CERCETĂRI INTERDISCIPLINARE – INTERDISCIPLINARY SURVEYS

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Preliminary results of an integrated Petrographic, Chemical and Organic Residue Analysis of Neolithic pottery from Makhvilauri

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In recent years, extensive archaeological and laboratory investigations have been conducted at prehistoric sites in south-western Georgia. The integrated analysis of data obtained through interdisciplinary research has made it possible to develop a clearer understanding of ancient human activities, stone-processing technologies, climatic conditions, mobility patterns, chronology, and other aspects of prehistoric life.

Within the assemblage from the Neolithic settlement of Makhvilauri, pottery occupies a prominent place. From a typological perspective, vessel bases are particularly informative, as they clearly preserve traces of use. The present study provides the first comprehensive analysis of the Neolithic ceramic assemblage from Makhvilauri, carried out in laboratories in Georgia and abroad. For this research, two ceramic fragments dated to the 7th-6th millennia BCE were selected.

The investigations have made it possible to draw several important preliminary conclusions, which lay the foundation for future research involving a larger number of ceramic samples.

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Rezultate preliminare ale unei analize integrate petrografice, chimice și a reziduurilor organice a ceramicii neolitice din Makhvilauri

În ultimii ani, s-au desfășurat cercetări arheologice și de laborator ample la siturile preistorice din sud-vestul Georgiei. Analiza integrată a datelor obținute prin cercetarea interdisciplinară a permis o înțelegere mai clară a activităților umane din antichitate, a tehnologiilor de prelucrare a pietrei, a condițiilor climatice, a modelelor de mobilitate, a cronologiei și a altor aspecte ale vieții preistorice.

În cadrul ansamblului provenit din așezarea neolitică de la Makhvilauri, ceramica ocupă un loc important. Din perspectivă tipologică, bazele vaselor sunt deosebit de informative, deoarece păstrează în mod clar urme de utilizare. Prezentul studiu oferă prima analiză cuprinzătoare a ansamblului ceramic neolitic de la Makhvilauri, realizată în laboratoare din Georgia și din străinătate. Pentru această cercetare, au fost selectate două fragmente ceramice datate în mileniile VII-VI a.Chr.

Cercetările au permis formularea mai multor concluzii preliminare importante, ce pun bazele unor cercetări viitoare care vor implica un număr mai mare de eșantioane ceramice.

Introduction

The Neolithic period represents one of the most significant stages in human history, marked by fundamental transformations in lifeways. During this period, societies transitioned from a nomadic hunter-gatherer mode of subsistence to a productive economy, laying the foundations for agriculture and animal husbandry. At the same time, the Neolithic witnessed major innovations in lithic technology, including the refinement of stone-working techniques, the expansion and diversification of tool assemblages, the emer-

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gence of ceramic vessels, and the development of weaving. One of the most distinctive innovations of this period, however, was the production, processing, and preparation of food resources in ceramic containers. Culinary practices, as an integral component of everyday life, provide valuable insights into the adaptive strategies, technological knowledge, and social interactions of Neolithic communities.

Two main phases are generally distinguished within the Neolithic: the Pre-Pottery Neolithic and the Pottery Neolithic. According to the periodization of prehistoric Georgia, the Pottery Neolithic is dated to the 7th-6th millennia BCE.

Numerous important Pottery Neolithic sites have been identified and systematically investigated in Georgia [Nebieridze 1972; Gogitidze 1978; Chikovani *et all.* 2015; Japaridze, Javakhishvili 1971; Hamon *et all.* 2016; Kiguradze 1976]. Some of these sites, such as Gadachrili Gora and Shulaveri Gora, have attracted global attention following the identification of the putative earliest evidence for wine production in Europe [McGovern *et all.* 2017]. However, analyses of lipid residues preserved in Neolithic ceramic vessels have not yet been undertaken. Moreover, petrographic and chemical analyses of Neolithic ceramics have been conducted only sporadically [Kiguradze 1986; Kohl, Harbottle 1984; Badalyan *et all.* 2010] and lack an integrated analytical framework.

The present study provides a comprehensive analysis of Neolithic ceramic vessels from the site of Makhvilauri. This approach aims to reconstruct aspects of pottery production technology, mineralogical composition, and food preparation practices, thereby contributing to a better understanding of culinary traditions in Neolithic communities.

The Makhvilauri Site

The Makhvilauri settlement is located 8 km southeast of Batumi, in Khelvachauri Municipality, in the village of the same name (fig. 1-2). The site occupies a moderately elevated hill which, according to ethnographic accounts, was formerly bordered by the Chorokhi River. At present, the river flows approximately 1.5-2 km south of the site. The hill is also flanked on two sides by small streams, the Makhvilauristskali and the Mejinisistskali.

Makhvilauri is an open-air settlement situated in the southern part of the Colchian Lowland, a region characterized by a humid subtropical climate. High precipitation and persistently moist soils have adversely affected the preservation of organic remains at the site. Consequently, the principal sources of information on prehistoric activity at Makhvilauri are lithic artifacts and ceramic assemblages.

Palynological research conducted in 2025 did not reveal plant species characteristic of cold climates. The presence of pollen from thermophilic taxa – including fir, alder, hornbeam, willow, hazel, and elm – as well as spores of fern species

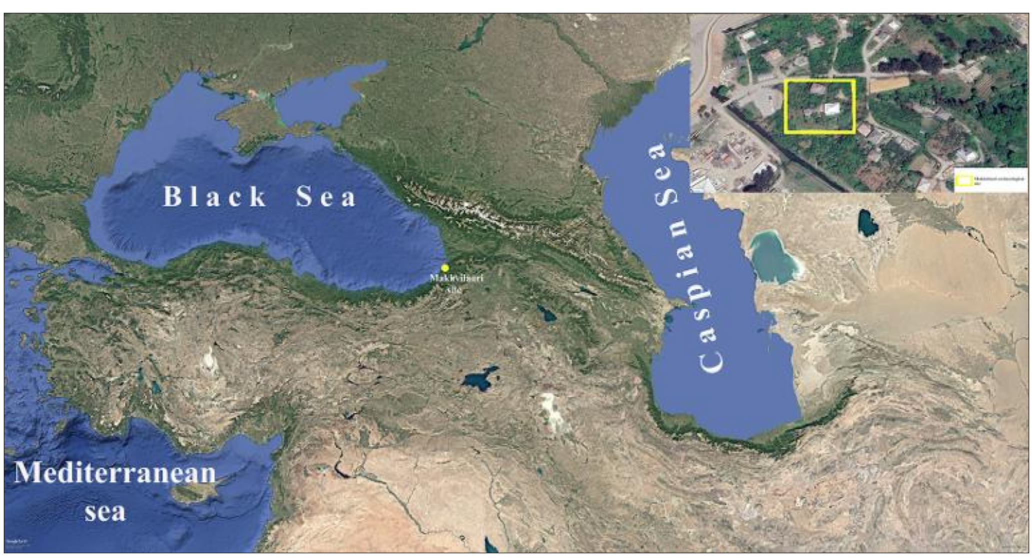

Fig. 1. Map showing the Makhvilauri site.

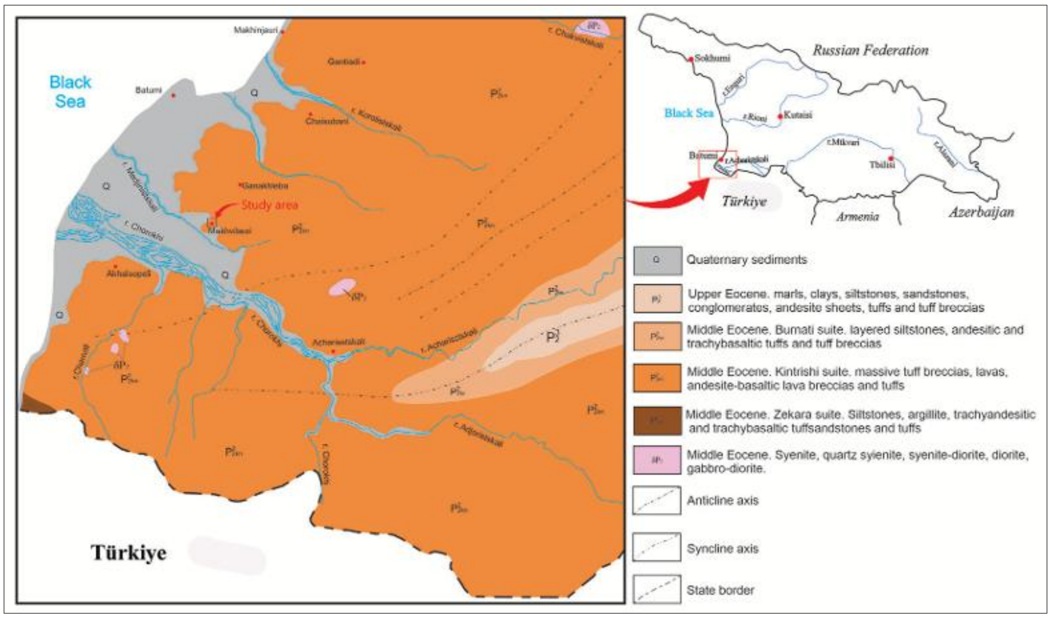

Fig. 2. Geological map of Chorokhi basin.

typical of broadleaf forests on lower mountain slopes, supports this observation [Chkhatarashvili *et all.* 2026]. The occurrence of freshwater algae in the spectra also indicates warm climatic conditions [Scott 1992]. These data suggest that Holocene warming began approximately 8,000 years ago in the environs of Makhvilauri and more broadly across Georgia [Kvavadze, Connor 2005; Connor 2011].

The settlement was discovered in 1968 during the construction of a residential building, when earthworks exposed numerous stone artifacts, including flint and obsidian tools, polished stone axes, sling stones, and hoe-like implements. Systematic archaeological investigations began in 1969. It was later established that during the Late Bronze – Early Iron Age the area was reused as a burial ground, severely disturbing the underlying Neolithic cultural layer [Gogitidze 1978].

Excavations resumed in 2001 and again in 2014-2015. Intensive agricultural activity has significantly damaged the cultural deposits. Work during these campaigns focused primarily on the southern sector of the previously investigated area, mainly in connection with the study of Late Bronze – Early Iron Age burials [Kakhidze *et all.* 2012].

Reconnaissance and exploratory investigations continued during the 2022-2025 field seasons. An area of approximately 48 m² was examined, revealing the following stratigraphic sequence:

1. Topsoil (0-5 cm)
2. Humus (5-15 cm)
3. Black layer (15-25 cm)
4. Light-brown layer (25-40 cm)
5. Yellow clay layer (below 40 cm)

The light-brown layer corresponds to the Neolithic cultural horizon and yielded a substantial assemblage of flint and obsidian tools and debitage, pebble and basalt implements, ceramic fragments, and other materials. Charred wood and charcoal samples were collected in situ for laboratory analysis.

As a result of investigations conducted between 1968 and 2025, approximately 2,500 artifacts have been recovered, including 552 flint and obsidian items (fig. 3), 643 pebble stone artifacts, 714 ceramic fragments, and other finds. Based on relative dating, the first investigator of the site, Sergo Gogitidze, attributed the assemblage to the Late Neolithic [Gogitidze 1978], corresponding to the 7th-6th millennia BCE in the archaeological periodization of Georgia. This chronology has since been confirmed by AMS radiocarbon dating (*see* Table 1) [Chkhatarashvili *et all.* 2024].

The ceramic assemblage from Makhvilauri is diverse and abundant. Particularly noteworthy are fragments of vessel bases and rim sherds with portions of the vessel wall still attached. Complete vessel reconstruction was not possible; however, the bases allowed estimation of vessel diameters.

№	Sample	Lab. Index	Location	Dates (BP)	Dates (BC) 68.3 %	Dates (BC) 95.4 %	Reference
1.	Charcoal	FTMC-JU83-2	Depth 38 cm.	7070±32	5993-5901	6018-5851	Chkhatarashvili *et. all.* 2024
2.	Ceramic	FTMC-JU83-3	Depth 34 cm.	6802±39	5725-5661	5744-5627	Chkhatarashvili *et. all.* 2024

Table 1. Absolute dates from the Neolithic layers of the Makhvilauri site.

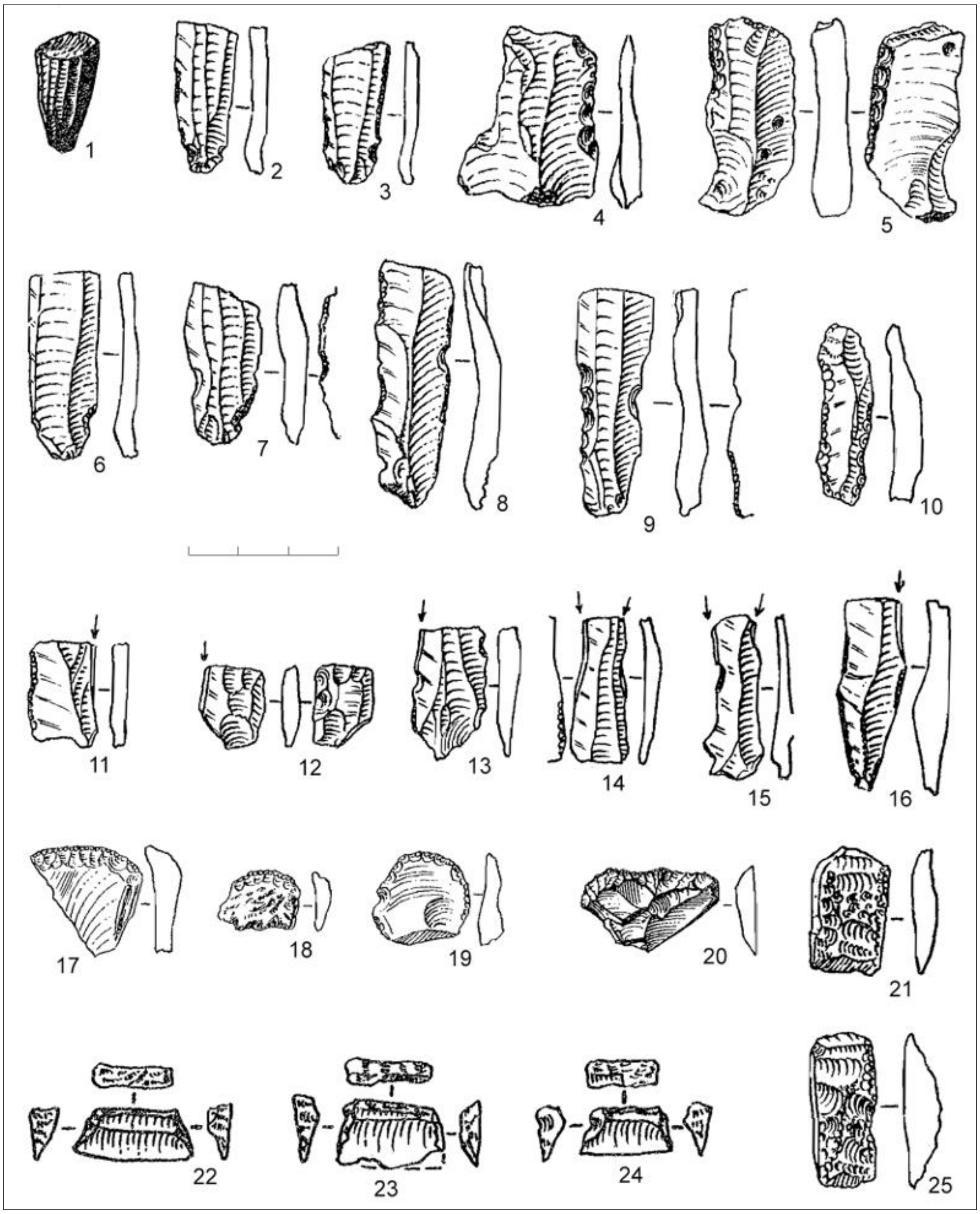

Fig. 3. Makhvilauri site. Flint and obsidian tools [Gogitidze, 1978, Fig. XLIV, XLV, XLVII].

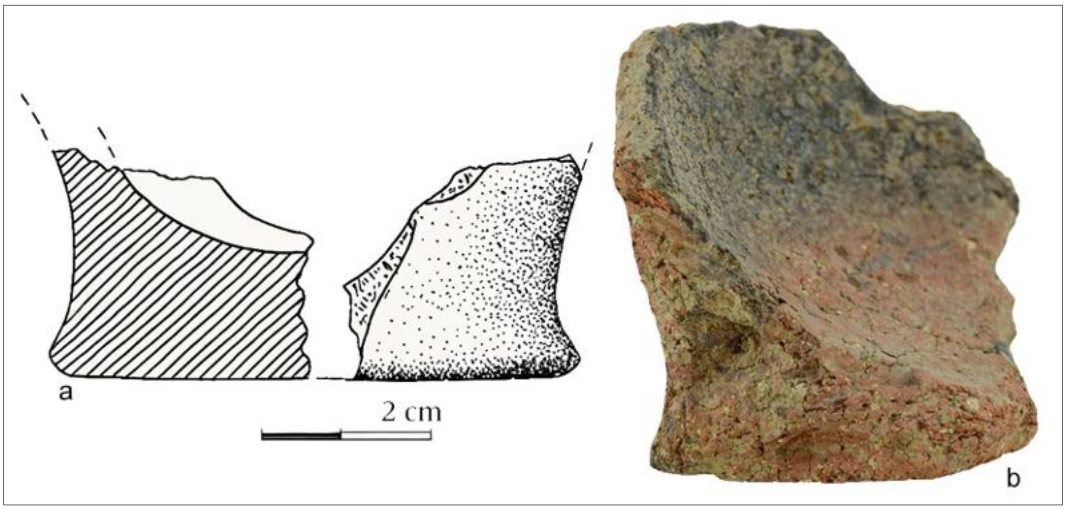

Fig. 4. Neolithic ceramic vessel from Makhvilauri site.

The assemblage appears to be dominated by medium-sized vessels with diameters exceeding 15-20 cm (fig. 4). Vessel bases were selected for detailed analysis, as the rim sherds are highly fragmented and less informative.

The vessel bases are coarse-grained and poorly fired, with inclusions visible macroscopically. To obtain more detailed information on their composition and use, a series of integrated analytical methods was applied.

Materials and methods

Petrographic Analysis. For the petrographic analysis of Neolithic ceramics (fig. 5-6), two base samples were selected and examined using a transmitted light microscope. The aim of the study was to determine the mineralogical composition, texture, porosity, and technological characteristics of the ceramic fabric from the Makhvilauri Neolithic settlement.

Chemical analysis of the ceramics was conducted in order to identify the elemental composition of the ceramic samples, employing non-destructive analytical methods (XRF). The objective of this analysis was to determine trace-element concentrations (*see* Table 2), which enables the identification of raw material sources, technological variations, and ceramic production practices[1].

Organic Residue Analysis. Lipid residue analyses and interpretations were based on established protocols [Evershed *et all.* 1990; Correa-Ascencio, Evershed 2014]. Approximately 2 g of ceramic fabric samples were taken from the same two base samples and their surfaces cleaned using a solvent-cleaned modelling drill to remove any exogenous lipids (e.g. soil or finger lipids due to handling). The samples were then ground to a fine powder using a solvent-cleaned glass mortar and pestle.

The powdered ceramic was transferred to a glass culture tube and an internal standard was added for quantification (*n*-tetratriacontane, 20 μg) before extraction, using an acidified methanol solution (H_2SO_4/MeOH, 4% *v*/*v*, 5 mL, 70 °C, 1 h) [Correa-Ascencio, Evershed 2014]. Lipids were then extracted from the H_2SO_4/MeOH portion with *n*-hexane (2×3 mL and 2×2 mL). The solvent was evaporated under a gentle stream of nitrogen to obtain the total lipid extract (TLE). Aliquots of the TLE (generally one quarter aliquots) were trimethylsilylated using *N,O*-bis (trimethylsilyl) trifluoroacetamide containing 1% trimethylsilyl chloride (20 μL, 70 °C, 1 h) and re-dissolved into *n*-hexane for analysis by gas chromatography (GC-FID). GC-FID analysis was undertaken on an Agilent 7890A using an HP-1 column (50 m × 0.32 mm, film thickness: 0.17 μm, coated with 100% dimethylpolysiloxane). Helium was used as a carrier gas (constant flow: 2 mL min^{-1}). The method comprised a 2 min isothermal at 50°C followed by a ramp to 300°C (10°C min^{-1}) and a 15 min isothermal

1. X-ray fluorescence analyses were performed at the Al. Janelidze Institute of Geology, Complex Laboratory of Geological Research, using a portable SPECTROSCOUT Geo XRF spectrometer.

№	Symbol	Concentrate		Error		Unit	
		Sample 1	*Sample 2*	*Sample 1*	*Sample 2*	*Sample 1*	*Sample 2*
1	SiO2	41.6	34.14	0.05	0.05	%	%
2	Al2O3	20.49	18.25	0.04	0.04	%	%
3	Fe2O3	7.423	10.17	0.007	0.01	%	%
4	P2O5	1.474	1.016	0.005	0.005	%	%
5	K2O	1.245	1.071	0.009	0.009	%	%
6	TiO2	1.179	1.158	0.005	0.005	%	%
7	CaO	0.7681	0.7479	0.0061	0.006	%	%
8	MgO	0.5656	0.5094	0.026	0.028	%	%
9	SO3	0.06026	0.09599	0.00063	0.05	%	%
10	CI	594.8	527.8	2.9	2.9	ppm	ppm
11	Ba	369.1	317.6	4.4	4.5	ppm	ppm
12	MnO	0.02266	0.02236	0.00042	0.00046	%	%
13	V	199.2	217.1	7.4	7.3	ppm	ppm
14	Zr	161.7	105.7	0.4	0.4	ppm	ppm
15	Cr	149.7	189.5	2.8	3	ppm	ppm
16	Sr	112.8	125.3	0.4	0.4	ppm	ppm
17	Cu	68.25	82.27	0.86	1	ppm	ppm
18	Zn	63.87	61.19	0.65	0.71	ppm	ppm
19	Nd	55.19	62.69	3.8	4.2	ppm	ppm
20	Ni	50.43	69.58	0.8	0.98	ppm	ppm
21	Rb	47.64	43.89	0.28	0.29	ppm	ppm
22	Y	23.3	19.09	0.24	0.23	ppm	ppm
23	Co	21.84	34.37	1.4	1.9	ppm	ppm
24	Ce	19.5	33.69	3.7	4.9	ppm	ppm
25	Ga	18.89	14.15	0.91	0.98	ppm	ppm
26	Pb	18.58	15.74	0.55	0.55	ppm	ppm
27	As	15.07	11.94	0.46	0.46	ppm	ppm
28	Br	11.15	10.46	0.24	0.25	ppm	ppm
29	Th	10.05	7.107	0.33	0.32	ppm	ppm
30	La	10.04	10.64	0	0	ppm	ppm
31	Nb	9.854	6.262	0.27	0.26	ppm	ppm
32	Cs	5.387	5.619	0	0	ppm	ppm
33	U	3.238	2.641	0.51	0.49	ppm	ppm
34	Hf	2.649	3.898	0.23	0.34	ppm	ppm
35	Ta	2.487	2.785	0	0	ppm	ppm
36	Hg	1.881	1.947	0	0	ppm	ppm
37	Sn	1.615	1.729	0	0	ppm	ppm
38	Sb	1.506	3.915	0.65	0.96	ppm	ppm
39	W	1.432	1.604	0	0	ppm	ppm
40	Bi	0.7274	0.7654	0	0	ppm	ppm

41	Ge	0.7005	0.74	0	0	ppm	ppm
42	TI	0.6365	0.6548	0	0	ppm	ppm
43	Mo	0.5854	0.6126	0	0	ppm	ppm
44	Se	0.4536	0.4712	0.11	0.11	ppm	ppm
45	Na2O	0.1353	0.1353	0	0	%	%
	Σ=	75		%			
	Σ=	67.4		%			

Table 2. Results of Chemical analysis of two ceramic samples.

[Correa-Ascencio, Evershed 2014]. Combined GC/MS analyses were performed on a Thermo Trace 1300 GC with a non-polar capillary column (HP^{-1}; 50 m × 0.32 mm × 0.17 µm, 100% dimethylpolysiloxane; helium as carrier gas at 2 mL min^{-1} constant flow; 34 min run) coupled to an ISQ LT single-quadrupole MS (transfer line at 300°C) operating in EI mode (70 eV) and (acquiring *m/z* 50-650 with 2 scans per second A selected ion monitoring mode) was used to detect dihydroxy-FAMEs (*m/z* 215, 243, 259, 443, 459, 471, 487, 499, 515), some of which are diagnostic of aquatic resources [Cramp, Evershed 2014].

The samples containing saturated fatty acids characteristic of degraded animal fats were then submitted to GC-combustion-isotope ratio mass spectrometry (GC-C-IRMS) in order to distinguish between non-ruminant and ruminant fats, and dairy from adipose fats [Copley *et all.* 2003].

Table 3 lists the pottery details and the results of the lipid residue analyses.

Results and discussion

The ceramic vessels exhibit high porosity. The fabric of both samples is similar and consists primarily of a brown-colored matrix containing inclusions and lithic fragments of various sizes and shapes. Among the granular components, quartz fragments are the most common, generally not exceeding 1 mm in size. In addition to quartz, fragments of plagioclase and microcline crystals were identified. Notably, both rounded and angular rock fragments occur within the fabric. The distribution of inclusions is heterogeneous; some are oriented parallel to one another, indicating directed mechanical stress during the forming process. A significant quantity of grog (chamotte) fragments was also observed among the inclusions. Besides, biotite is also encountered, while amphibole and pyroxene occur more rarely. The clay matrix also contains iron oxides and some chlorite.

Overall, the petrographic data indicate the use of a naturally multi-component clay raw material. This approach is generally considered to reduce shrinkage and increase the durability of ceramic products. The orientation of inclusions further suggests a hand-forming technique.

The high porosity and the presence of iron oxides may be associated with firing at relatively low to moderate temperatures. The occurrence of amphibole and pyroxene may reflect the use of local raw materials linked to volcanic or metamorphic rocks present in the surroundings of Makhvilauri site.

The results of the chemical analysis of the ceramics indicate a raw material based on an aluminosilicate matrix, typical of clayey sedimentary materials. Both samples show high contents of SiO_2 (34.14-41.6%) and Al_2O_3 (18.25-20.49%), pointing to a significant proportion of quartz and clay minerals (e.g., illite, kaolinite). Variations in the SiO_2/Al_2O_3 ratio between the samples may reflect raw material heterogeneity, intentional mixing, or the addition of grog and/or quartz.

Relatively high concentrations of Fe_2O_3 (7.42-10.17%) suggest iron-rich clays and may also account for the reddish-brown coloration of the vessels. Stable TiO_2 values (~1.16-1.18%) and the correlation between Al_2O_3 and TiO_2 indicate geological consistency of the raw material and reduce the likelihood of clay procurement from distant sources.

Low concentrations of alkali oxides (Na_2O = 0.13%; K_2O = 1.07-1.25%), as well as low CaO (=0.74-0.77 %) and MgO values, indicate that the clay is not enriched in carbonates

Elevated concentrations of certain elements (V, Cr, Ni, Co; e.g., V: 199-217 ppm; Cr: 149-189

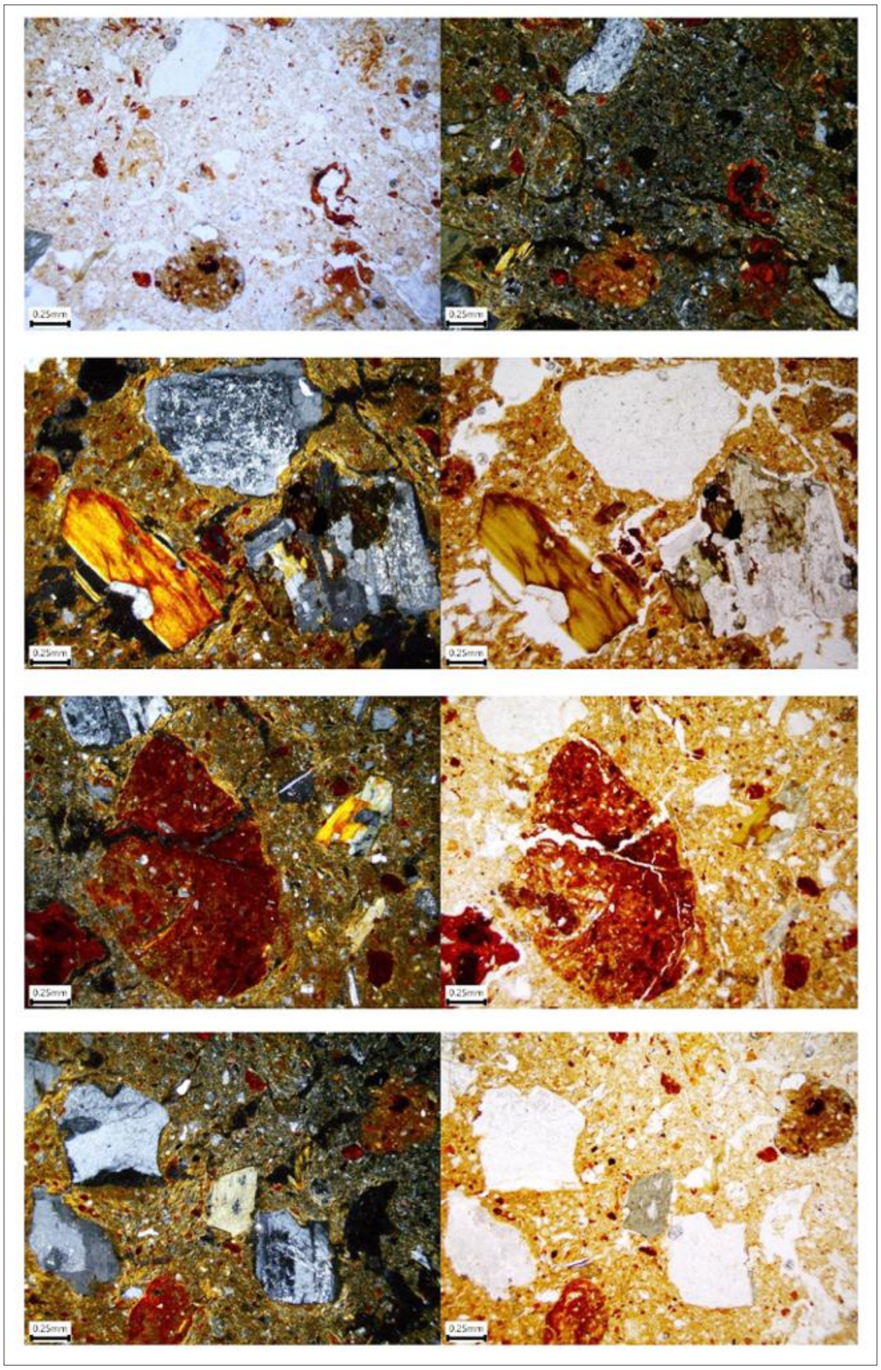

Fig. 5. Petrographic analysis of Makhvilauri ceramic (*Sample 1*).

ppm; Ni: 50-70 ppm) suggest the presence of mafic components or heavy minerals, which may be related to the natural sedimentary environment or to the natural admixture of sand within the clay. The presence of Zr (105-162 ppm) and Hf confirms the occurrence of a zircon mineral phase, which is commonly used as a stable geochemical indicator of raw material provenance.

The concentrations of Ba, Rb, and Sr reflect a feldspathic component and may be useful for grouping the samples. The relatively similar values of these elements in both samples indicate a shared technological tradition and, most likely, a common raw material base.

Notably, elevated P_2O_5 contents (1.02-1.47%) may be associated with the infiltration of

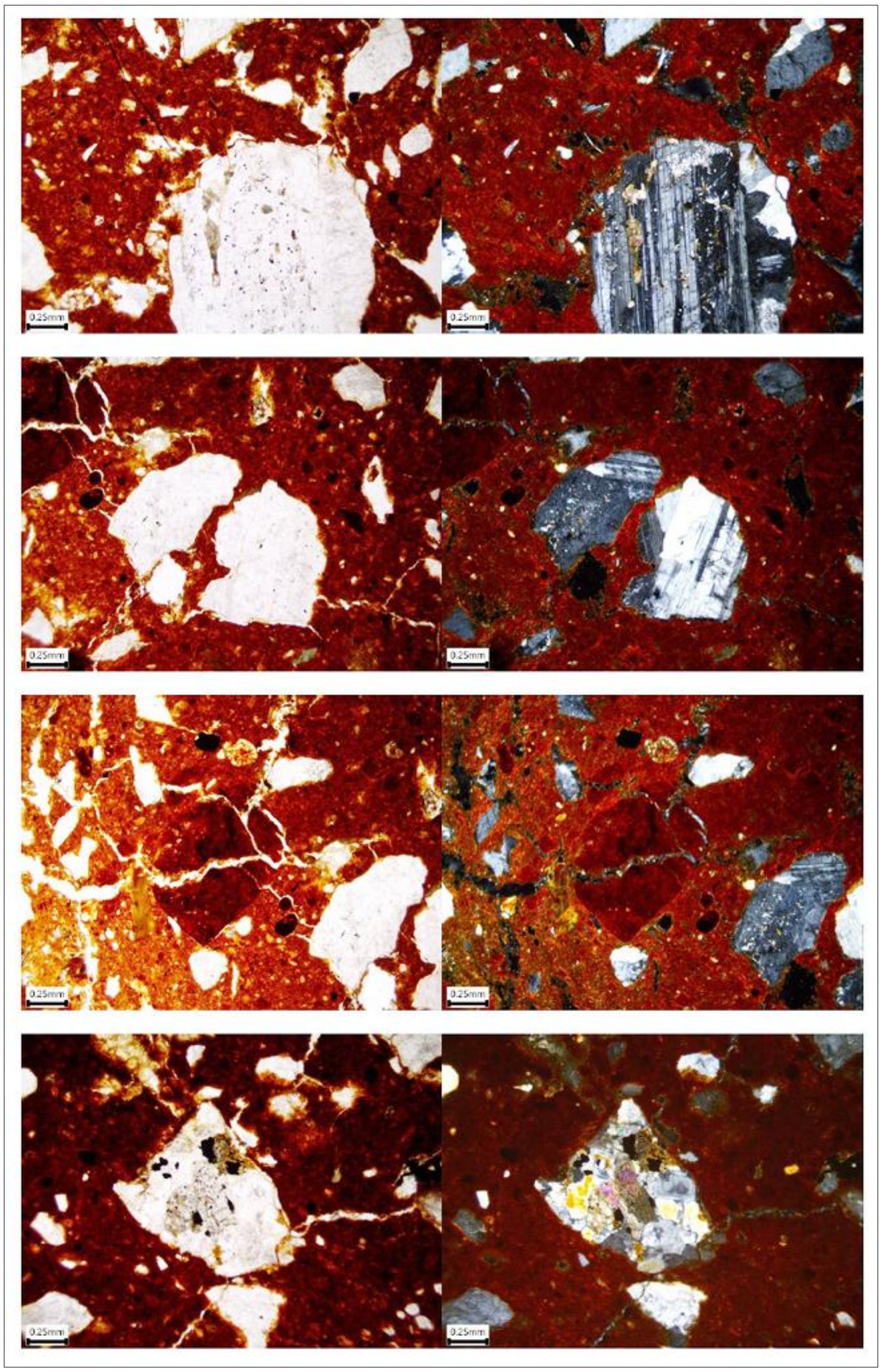

Fig. 6. Petrographic analysis of Makhvilauri ceramic (*Sample 2*).

organic substances into the ceramic pores during use or with naturally occurring phosphate inclusions in the raw material. This indicator is particularly relevant in the context of organic residue analysis and may point to the culinary function of the vessels.

The extract (GEO 1029; № 1) contained substantial amounts of phthalate contamination (widely used as plasticisers). The lipid extract was not investigated further.

Ceramic vessel sample GEO 1030; № 2 contained archaeological lipids, with lipid concentrations of 36 μg/g. The lipid profile of this sample was dominated by free fatty acids (principally $C_{16:0}$ and $C_{18:0}$) characteristic of degraded animal fats (fig. 7).

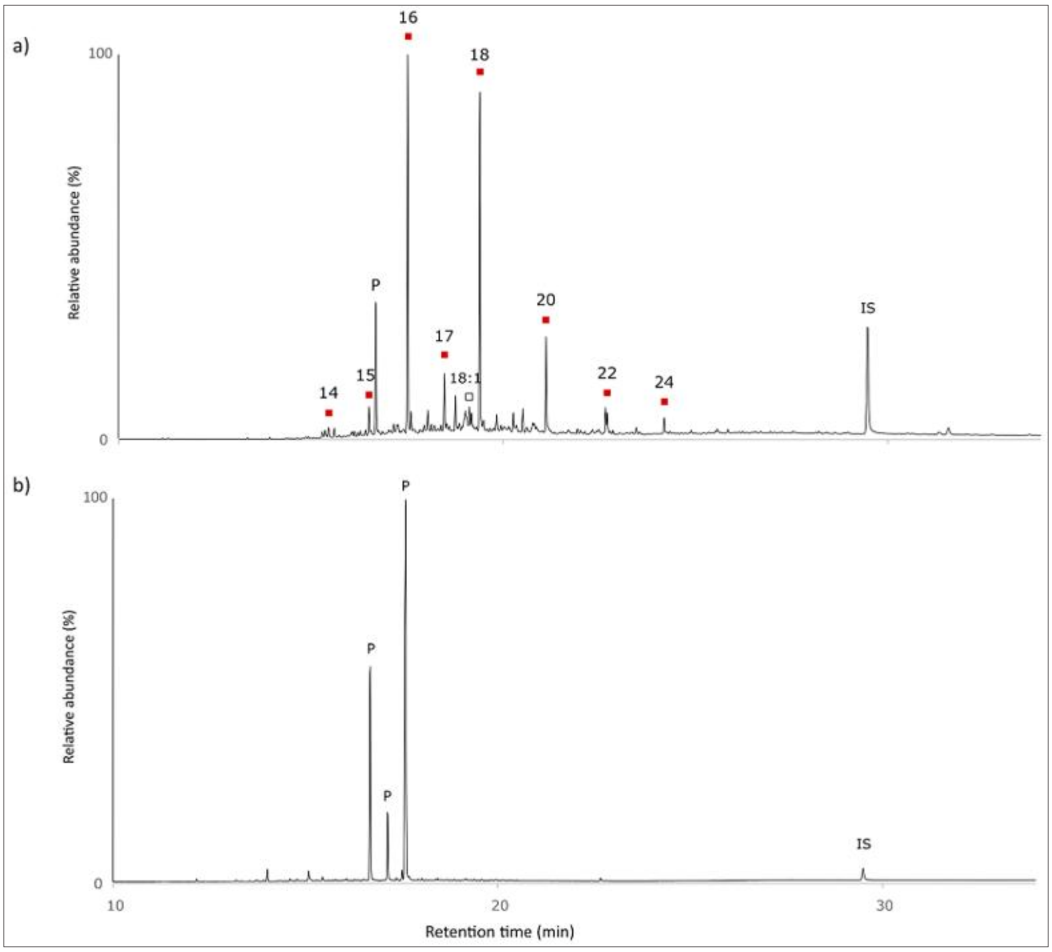

Fig. 7. Partial gas chromatogram of total lipid extracts from a) GEO 1030 (№ 2), characteristic of degraded animal fats and b) GEO 1029 (№ 1), showing plasticiser contamination. Squares: *n*–alkanoic acids (red for saturated fatty acids, unfilled/white for unsaturated fatty acids); IS: internal standard (*n*–tetratriacontane); P: phthalates; number n and n:i: acyl carbon number with zero or i degrees of unsaturation.

Monounsaturated fatty acids ($C_{18:1}$) were present in low abundance in this extract. These are the main fatty acids present in fresh animal fats, but they are prone to oxidation and their low abundance suggests that the lipids extracted are indeed archaeological. Oxidation products of unsaturated fatty acids (hydroxy fatty acids, dihydroxy fatty acids) and alcohols (C_{16}, C_{18}) were also identified in this lipid extract (*see* Table 3). Oxidation products can form naturally through degradation processes or under elevated temperatures during vessel use [Regert *et all.* 1998; Evershed 2008].

Extract GEO 1030 further included a series of long-chain fatty acids (LCFAs), ranging from C_{20} to C_{24} carbon atoms, and are present in lower abundance than palmitic acid ($C_{16:0}$) and stearic acid ($C_{18:0}$). The distribution suggests that these LCFAs may originate from animal fats, incorporated into animal tissues via routing from the ruminant animals' plant diet [Halmemies-Beauchet-Filleau *et all.* 2013; Halmemies-Beauchet-Filleau *et all.* 2014; Whelton *et all.* 2018]. LCFAs can also originate directly from leaf or stem epicuticular waxes [Kolattukudy *et all.* 1976; Kolattukudy 1980; Jetter *et all.* 2006] although typically with a differing relative distribution and often accompanying compound classes such as *n*-alkanes and alkanols.

The extract did not contain dihydroxy fatty acids with a carbon chain length of >C_{18}, which are indicative of aquatic resource processing [Hansel, Evershed 2009; Cramp, Evershed 2014]. Dihydroxy fatty acids originate from oxidation of long-chain monounsaturated fatty acids, which occur widely in fats and oils. Terrestrial fats con-

Sample name	Sample №	Context/ Feature	Lipid concentration (μg/g)	Compounds	$\delta^{13}C_{16:0}$ (‰)	$\delta^{13}C_{18:0}$ (‰)	$\Delta^{13}C$ (‰)	Interpretation (molecular and isotopic compositions)
GEO 1030	N2	Neolithic layer	36	FAs, *n* = 14, 15, 16, 17, 17 br, 18, 18:1, 19, 20, 21, 22, 23, 24; *n*-Alcohols (TMS), *n* = 16, 18; Hydroxy FAs, *n* = 16, 18; Dihydroxy FAs, *n* = 18	-26.7	-26.1	0.7	Non-ruminant fats

Table 3. Sample details and results of lipid residue analysis. FA – fatty acid; br – branched fatty acids; number n and n:i acyl carbon number with zero or i degrees of unsaturation.

tain long-chain monounsaturated fatty acids that are usually ≤C_{20} while aquatic fats also contain monounsaturated fatty acids with carbon chain lengths >C_{20} [Cramp, Evershed 2014; Bondetti *et all.* 2021]. The samples were not screened for further aquatic biomarkers (such as isoprenoid fatty acids or APAAs).

The $\delta^{13}C$ values of the individual $C_{16:0}$ and $C_{18:0}$ fatty acids were determined by GC-C-IRMS to characterise the sources of the animal fats extracted from vessel № 2 (GEO 1030; fig. 8). The $\delta^{13}C$ values of the archaeological fats were plotted against the $\delta^{13}C$ values of modern reference fats from animals raised on a pure C_3 diet (fig. 8a) [Copley *et all.* 2003].

The extract GEO 1030 showed $\delta^{13}C$ values consistent with a non-ruminant (e.g. pig, wild boar) origin. Using the $\Delta^{13}C$ proxy ($\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$; fig. 8b) reduces localised environmental effects on the absolute $\delta^{13}C$ values of fatty acids and emphasises their metabolic origins [Copley *et all.* 2003; Dunne *et all.* 2012]. Given the different climate of the archaeological site (Western Georgia) and the area where the modern reference animals were raised (Southern Britain), this is the more robust approach to characterise the origin of animal fats.

Using this proxy, it is also suggested that GEO 1030 was predominantly used to process non-ruminant resources.

The lipid residue analysis of the Makhvilauri Neolithic ceramics shows close similarities to Neolithic sites in northern Greece [Whelton *et all.* 2018], Anatolia [Gregg *et all.* 2009; Evershed 2008], and southeastern Europe [Spangenberg *et all.* 2006], where ceramic vessels were predominantly used for the processing of non-ruminant animal resources.

Conclusion

The results of the petrographic and chemical analyses of the ceramics are fully consistent with one another and clearly reflect a coherent technological knowledge of raw material selection and processing.

The petrographically described aluminosilicate clay matrix, characterized by a brown coloration and high porosity, corresponds closely with the chemically recorded high contents of SiO_2 (34-42%) and Al_2O_3 (18-20%), indicating the dominance of quartz and clay minerals. The presence of clay minerals, occasionally including chlorite, is consistent with the low concentrations of alkali oxides (Na_2O, K_2O) and carbonates (CaO, MgO), confirming the use of non-carbonate clays.

The petrographically identified quartz inclusions (commonly up to 1 mm in size and occasionally larger) are clearly reflected in the elevated SiO_2 values observed in the chemical analysis. Variations in the size and shape of quartz grains, as well as their heterogeneous distribution, suggest both a natural sedimentary component and the intentional addition of mineral temper.

The presence of plagioclase and microcline corresponds well with the low but stable concentrations of K_2O and Na_2O, indicating a moderate contribution of feldspathic components. In addition, the elemental concentrations of Rb, Ba, and Sr further support a geochemical association with feldspar minerals.

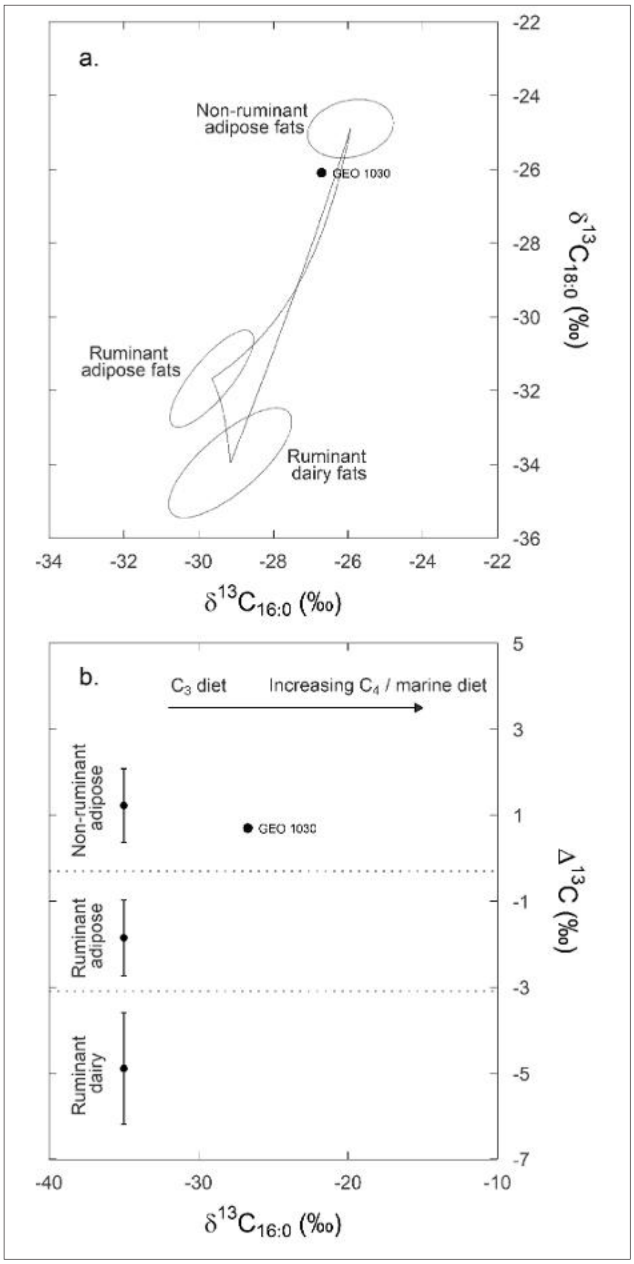

Fig. 8. (a) $\delta^{13}C$ values for the $C_{16:0}$ and $C_{18:0}$ *n*-alkanoic acids prepared from Neolithic pottery from Western Georgia. The three fields correspond to the P = 0.684 confidence ellipses for animals raised on a strict C_3 diet in Britain [Copley *et all.* 2003]. The $\delta^{13}C$ values obtained for the modern reference fats were adjusted for post-Industrial Revolution effects of fossil fuel burning by the addition of 1.2‰ (Friedli *et all.* 1986). (b) Difference in the $\delta^{13}C$ values of the $C_{18:0}$ and $C_{16:0}$ fatty acids ($\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$) obtained for the same archaeological fats. The ranges represent the mean ± 1 standard deviation of the $\Delta^{13}C$ values for the global database comprising modern animal fats from different locations including: Britain [Copley *et all.* 2003], Switzerland [Spangenberg *et all.* 2005], Kazakhstan [Outram *et all.* 2009], the Near East [Gregg *et all.* 2009], and Kenya and Libya [Dunne *et all.* 2012]. Analytical precision is ± 0.3‰.

Petrographically observed biotite, and the rarer occurrences of amphibole and pyroxene, are in full agreement with the chemically detected concentrations of Fe_2O_3 (7.4-10.2%), TiO_2 (~1.16%), and relatively elevated levels of elements such as V, Cr, Ni, and Co, which are typical of mafic and ferromagnesian minerals. These data point to a geological environment of the raw materials in which ferromagnesian components are naturally present.

Of particular importance is the petrographically inferred presence of grog (chamotte) fragments, which corresponds well with the relative dispersion of elemental values in the chemical dataset and with minor but noticeable inter-sample variations (e.g., SiO_2, Fe_2O_3). The use of grog indicates an advanced level of technological knowledge aimed at enhancing the mechanical strength and thermal stability of the ceramics.

The high porosity of the ceramics, in combination with a low proportion of fluxing phases, suggests firing at relatively low temperatures. Together with the presence of iron oxides, this is consistent with firing under oxidizing conditions, which is also reflected in the coloration of the ceramics. Moreover, high porosity facilitates the deep penetration of organic residues (lipids) into the ceramic matrix, increasing their likelihood of preservation. This assumption is confirmed by the detection of lipid residues in one of the Makhvilauri ceramic samples (GEO 1030; № 2).

The organic residue analysis indicates that the non-ruminant animal fats identified in the ceramics most closely correspond to the processing of pork or wild boar. The use of products from other non-ruminant animals, including bear, cannot be entirely excluded; however, based on the currently available data, no alternative interpretation can be reliably supported. Although the Makhvilauri settlement is located near a water source and net sinkers associated with fishing activities have been identified within the lithic assemblage, there is, as yet, no evidence for the processing of aquatic resources in the ceramic vessels.

As demonstrated by the study, the subtropical environment and high soil moisture characteristic of the Colchian Lowland did not result in the complete destruction of organic residues.

Consequently, future research is expected to yield more extensive data and provide deeper insights into the dietary practices and culinary traditions of prehistoric populations.

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