDX data analysis, the clay of most Kos and Knidos samples is characterized by a large amount of Ca and K, reaching 23.8 and 10.1%, respectively (Table 3). Among the differences between the products of Kos and Knidos, it is neces-

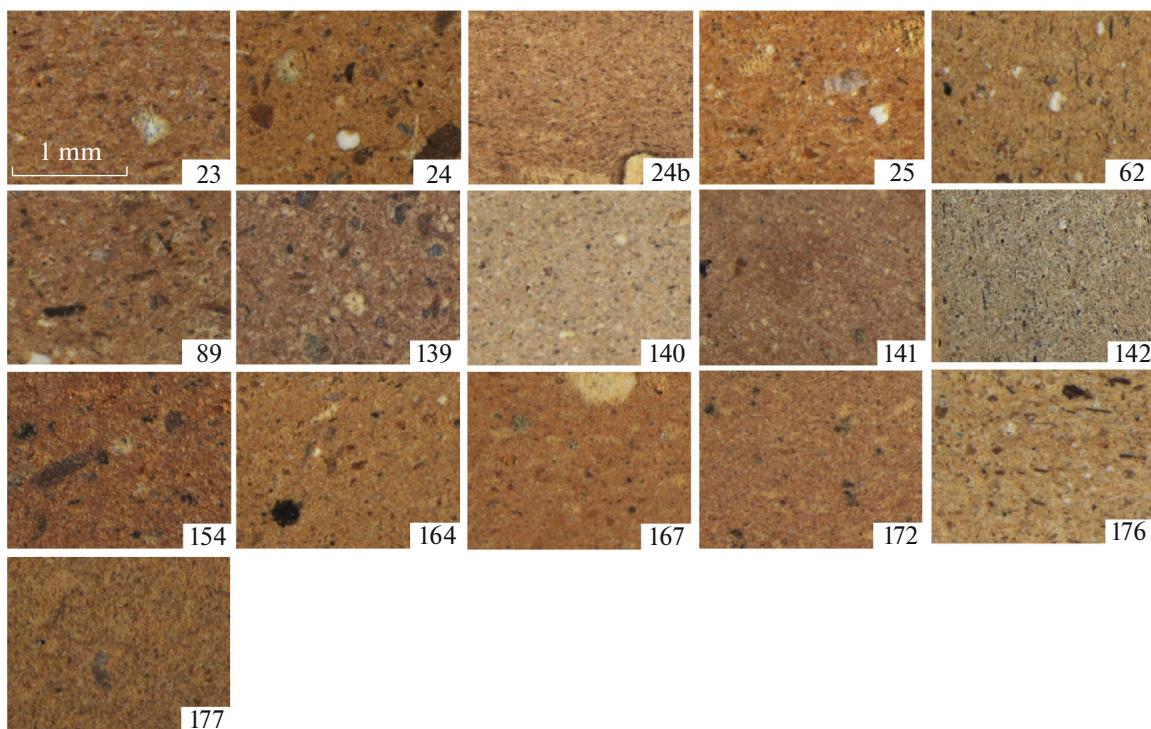


Fig. 5. Optical photographs of thin sections of Koan samples.

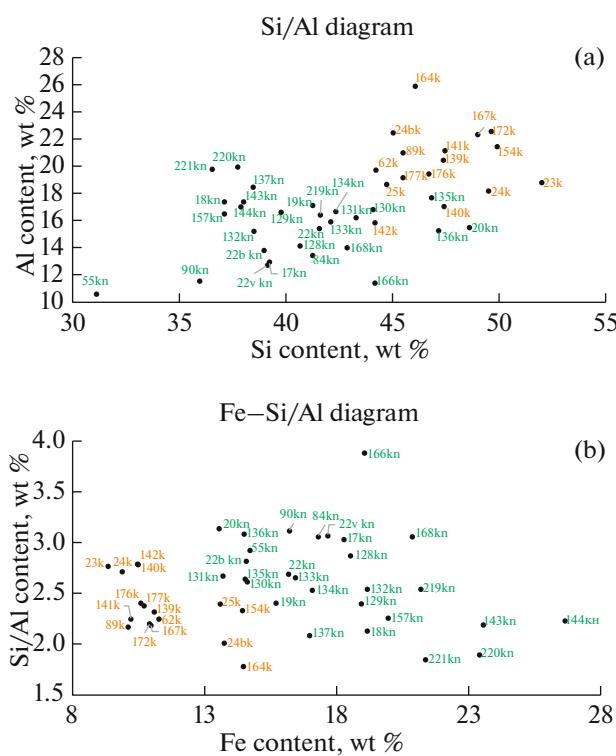


Fig. 6. Binary diagrams of the distribution of the Koan and Knidian samples according to SEM/EDX data depending on the content in the clay base of the samples of: (a) Al (Si), (b) Si/Al (Fe) ratio.

sary to note the variations in the content of Fe, Si, and Al. Analysis of binary diagrams of the contents of various elements according to SEM/EDX data shows that in most cases the samples from Kos are isolated into a separate group (Figs. 6, 7).

In the course of PCA of the composition of the clay base, according to SEM/EDX data, ten factors were identified (Table 4), of which factor 1 is determined by the content of Ca, Mg, Fe, Al, and Si (presumably, reflecting the correlation in the composition of the clay base), and factor 2, the content of K, Ca, Ti, and Fe (corresponding to the most frequently observed impurities in the composition of ceramics: field spar, field rutile, and iron oxides). Figure 8 shows the distribution of samples depending on factors 1 and 2. Two groups of the Knidos production center can be distinguished: {90kn, 17kn, 22-bkn, 22-bkn, 166kn} and {18kn, 19kn, 20kn, 22kn, 84kn, 128kn, 129kn, 130kn, 131kn, 132kn, 133kn, 134kn, 135kn, 136kn, 137kn, 138kn, 143kn, 144kn, 157kn, 168kn}, except for sample 55kn. Almost all of Kos is included in one group (with the exception of samples 142k and 164k). Note that sample 164k is distinguished by the highest Al content (Fig. 6a), as well as a high Fe level in combination with the smallest amount of Ca in the Koan group (Fig. 7a).

From a historical point of view, the group of Knidian samples is very interesting, demonstrating

Table 3. Elemental composition of the clay base according to SEM/EDX data

Sample	Chemical element content, wt %											
	Na	Mg	Al	Si/Al	Si	P	S	Cl	K	Ca	Ti	Fe
137kn	0.5	1.9	18.5	2.08	38.5	0.8	<0.5		8.9	12.0	1.8	17.0
220kn		4.0	19.9	1.89	37.7	0.8			6.1	7.0	0.9	23.4
130kn	0.5	2.6	16.8	2.62	44.1	<0.5	<0.5	<0.5	9.6	9.7	1.4	14.6
55kn	<0.5	5.8	10.6	2.93	31.1	0.6	<0.5	2	4.9	28.9	0.6	14.7
84kn	<0.5	4.6	13.5	3.06	41.2	<0.5		0.1	7.4	13.5	1.8	17.3
219kn	<0.5	6.7	16.4	2.54	41.6	<0.5			5.0	7.7	1.0	21.2
128kn	0.6	3.5	14.2	2.87	40.7	<0.5		<0.5	7.4	13.6	1.1	18.5
90kn	0.6	7.9	11.6	3.11	36.0	<0.5			7.7	19.1	0.7	16.2
143kn	0.6	3	17.4	2.19	38.0	0.6		0.6	9.0	5.8	1.4	23.6
144kn	0.6	2.8	17.0	2.22	37.9	0.5		<0.5	7.1	6.0	1.3	26.6
22-v kn	<0.5	6.8	12.8	3.07	39.2			<0.5	5.2	16.7	1.0	17.7
133kn	0.5	2.5	15.9	2.65	42.1			<0.5	9.3	10.8	2.3	16.4
157kn	<0.5	2.8	16.5	2.25	37.1			<0.5	6.4	14.3	2.4	20
134kn	0.5	2.1	16.7	2.53	42.3	0.5		<0.5	8.0	10.6	1.9	17.1
132kn	0.6	5.8	15.2	2.54	38.5				6.3	12.8	1.6	19.2
136kn	0.6	1.7	15.3	3.08	47.1	<0.5			8.7	10.6	1.1	14.5
131kn	0.6	2.5	16.2	2.67	43.3	0.5		<0.5	10.1	11.8	0.9	13.7
17kn	0.7	6.5	12.9	3.03	39.3	1.1			6.6	13.9	0.7	18.3
18kn	<0.5	4.5	17.4	2.13	37.1			0.5	9.1	9.0	2.8	19.2
19kn	0.7	4.1	17.1	2.41	41.3				7.4	12.3	1.3	15.7
20kn	1.0	2.6	15.5	3.13	48.6			<0.5	9.6	8.1	0.7	13.6
22kn	0.7	6.0	15.5	2.69	41.6	<0.5		<0.5	8.3	10.0	1.3	16.2
22-b kn	<0.5	3.1	13.8	2.82	39.0		0.5	<0.5	8.0	19.5	1.0	14.6
129kn	0.5	3.3	16.6	2.39	39.8			<0.5	9.2	10.2	1.4	18.9
135kn	0.6	2.3	17.7	2.64	46.8	<0.5		<0.5	10.1	6.2	1.3	14.6
168kn	0.6	3.8	14.0	3.06	42.9				6.1	10.9	0.8	20.9
166kn	<0.5	6.1	11.4	3.88	44.2				4.1	13.8	0.9	19
221kn	0.5	3.1	19.8	1.85	36.6	0.6	<0.5		7.7	8.9	1.4	21.4
23k	0.6	3.2	18.8	2.76	52.0	<0.5	<0.5		6.7	7.7	0.8	9.3
24k	0.7	3.4	18.2	2.72	49.5	<0.5		<0.5	6.3	10.4	1.0	9.9
24-b k	0.7	4.2	22.5	2.00	45.0	<0.5		<0.5	6.0	6.8	0.7	13.8
25k	<0.5	4.9	18.6	2.40	44.7	<0.5	<0.5	<0.5	6.6	9.9	0.8	13.6
62k	0	3.2	19.7	2.24	44.3	0.3	0	0.2	7.4	12.6	0.9	11.3
89k	0	2.1	21	2.17	45.5	0.3	0	0.4	7.1	12.6	0.9	10.1
139k	0.1	2.3	20.4	2.32	47.4	0.2	0	0.1	7.2	9.9	1.4	11.1
140k	0	3	17	2.79	47.4	0.4	0	0.1	6	14.7	0.8	10.5
141k	0.6	1.7	21.1	2.25	47.5	0.4	0	0.2	5.9	11.2	1.2	10.2
142k	0.5	6.9	15.8	2.79	44.2	0.4	0.2	0.7	5.6	14.6	0.6	10.5
154k	0	2.2	21.4	2.33	49.9	0.3	0.2	0.2	4.5	5.6	1.3	14.4
164k	0	2.7	25.9	1.78	46.1	0.3	0	0	5.8	3.3	1.5	14.5
167k	0	1.5	22.4	2.19	49	0.6	0	0	4.6	10.1	0.7	11
172k	0.3	1.5	22.5	2.2	49.6	0.3	0	0	3.5	9.9	1.3	10.9
176k	0	2.5	19.5	2.4	46.7	0.6	0	0	6.8	12.6	0.8	10.6
177k	1.5	5.7	19.2	2.37	45.5	0.4	0	0	6	10.2	0.8	10.7

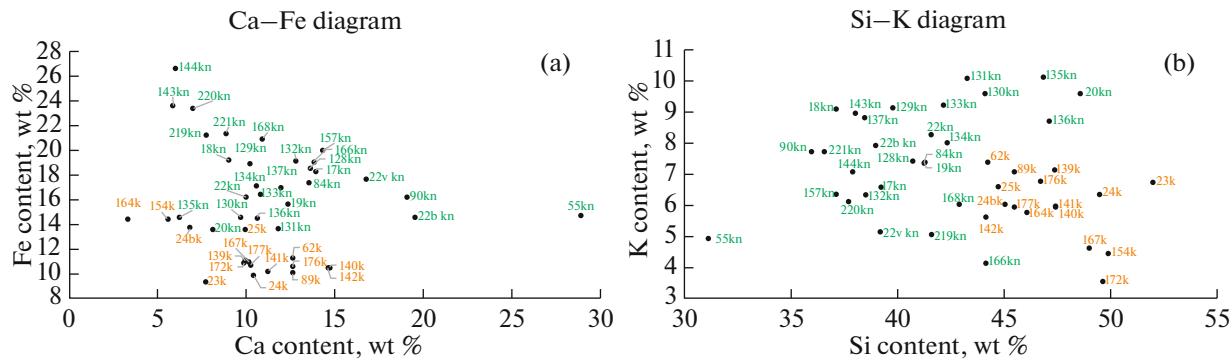


Fig. 7. Binary diagrams of the distribution of the Koan and Knidian samples according to SEM/EDX data depending on the content in the clay base of the samples of: (a) Fe (Ca), (b) K (Si).

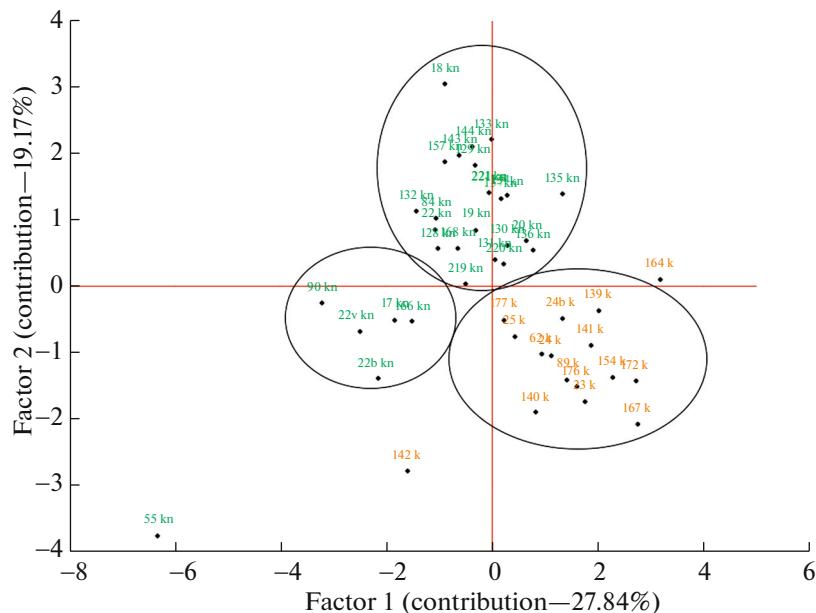


Fig. 8. Diagram of the distribution of samples by factors 1 and 2 of PCA according to SEM/EDX data on the main composition of the clay base.

a slightly different composition of clay dough (samples 90kn, 17kn, 22-bkn, 22-vkn, 166kn, 55kn). First of all, attention is drawn to the fact that this group includes both ΠΑΘ stamps (samples 55kn and 90kn), as well as a stamp with the image of a “hole” and the name of Pasikrat (sample 22-vkn). The simplest explanation for this fact lies in the location of ceramic workshops in the center of the Knidian Peninsula in the town of Rezadie. Here, the discards of defective products were studied in which such stamps occurred. It is not surprising that sample 166kn adjoins this group, since it is typologically identical to the amphora with number 55kn and could have been produced in the same places. Also, the vessel with number 17kn could have been

made in the vicinity of the clay deposit. It is surprising that the same group includes a spall from the stamp of the beginning of the 2nd century BC (sample 22b kn). The fact is that the clay mines of the Knidian Peninsula are not rich, although they are not as scarce as in Thasos [10, pp. 124–125]. It is rather difficult to assume that one of them was in development for 200 years. In addition, the researchers associated the name of Asklepiodorus with workshops located in the south of the peninsula [1, p. 119]. At the same time, they do not mention the finds in those places of early Knidian stamps. This issue requires additional consideration.

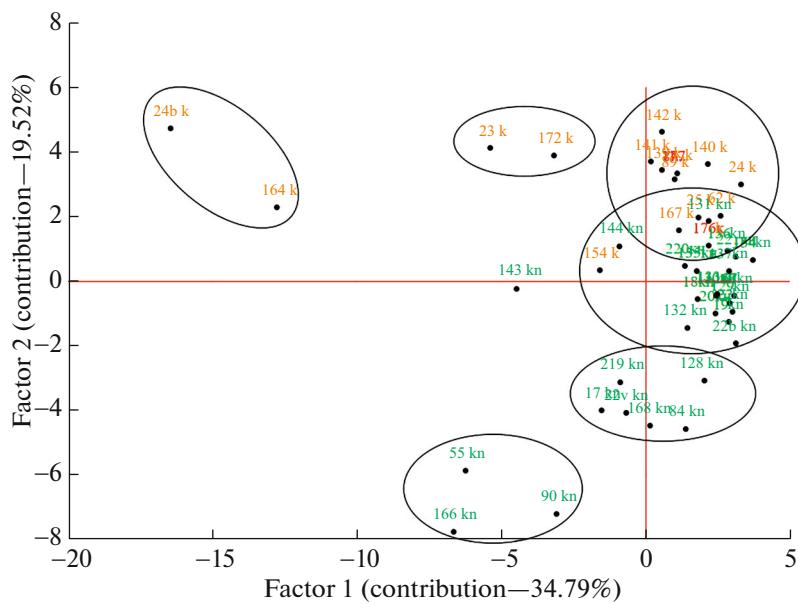


Fig. 9. Diagram of the distribution of samples by factors 1 and 2 of PCA according to ICP-MS data on the microimpurity composition of ceramic samples.

Analysis of ICP-MS data on the microimpurity composition of the Koan (Tables 5, 6) and Knidos (Tables 7, 8) ceramic samples by the PCA method also identifies groups of samples correlated with the centers of their production, as shown in Fig. 9, which gives the distribution of samples by factors 1 and 2. Factor 1 summarizes the following elements (percentages reflect the degree of participation of elements in this

factor): 3–6% (rare earth elements (Y, La–Lu), Th) and 1–3% (Mg, Na, Fe, Mn, Sr, Mo, Ag, U). Factor 2 includes the following elements: 3–7% (Ca, Sc, Ti, Cr, Co, Ni, Ga, Zr, Nb, Sn, Gd, Hf, Ta, Tl, U) and 1–3% (Na, V, Mn, As, Sb, Ba, Pr, Nd, Sm, Pb, Th).

Analysis of binary diagrams for samples from Knidos (Fig. 10) showed that a subgroup of samples 55kn and 90kn is distinguished by the Sr con-

Table 4. Result of statistical processing of SEM/EDX data (PCA)—factors

Variable (chemical element)	Factor loads										
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
Na	0.011	0.072	0.294	0.100	0.157	0.001	0.079	0.042	0.237	0.006	0.002
Mg	0.157	0	0	0.240	0.012	0.038	0.128	0.098	0.072	0.247	0.008
Al	0.249	0.013	0.016	0.008	0.010	0	0.205	0	0	0.092	0.406
Si	0.162	0.045	0.147	0.015	0	0.004	0.067	0.186	0.100	0.237	0.037
P	0.001	0.041	0.193	0.001	0.579	0	0.001	0.105	0.022	0	0.056
S	0.025	0.057	0.056	0.259	0.015	0.551	0.009	0.008	0.002	0.012	0.008
Cl	0.136	0.026	0	0.118	0.023	0.216	0.254	0.086	0.113	0.015	0.012
K	0	0.229	0.110	0.059	0.132	0.010	0.093	0.042	0.234	0.065	0.026
Ca	0.224	0.043	0.011	0.024	0.006	0.018	0.009	0.273	0.058	0.051	0.282
Ti	0.008	0.245	0.014	0.164	0.059	0.008	0.123	0.153	0.117	0.009	0.100
Fe	0.027	0.229	0.158	0.012	0.007	0.154	0.032	0.007	0.046	0.267	0.064

Table 5. ICP-MS data on the composition of Koan ceramic samples (group 1—samples 24k, 25k, 62k, 89k, 139k, 140k, 141k, 142k, 167k, 176k, 177k)

Che- mical element, μg/g	Sample											
	DL	24k	25k	62k	89k	139k	140k	141k	142k	167k	176k	177k
Li	0.02	24.18	28.47	41.69	40.88	49.07	38.41	49.81	42.38	87.47	30.67	37.82
B	4.76	59.66	29.33	98.48	108.66	71.28	67.15	100.78	77.93	57.83	79	66.62
Na	26.14	7387.75	9683.14	5921.98	6950.29	8251.35	9092.25	10779.78	9052.46	3007.69	6348.07	6637.82
Mg	2.47	2313.77	6437.77	3036.21	5064.95	3164.1	4881.69	1832.86	7751.24	1826.11	2515.8	5964.37
Ca	37.93	2026.25	3345.24	3848.58	3749.18	4223.8	3152.25	3273.89	4063.74	1577.03	2856.15	2973.05
Sc	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Ti	5.22	3330.95	4709.52	4371.3	5330.51	5171.25	3849.23	6017.07	4259.6	4974.95	4372.54	5037.3
V	0.18	68.9	113.41	119.56	141.62	129.27	90.75	132.95	103.64	120.93	90.48	104.98
Cr	1.5	136.23	216.81	254.91	313.07	149.42	179	155.94	202.8	102.41	242.37	215.2
Mn	0.43	298.78	1028.7	646.21	641.64	823.51	492.23	781.33	570.97	1648.57	532.86	459.85
Fe	20.58	32858.86	50602.42	42340	45512.89	46928.34	39035.15	48519.01	43219.16	47535.69	39447.79	51339.73
Co	0.13	14.06	29.69	19.82	21.85	22.38	20.61	19.13	23.28	25.02	17.99	22.82
Ni	3.39	143.81	279.22	156.05	177.44	132.77	215.04	124.44	243.88	111.71	142.66	252.47
Cu	10.85	<DL	29.74	45.24	36.15	44.74	27.25	44.77	35.61	61.58	31.05	28.3
Zn	19.32	531.18	68.71	<DL	<DL	50.19	<DL	<DL	<DL	76.81	<DL	<DL
Ga	0.36	15.15	20.91	18.8	20.3	21.78	18.3	24.19	20.56	23.37	16.9	21.26
As	1.32	10.84	19.7	17.2	27.2	10.21	19.7	16.47	23.14	15.95	15.53	8.44
Sr	0.14	88.69	55.72	31.66	50.93	142.22	89	172.97	125.08	124.4	211.12	155.33
Y	0.01	2.04	2.52	2.24	3.54	3.01	3.61	1.9	2.07	3.26	3.64	2.42
Zr	0.004	84.87	37.46	33.13	138.12	107.28	102.82	101.21	121.23	71.76	33.61	113.82
Nb	0.01	16.18	13.37	12.69	14.69	23.19	19.02	22.84	21.23	13.83	12.73	23.52
Mo	0.38	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Ag	0.69	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Cd	0.64	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
In	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Sn	0.09	2.52	1.98	1.86	2.71	2.65	2.71	1.99	3.49	2.15	2.9	2.34
Sb	0.01	1.86	1.64	2.69	1.73	1.32	2.36	1.36	2.83	1.2	1.98	2.02
Ba	0.01	301.26	886.39	730.77	644.82	424.06	467.83	205.05	537.44	380.08	549.71	420.98
La	0.21	5.07	4.23	3.91	3.63	8.45	4.75	11.4	5.72	6.29	5.79	6.93
Ce	0.31	17.54	18.6	11.78	11.57	32.21	17.54	44.54	18.25	29.22	27.26	31.97
Pr	0.04	1.11	1.04	1.12	1	1.79	1.05	2.53	1.3	1.61	1.37	1.33
Nd	0.02	4.33	4.06	4.12	3.76	6.44	3.82	9.08	4.56	5.83	5.07	4.78
Sm	0.05	0.72	0.73	0.91	0.87	1.22	0.75	1.45	0.88	1.08	1.09	0.96
Eu	0.03	0.21	0.34	0.32	0.26	0.33	0.22	0.34	0.3	0.29	0.34	0.28
Gd	0.03	0.58	0.74	0.81	0.6	0.95	0.56	1.08	0.63	0.92	1	0.82
Tb	0.03	0.08	0.09	0.1	0.08	0.12	0.08	0.15	0.11	0.13	0.16	0.12
Dy	0.02	0.4	0.52	0.51	0.57	0.75	0.44	0.7	0.64	0.71	0.85	0.61
Ho	0.041	<DL	0.15	<DL	0.18	0.13	<DL	0.13	0.11	0.17	0.15	0.13
Er	0.036	0.22	0.32	0.34	0.31	0.52	0.59	0.35	0.36	0.45	0.46	0.29
Tm	0.03	<DL	<DL	<DL	0.09	<DL						
Yb	0.03	0.19	0.39	1.07	0.6	0.41	0.26	0.33	0.36	0.57	0.38	0.3

Table 5. (Contd.)

Che- mi- cal ele- ment, $\mu\text{g/g}$	Sample											
	DL	24k	25k	62k	89k	139k	140k	141k	142k	167k	176k	177k
Lu	0.03	<DL	<DL	<DL	0.1	<DL	<DL	<DL	0.07	<DL	<DL	<DL
Hf	0.05	2.16	1.28	0.77	2.3	2.97	2.61	2.84	3.25	2.33	0.69	3.28
Ta	0.35	0.96	0.82	0.8	0.92	1.32	1.18	1.43	1.33	0.87	0.76	1.46
1W	0.156	2.29	1.97	2.69	2.37	2.81	3.13	3.03	3.45	2.07	2.26	2.7
Tl	0.047	0.59	0.8	0.74	0.6	0.51	0.89	0.74	1.14	0.57	0.59	0.2
Pb	0.081	71.79	38.45	29.12	23.15	33.58	46.19	40.54	59.87	28.59	22.22	35.09
Bi	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Th	0.664	2.26	1.45	<DL	2.46	3.37	2.3	3.91	2.93	2.79	1.78	3.36
U	0.078	3.72	1.68	2.63	2.32	2.69	4.56	2.76	5.35	2.21	2.73	5.28

DL—detection limit.

tent, sample 166kn, by Nd, sample 143kn, by Th, and subgroup of samples 131kn, 143kn, 144kn, 166kn 220kn, by U. On the Cu–Y diagram, sample 221kn with the maximum Cu content and a subgroup of samples with the highest Y concentration (samples 55kn, 143kn, 166kn) stand out.

Thus, samples 55kn, 90kn, 143kn, 166kn, and 221kn stand out the most in terms of the content of

a number of elements in the group of Knidos samples. This fact is interesting in that samples 55kn, 90kn, and 143kn were picked from stamps, i.e., their attribution as Knidos is indisputable, sample 166kn is an amphora, the production of which is also not in doubt, and sample 221kn belongs to a rather rare form of amphora, the production of which in Knidos raises some questions.

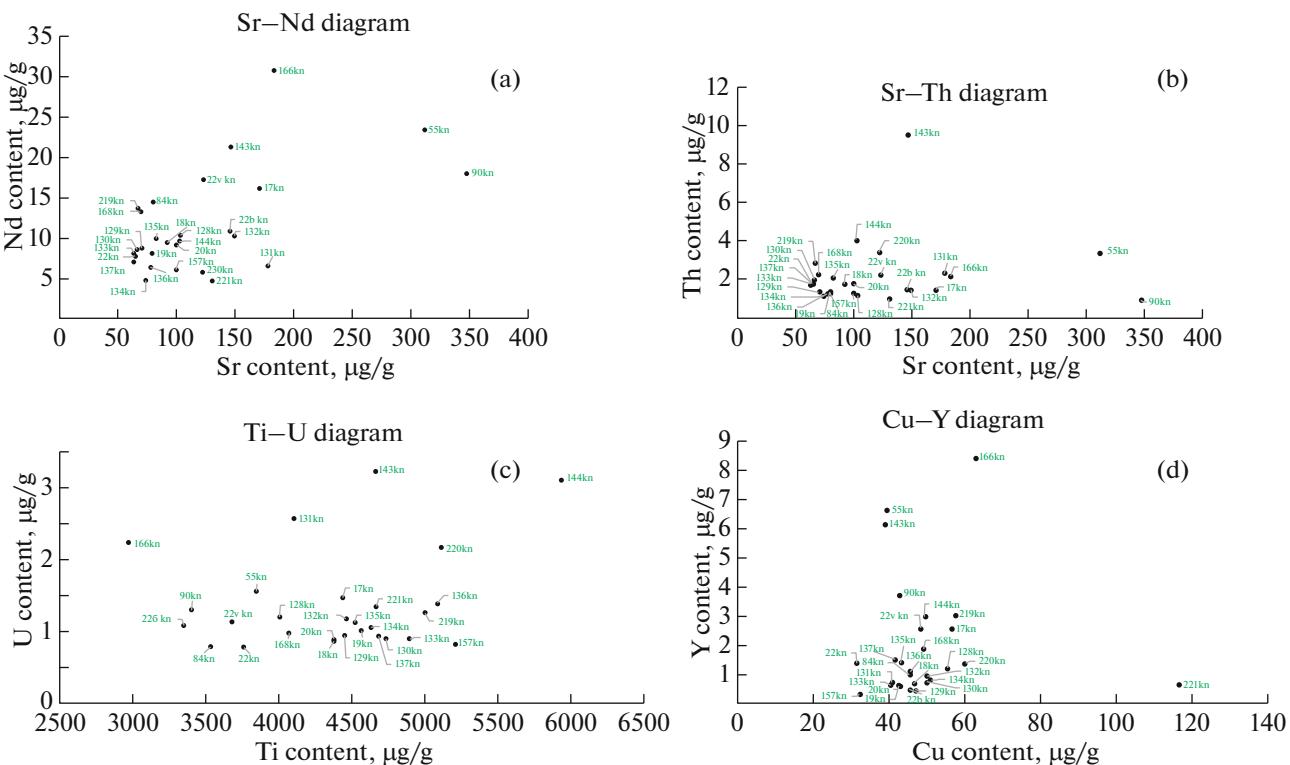


Fig. 10. Binary diagrams of the content of elements in ceramic samples from Knidos: (a) Nd (Sr), (b) Th (Sr), (c) U (Ti), (d) Y (Cu).

Table 6. ICP-MS data on the composition of Koan ceramic samples (group 2—samples 23k, 172k, group 3—24bk, 164k, group 4—154k)

Chemical element, $\mu\text{g/g}$	Sample					
	DL	23k	172k	24-b k	164k	154k
Li	0.02	44.65	45.11	58.14	101.59	85.56
B	4.76	89.14	83.07	121.03	117.07	69.52
Na	26.14	6603.73	7302.53	12836.78	6751.44	3950.7
Mg	2.47	6658.63	2380.85	15342.95	8265.09	3693.23
Ca	37.93	4247.17	2385.72	7390.4	2200.86	2249.38
Sc	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Ti	5.22	5573.75	6160.95	6496.91	6005.35	5300.89
V	0.18	129.46	105.08	189.32	121.44	116.04
Cr	1.5	223.24	146.7	216.33	259.94	214.64
Mn	0.43	537.5	1154.08	1164.64	1067.61	1220.14
Fe	20.58	53330.43	52654.3	74816.27	58886.76	54369.34
Co	0.13	24.57	21.88	34.35	31.74	30.1
Ni	3.39	249.53	127.99	181.32	312.69	261.17
Cu	10.85	40.03	45.8	48.24	38.93	45.65
Zn	19.32	88.09	<DL	589.58	<DL	350.12
Ga	0.36	24.88	22.81	34.35	23.19	18.07
As	1.32	24.8	13.44	64.31	19.8	17.61
Sr	0.14	284.55	163.87	277.05	186.45	170.64
Y	0.01	5.37	5.07	25.11	11.13	4.21
Zr	0.004	152.53	134.78	52.25	152.62	34.46
Nb	0.01	27.83	25.24	21.46	26.12	14.29
Mo	0.38	<DL	<DL	0.91	<DL	<DL
Ag	0.69	<DL	<DL	2.46	<DL	<DL
Cd	0.64	<DL	<DL	<DL	<DL	<DL
In	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Sn	0.09	3.61	7.61	8.38	3.22	1.53
Sb	0.01	2.77	1.41	6.56	2.08	2.02
Ba	0.01	457.2	293.72	588.11	660.07	667.08
La	0.21	25.05	15.28	29.44	33.59	11.09
Ce	0.31	77.15	60.37	84.11	84.81	54.63
Pr	0.04	4.99	3.75	6.94	7.61	2.96
Nd	0.02	17.4	13.6	25.29	28.04	11.22
Sm	0.05	2.78	2.37	5.47	5.53	2.18

Table 6. (Contd.)

Chemical element, $\mu\text{g/g}$	Sample					
	DL	23k	172k	24-b k	164k	154k
Eu	0.03	0.65	0.5	1.27	1.34	0.59
Gd	0.03	2.17	1.65	4.68	4.35	1.65
Tb	0.03	0.44	0.24	0.73	0.67	0.23
Dy	0.02	1.39	1.26	3.85	3.4	1.31
Ho	0.041	0.23	0.21	0.67	0.63	0.22
Er	0.036	0.78	0.75	2.05	2.07	0.68
Tm	0.03	0.09	0.1	0.23	0.26	0.07
Yb	0.03	0.6	0.65	1.54	1.92	0.6
Lu	0.03	0.11	0.1	0.2	0.27	0.08
Hf	0.05	3.87	3.93	1.59	3.78	1.06
Ta	0.35	1.7	1.6	1.35	1.61	0.83
1W	0.156	3.78	2.9	3.13	3.93	1.95
Tl	0.047	0.89	0.73	1.06	1.02	0.58
Pb	0.081	61.73	41.68	42.39	56.36	27.64
Bi	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Th	0.664	10.61	7.67	11.15	19.71	4.58
U	0.078	5.94	3.21	5.69	4.88	1.3

Table 7. ICP-MS data on the composition of Knidian ceramic samples (group 1—samples 18kn, 19kn, 20kn, 22kn, 22bkn, 129kn, 130kn, 131kn, 132kn, 133kn, 134kn, 135kn, 136kn, 137kn, 144kn, 157kn, 220kn, 221kn)

Chemical element, $\mu\text{g/g}$	Sample									
	DL	18kn	19kn	20kn	22kn	22-b kn	129kn	130kn	131kn	132kn
Li	0.03	43.8	40.32	43.3	27.69	38.42	39.75	42.23	39.24	18.51
B	4.25	107.95	97.49	109.53	86.6	86.02	111.35	129.64	83.68	34.25
Na	22.49	2155.5	1997.63	2373.2	3091.29	2587.09	3322.09	3510.4	2621.78	4811.06
Mg	15.23	3684.42	3208.19	3840.87	4502.53	4717.37	4019.87	4160.86	3754.09	3512.15
Ca	40.51	5332.82	4548.36	4421.84	3232.53	5649.13	5092.43	4902.64	4485.11	6927.06
Sc	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Ti	2.66	4377.57	4564.18	4381.71	3762.29	3348.46	4448.48	4734.52	4107.13	4464.03
V	2.03	112.51	108.01	121.09	92.83	94.92	106.79	127.75	105.59	103.57
Cr	0.05	294.55	324.98	277.1	144.49	208.13	257.38	244.82	139.83	265.04
Mn	1.05	661.04	770.76	655.46	373.73	593.19	552.26	662.8	691.69	920.09
Fe	13.23	50204.23	53902.07	49336.71	36726.05	38956.31	48753.34	53733.99	40997.95	49430.33
Co	0.06	35.75	39.39	36.6	17.75	23.35	29.82	33.77	19.64	29.52
Ni	0.47	380.39	409.98	373.85	116.22	169.12	254.13	344.71	107.65	182
Cu	0.11	46.45	42.73	42.5	31.4	45.39	46.92	49.93	40.76	50.01

Table 7. (Contd.)

Chemical element, $\mu\text{g/g}$	Sample									
	DL	18kn	19kn	20kn	22kn	22-b kn	129kn	130kn	131kn	132kn
Zn	3.95	57.15	26.15	28.2	<DL	<DL	31.04	27.48	13.63	43.56
Ga	0.14	19.7	20.29	20.84	15.57	17.11	20.19	22.57	19.84	18.36
As	0.5	9.11	6.03	5.56	5.09	12.89	12.89	15.26	75.34	8.87
Sr	0.33	92	79.34	99.86	64.82	145.48	69.98	66.11	177.92	149.15
Y	0.04	0.69	0.6	0.61	1.37	0.48	0.45	0.73	0.72	0.93
Zr	0.17	22.58	25.04	21.09	19.42	25.6	19.82	21.25	53.01	15.19
Nb	0.04	13.59	14.46	13.82	11.91	11.14	14.99	15.26	12.56	10.47
Mo	3.45	<DL								
Ag	0.37	<DL								
Cd	0.12	<DL								
In	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Sn	0.08	5.6	2.28	3.13	1.61	1.39	1.42	1.65	1.65	1.45
Sb	0.02	6.83	0.65	0.65	0.48	0.67	0.71	0.7	4.53	0.5
Ba	0.4	243.17	218.78	248.89	403.08	304.48	226.96	241.14	424.28	276.43
La	1.97	4.73	<DL	4.62	4.99	14.58	5.7	4.01	<DL	6.77
Ce	2.24	33.78	27.73	28.55	29.2	37.64	36.28	33.71	26.4	30.94
Pr	0.004	2.34	1.94	2.26	2	2.69	2.35	1.99	1.59	2.65
Nd	0.006	9.43	8.08	9.15	7.76	10.85	8.73	8.55	6.59	10.24
Sm	0.009	1.66	1.35	1.46	1.48	1.6	1.27	1.4	1.18	1.97
Eu	0.003	0.32	0.27	0.29	0.33	0.3	0.23	0.27	0.23	0.38
Gd	0.131	2.01	1.65	1.97	2.66	2.54	1.63	1.76	2.2	2.41
Tb	0.0001	0.14	0.11	0.13	0.15	0.11	0.09	0.12	0.09	0.21
Dy	0.007	0.62	0.49	0.54	0.71	0.4	0.38	0.52	0.46	1.01
Ho	0.001	0.11	0.09	0.09	0.15	0.05	0.05	0.08	0.07	0.18
Er	0.003	0.26	0.2	0.25	0.34	0.13	0.15	0.2	0.2	0.43
Tm	0.002	0.04	0.02	0.03	0.06	0.02	0.02	0.02	0.02	0.05
Yb	0.005	0.31	0.13	0.24	0.27	0.08	0.36	0.15	0.14	0.23
Lu	0.001	0.02	0.02	0.02	0.05	0.01	0.01	0.02	0.02	0.03
Hf	0.017	0.7	0.87	0.68	0.69	0.84	0.65	0.63	1.7	0.54
Ta	0.01	1.01	1.06	1.05	0.87	0.79	1.02	1.07	1	0.82
W	0.56	127.6	43.33	6.24	1.96	1.13	<DL	<DL	1.85	1.93
Tl	0.05	0.2	0.27	0.3	<DL	0.15	0.16	0.29	0.69	0.28
Pb	0.11	15.61	23.01	17.03	10.48	17.91	40.73	21.74	31.58	116.81
Bi	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Th	0.001	1.79	1.41	1.81	1.81	1.51	1.39	2.03	2.35	1.5
U	0.0001	0.87	1.02	0.89	0.77	1.08	0.94	0.9	2.56	1.18
Chemical element, $\mu\text{g/g}$	Sample									
	DL	133kn	134kn	135kn	136kn	137kn	144kn	157kn	220kn	221kn
Li	0.03	47.54	51.99	53.02	62.04	51.53	34.77	49.13	40.4	42.13
B	4.25	123.36	129.59	122.93	143.17	121.76	51.3	108.32	70.22	100.73
Na	22.49	2892.37	4120.96	3593.36	4402.65	3137.55	5273.68	2033.64	1373.2	3741.42
Mg	15.23	3916.98	2556.4	4135.68	3216.71	2570.25	3545.85	3230.01	3770.98	2947.16
Ca	40.51	5573.22	3055.4	4915.28	4118.18	3257.84	2941.54	4421.84	3181.93	3839.84

Table 7. (Contd.)

Chemical element, $\mu\text{g/g}$	Sample									
	DL	133kn	134kn	135kn	136kn	137kn	144kn	157kn	220kn	221kn
Sc	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Ti	2.66	4893.93	4629.58	4524.82	5088.23	4688.64	5934.33	5211.46	5116.48	4670.29
V	2.03	127.04	123.82	123.42	131.07	112.72	135.88	127.45	89.14	130.39
Cr	0.05	290.38	191.03	193.63	192.85	191.55	163.23	290.12	353.57	167.13
Mn	1.05	647.86	673.13	648.31	831.24	553.79	1109.21	632.47	841.14	793.52
Fe	13.23	56310.27	46425.08	45463.39	45841.17	46191.3	60008.38	54767.95	68342.21	50354.52
Co	0.06	34.47	26.73	25.81	28.2	26.52	27.68	35.72	34.27	30.81
Ni	0.47	356.74	166.79	171.41	180.4	181.71	152.98	349.47	264.26	112.59
Cu	0.11	40.31	51.07	43.06	45.58	41.46	49.47	32.11	60.1	116.54
Zn	3.95	36.45	20.74	40.45	15.05	34.59	52.71	17.01	72.6	39.12
Ga	0.14	23.66	21.09	23.27	21.75	21.25	26.69	21.67	23.48	23.35
As	0.5	18.8	19.99	13.6	11.47	17.39	5.09	8.63	24.72	12.89
Sr	0.33	63.33	73.86	82.19	77.72	63.18	102.14	99.48	122.17	130.4
Y	0.04	0.63	0.81	1.4	1.1	1.5	2.97	0.31	1.37	0.63
Zr	0.17	20.49	29.49	31.15	44.29	24.58	17.58	21.58	52.62	28.96
Nb	0.04	15.76	14.65	14.68	16.13	15.43	18.39	16.2	18.03	15.4
Mo	3.45	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Ag	0.37	<DL	<DL	<DL	<DL	0.81	<DL	0	0	0
Cd	0.12	<DL	0.25	<DL	<DL	0.3	<DL	0	0	0
In	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Sn	0.08	1.54	1.42	2.48	1.23	1.89	3.52	1.52	2.61	5.73
Sb	0.02	0.8	0.77	0.98	0.68	0.67	0.58	0.6	3.34	0.65
Ba	0.4	246.34	290.21	328.85	283.74	247.31	224.28	331.97	272.71	268.67
La	1.97	<DL	<DL	6.61	<DL	4.15	6.44	0	0	0
Ce	2.24	30.56	18.4	31.87	22.26	26.72	32.35	28.72	19.02	19.61
Pr	0.004	1.99	1.21	2.58	1.65	1.77	2.52	1.45	1.3	1.21
Nd	0.006	8.15	4.8	9.95	6.31	7.01	9.62	6.05	5.73	4.63
Sm	0.009	1.38	0.83	1.55	0.97	1.01	2	1.04	1.24	0.7
Eu	0.003	0.25	0.18	0.28	0.19	0.19	0.43	0.23	0.29	0.15
Gd	0.131	1.74	1.56	2.31	1.62	1.48	2.63	1.69	1.9	1.43
Tb	0.0001	0.12	0.07	0.13	0.08	0.1	0.26	0.1	0.15	0.07
Dy	0.007	0.47	0.34	0.62	0.38	0.44	1.37	0.42	0.78	0.3
Ho	0.001	0.09	0.06	0.11	0.07	0.07	0.25	0.07	0.11	0.05
Er	0.003	0.2	0.15	0.26	0.21	0.19	0.66	0.16	0.32	0.12
Tm	0.002	0.03	0.02	0.04	0.03	0.03	0.1	0.02	0.04	0.02
Yb	0.005	0.12	0.1	0.32	0.18	0.16	0.51	0.08	0.31	0.12
Lu	0.001	0.02	0.02	0.03	0.02	0.02	0.07	0.02	0.03	0.01
Hf	0.017	0.67	0.88	0.95	1.26	0.71	0.59	0.69	1.4	0.91
Ta	0.01	1.11	1.09	1.02	1.09	1.08	1.42	1.15	1.34	1.16
W	0.56	2.28	<DL	2.03	<DL	<DL	<DL	0	0	0
Tl	0.05	0.32	0.24	0.23	0.36	0.27	0.49	0.13	0.29	0.31
Pb	0.11	16.57	30.51	30.53	29.96	25.77	46.51	16.77	39.33	27.48
Bi	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Th	0.001	1.8	1.15	2.11	1.31	1.82	4.08	1.31	3.45	1.01
U	0.0001	0.9	1.06	1.13	1.38	0.93	3.1	0.83	2.16	1.34

Table 8. ICP-MS data on the composition of Knidian ceramic samples (group 2—samples 17kn, 22v kn, 84kn, 128kn, 168kn, 219kn, group 3—55kn, 90kn, 166kn, group 4—143kn)

Chemical element, µg/g	Sample										
	DL	17kn	22v kn	84kn	128kn	168kn	219kn	55kn	90kn	166kn	143kn
Li	0.03	58.39	46.04	38.36	30.64	40.41	46.67	39.09	39.59	42.17	30.86
B	4.25	78.34	66.03	61.5	90.89	59.98	55.72	72.06	62.44	52.03	31.35
Na	22.49	6047.45	5938.49	3605.23	3445.96	2895.5	2207.46	7391.7	4994.37	3666.16	7167.54
Mg	15.23	3527.6	4932.78	1679.52	3529.22	3031.96	5739.74	12587.15	25179.16	5254.15	7190.58
Ca	40.51	9457.69	9660.14	8976.85	7230.72	6142.59	4244.71	17214.67	19290.12	10963.46	4624.28
Sc	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Ti	2.66	4442.75	3677.87	3533.24	4006.06	4067.13	5006.26	3845.51	3402.02	2972.06	4665.3
V	2.03	127.02	85.62	79.55	102.64	84.71	100.76	123.28	92.75	62.45	111.49
Cr	0.05	507.48	442.44	436.9	440.35	476.4	393.64	376.8	438.89	233.08	126.38
Mn	1.05	841.62	867.94	938.83	1165.58	1062.51	1109.98	1093.48	1003.01	1950.06	828.73
Fe	13.23	61293.92	46517.88	51077.5	53557.14	58826.32	67901.2	60998.27	59471.28	47492.44	53354.84
Co	0.06	47.54	41.21	45.2	47.79	50.63	53.72	49.39	59.06	40.55	20.79
Ni	0.47	533.4	513.9	586.6	578.24	716.48	627.42	631.3	817.47	476.84	116.39
Cu	0.11	56.36	48.25	45.47	55.45	49.07	57.41	39.36	42.91	62.73	38.95
Zn	3.95	45.96	13.9	21.98	27.31	22.33	49.78	23.75	24.11	21.89	52.97
Ga	0.14	17.83	16.46	15.45	18.45	17.01	20.53	17.15	14.28	13.62	24.19
As	0.5	9.34	6.5	12.42	8.87	8.4	6.27	28.74	12.42	8.4	13.13
Sr	0.33	170.65	123.08	79.72	103.12	69.3	66.55	311.8	347.53	183.22	146.34
Y	0.04	2.57	2.57	1.01	1.22	1.87	3.01	6.62	3.71	8.4	6.13
Zr	0.17	29.42	58.38	26.22	27.67	33.97	37.38	44.54	34.35	30.15	16.52
Nb	0.04	12.12	12.58	11.52	13.17	13.19	15.86	12.77	11.14	9.46	15.11
Mo	3.45	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL	<DL
Ag	0.37	<DL	<DL	<DL	<DL	0	0	<DL	<DL	0	<DL
Cd	0.12	<DL	<DL	<DL	<DL	0	0	0.24	<DL	0	<DL
In	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Sn	0.08	2.44	1.7	0.26	1.11	0.47	1.26	0.71	1.1	0	2.75
Sb	0.02	0.44	0.52	0.4	0.6	0.57	0.6	0.89	0.44	0.45	0.94
Ba	0.4	235.26	334.53	255.33	298.03	273.46	235.91	279.46	159.23	188.69	304.53
La	1.97	14.99	16.28	13.64	8.44	19.23	8.54	24.84	17.27	28.66	21.93
Ce	2.24	42	45.16	40.47	35.84	54.46	40.48	54.06	36.32	50.02	58.55
Pr	0.004	4.39	4.65	3.93	2.65	3.4	3.5	6.24	4.61	7.81	5.77
1Nd	0.006	16.15	17.14	14.45	10.28	13.29	13.68	23.41	17.93	30.77	21.22
Sm	0.009	2.87	2.83	2.35	1.57	2.26	2.6	4.45	3.22	5.95	3.49
Eu	0.003	0.6	0.59	0.47	0.34	0.43	0.51	0.99	0.7	1.32	0.69
Gd	0.131	3.74	3.95	2.81	2.38	3.57	2.96	5.68	3.82	6.75	4.68
Tb	0.0001	0.31	0.27	0.21	0.12	0.22	0.31	0.51	0.39	0.7	0.4
Dy	0.007	1.49	1.17	0.84	0.52	1.06	1.44	2.54	1.8	3.42	2.05
Ho	0.001	0.27	0.23	0.14	0.08	0.17	0.23	0.46	0.31	0.59	0.38
Er	0.003	0.64	0.73	0.34	0.18	0.48	0.57	1.14	0.83	1.5	0.95
Tm	0.002	0.09	0.07	0.04	0.02	0.06	0.07	0.15	0.11	0.18	0.14
Yb	0.005	0.48	0.45	0.21	0.11	0.38	0.54	1.16	0.59	1.08	0.81
Lu	0.001	0.08	0.05	0.03	0.01	0.05	0.06	0.14	0.08	0.14	0.1
Hf	0.017	0.89	0.92	0.85	0.94	1.03	1.25	1.21	0.96	0.94	0.53
Ta	0.01	0.94	0.92	0.82	0.96	0.9	1.14	0.86	0.74	0.65	1.2
W	0.56	5.72	3.51	<DL	<DL	0	0	1.61	2.96	0	<DL
Tl	0.05	<DL	<DL	<DL	0.21	0	0	0.18	<DL	0	0.58
Pb	0.11	15.77	19.96	19.99	26.39	17.61	22.85	18.16	19.64	19.32	47.39
Bi	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.	In.s.
Th	0.001	1.48	2.29	1.31	1.19	2.34	2.89	3.39	0.99	2.2	9.53
U	0.0001	1.46	1.13	0.79	1.2	0.98	1.26	1.56	1.3	2.23	3.22

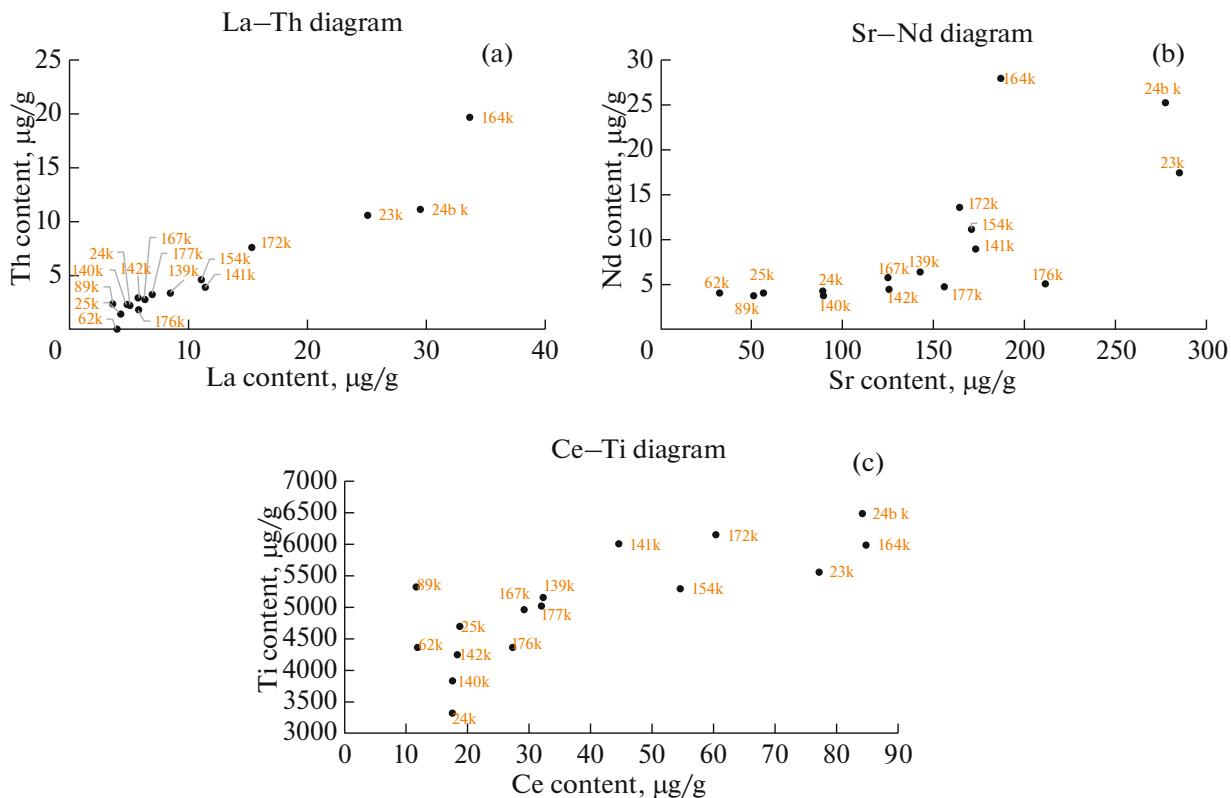


Fig. 11. Binary diagrams of the content of elements in ceramic samples from Kos: (a) Th (La), (b) Nd (Sr), (c) Ti (Ce).

According to binary diagrams of ICP-MS data (Fig. 11), significant differences in the content of several elements are observed in the group of samples from Kos. As can be seen from Fig. 11, samples 23k, 24-b k, 164k, and 172k are most often separated from the general group. The explanation for this can be found, first of all, in the chronology of the vessels. This concerns the amphora 24-b k, made at the beginning of the 2nd century BC, i.e., at least a century later than the rest of the specimens. As for the rest of the samples, their differences can be explained by the geological features of the area in which they were made. Despite its small size, Kos is divided by a mountain range into two parts with different geological structures. At the same time, these differences are not so great as to distinguish the samples from the general “Kos” group. It is especially necessary to note the significantly higher content of a number of elements in sample 164k, in particular, the maximum content of Ce, Nd, Th, and La. Note that sample 154k, which fits well into the total mass of the samples and stands out only in terms of Ce content, is morphologically quite different from typical Koan vessels.

CONCLUSIONS

Peculiarities of the basic and microimpurity compositions were revealed, along which the stratification

of the Koan and Knidian samples was found, despite the very close geological structure of the two regions. Differences were also revealed within the groups, which can be explained both by the location of individual pottery workshops and the chronological difference between the samples. Despite the fact that clay in the production centers under consideration was not as scarce as on the island of Thasos, it is difficult to argue that the same deposit in Knidos could have been used for several centuries. In this case, only archaeological excavations can prove the opposite, which will confirm or deny the fact of such long functioning of the workshop. The division of the Knidian samples into two unequal groups may be associated with the well-known fact of the transfer of the city from the central part of the Knidian Peninsula to its western promontory, which occurred approximately in the middle of the 4th century BC. It is known that the place of the old city was not abandoned; various workshops arose there, including ceramic ones, focused on the manufacturing of amphora containers.

Much less stratification is observed among the Koan samples. Here, the differences can be unambiguously explained by the differences in the geological structure of the island. Studies have shown that amphorae with single-barreled handles also belong to Kos. In addition, it was substantiated that three vessels

(samples 25k, 62k, and 154k), the correctness of the localization of which remained doubtful due to their morphological features, belonged to those from Kos.

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