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Chemical and mineralogical characterization of late chalcolithic pottery (ca. 3700–3300 BCE) from southwest Anatolia (Türkiye)

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ABSTRACT

This paper presents the results of chemical and petrographic investigations on the late chalcolithic (ca. 3700–3300 BCE) pottery from the Burdur Lake region in southwest Anatolia (Türkiye). Twenty-one ceramic sherds and a clay lump from four different levels of the late chalcolithic site of Kuruçay Höyük (Burdur) were examined with thin section petrography, XRF, and XRD to illuminate the element and mineral compositions of the ceramics. The chemical compositions and their statistical evaluation demonstrate the continuous use of at least two local clay sources within each different phase of the late chalcolithic. While sources stay the same, petrographic thin section analysis implies a change in the clay preparation techniques. This is visible via the homogeneity of the clay matrix and the existence of shell and lithic inclusions in the paste. About the end of the late chalcolithic period, clay preparation appears to be enhanced conceivably with the changing technological setting of the period toward the early bronze age.

1. Introduction

The late chalcolithic in Anatolia, the westernmost protrusion of Asia, displays regional differences apparent in settlement patterns, material culture, and subsistence economies. While eastern Anatolian sites like Malatya Arslantepe show centralized and urbanized establishments and complexity on many levels (Fragnoli & Frangipane, 2021) like its Mesopotamian counterparts, central and southwest Anatolia stands in contrast (Düring, 2011).

The nature of archaeological remains in the chalcolithic period resulted in several archaeological problems for the understanding of the period, particularly in southwest Türkiye (Dietz et al., 2018). Yet excavations at the Burdur Lake region provide data for discussion (Fig. 1). The region is located in southwestern Anatolia, which expands north of Antalya where the Taurus mountains separate the plain from the Mediterranean shore. The lakes and valleys dominated the landscape that has been inhabited since the Paleolithic (Belfer-Cohen and Goring-Morris, 2014; Özdoğan et al.). While the region is close to the central Anatolian Konya plain and Elmalı plain of Antalya, its idiosyncratic cultural pattern has been visible since the neolithic (Duru, 2016). Settlements in the Burdur plain were not isolated but developed in their own trajectories in which their subsistence practices can be investigated via their level of production capacity, organization, production technologies, etc. Small, village-type settlements with limited archaeological evidence of centralization during the late chalcolithic evolved into more complex societies in the 3rd millennium BCE.

Research in the Burdur plain yielded a considerable amount of data on the late chalcolithic/early bronze age (ca. 4000–2000 BCE) period (Duru, 2012; Umurtak, 2020). While the archaeological evidence regarding the chalcolithic period (ca. 5th–4th millennia BCE) of southwest Anatolia is thin, Kuruçay Höyük (hereafter also, Kuruçay) stands out as one of the major sites yielding early chalcolithic (beginning ca. 6000/5900 BCE) and late chalcolithic (ca. 3700/3600–3400/3300 BCE) levels at the region. During the middle chalcolithic that continued for almost 1500 years, there was a discontinuity of human activity in the region (Duru, 2016: 13). While there is a lacuna for the first half of the 4th millennium BCE, the second half of the millennium show a significant occupation confirmed by intensive surveys (Vandam and Kaptijn (2015): 168; Vandam et al., 2019).

The second half of the 4th millennium BCE was defined as a period of new players, and technological and social changes (Journal style correction). Yet, this hypothesis needs to be tested for southwest

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Anatolia specifically for the Burdur Lake region. The possible continuation of late chalcolithic ways of life into the 3rd millennium BCE demands a detailed analysis of archaeological data, which involves understanding production technologies as part of subsistence practices. The exploitation and use of clay sources and pottery production techniques are among the major technological practices waiting for further exploration. This paper aims to investigate the production technologies of the 4th millennium BCE selected ceramics of the case site Kuruçay via chemical and mineralogical analysis.

1.1. Archaeological Setting: Kuruçay Höyük

Kuruçay Höyük located 15 km southwest of the modern city of Burdur (Fig. 1). It is a small, mound-type settlement close (ca.5–6 km) to Burdur Lake. The site has levels dating from the neolithic to the early bronze age, yet the best-preserved archaeological strata date to the chalcolithic period.

The late chalcolithic layer of Kuruçay has six sublevels designated as 6A, 6, 5, 4, 3, and 3A from the earliest to the latest chronological distribution (Duru, 2016: 68). Seven radiocarbon samples from wood calibrated with dendrochronology indicate an occupation between 3620 and 3350 BCE (Duru 1996: 101–102). According to the excavation director Refik Duru, the first four levels of Kuruçay, namely levels 6A-4, have a common cultural context while levels 3A and 3 demonstrate a different cultural setting. This difference in cultural contexts might well be related to the changes in the sustainable economy —which depends on mixed farming and animal husbandry during the chalcolithic— environmental conditions, or to what Duru refers to as 'newcomers' (Duru, 2016: 95, 96). These interpretations are mostly based on the changes in the layouts of the architectural plans and typological evaluation of ceramic remains.

Among the architectural plans, level 6A (especially 6A2) demonstrates the best-preserved layout with 23 buildings (Fig. 2). Level 6A with its sublevels 6A1 and 6A2 are defined as extraordinary based on architecture, such as the three entrances and circulation among the buildings (Umurtak, 2022). In 6A2, building-8 was identified as a shrine/temple on the basis of its central position and the non-portable architectural features; yet such features are common also in other buildings. Building 5 and 6 were referred to as chief(s) residential areas regarding their sizes and better preservation conditions compared to the rest of the structures, yet this interpretation is challenged by many (Eslick, 1988; Düring, 2011; Vandam et al., 2019: 3).

Level 6 keeps similar characteristics to level 6A. The differences between them are limited to architectural changes (Duru, 1996: 14). Level 5 is not well preserved. Duru (1996:15) argues level 4 foundations as the reason for heavy destruction in level 5. At level 4, the settlement size was decreased with less precise building styles. Starting from level 4, the architectural features have changed and in levels 3A and 3, a significant layout is not observable (Duru 1996: 16-17).

The late chalcolithic ceramic repertoire from Kuruçay is composed of two main groups: 1) relatively elaborate kitchenware mostly including plates, bowls, cups, and jugs in different sizes; 2) medium-sized coarse ware used for storage, transport, and cooking. The main ceramic Group 1 has sub-groups named G and H wares, which are the most common

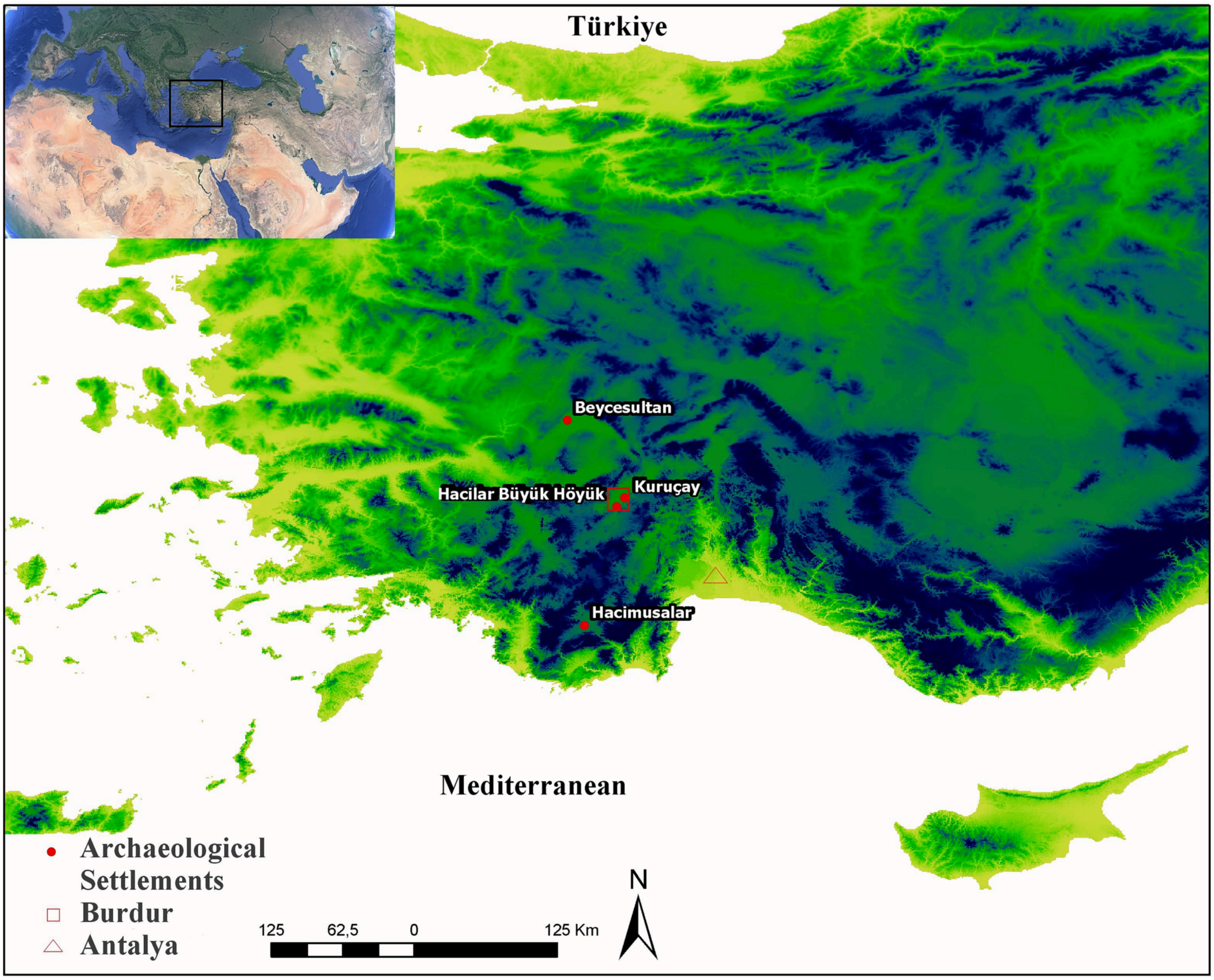

Fig. 1. Archaeological settlements mentioned in the text (map by Timur Güzey).

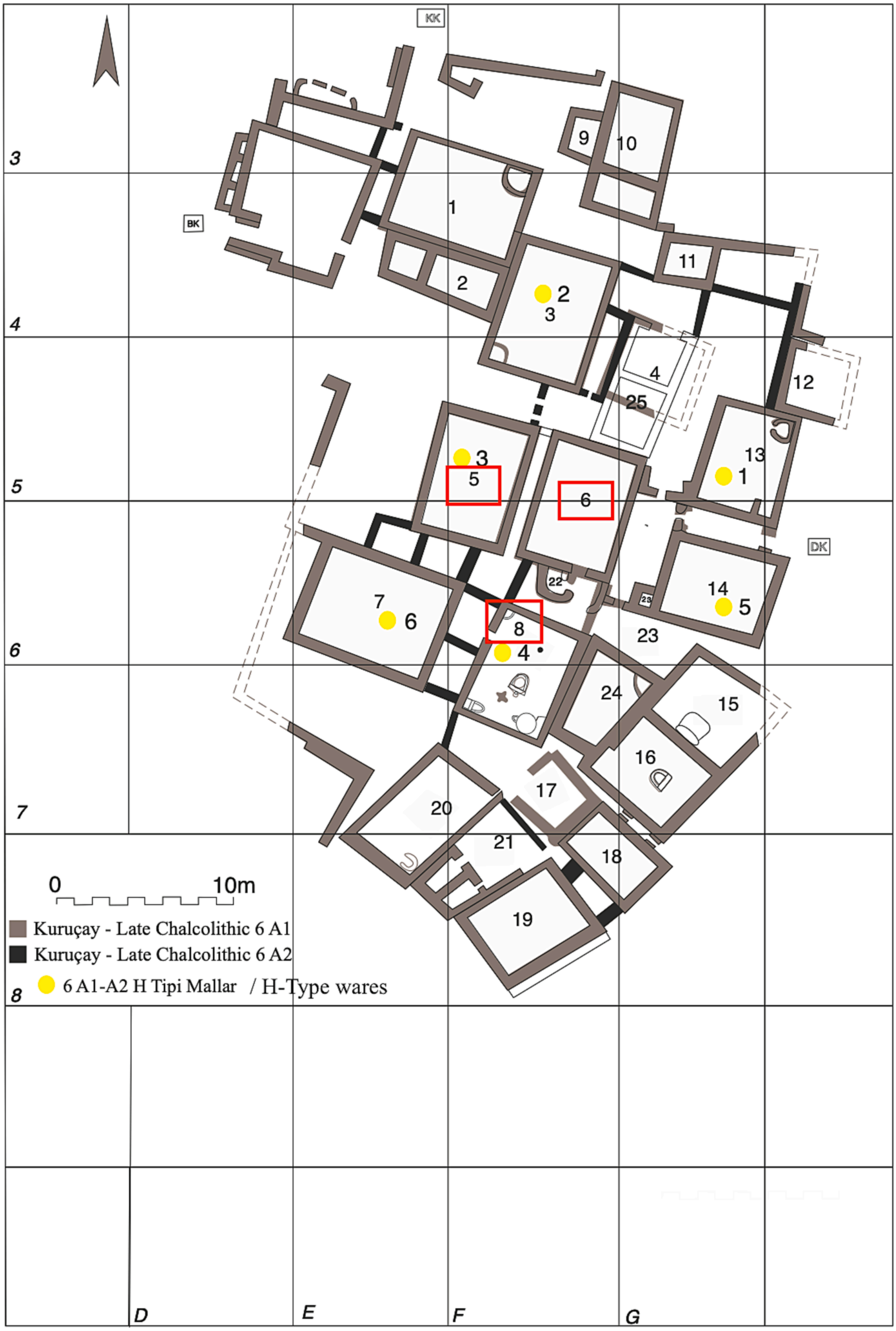

Fig. 2. Architectural plan of Kuruçay level 6A. Buildings mentioned in the text are shown in red frames (plan by Burak Mutlutürk).

among the repertoire. Toward the end of the late chalcolithic, another group (I ware) appeared for a short time in a limited amount. Ware group G almost includes 80 % of the repertoire in the late chalcolithic (Duru, 1996: 25), which is classified into 11 forms. The group has a broader typology including cups to jars with lug handles. Ware group H (hereafter H-wares) has seven, and I-wares have five different forms. H-wares mostly include plates and deep bowls (Duru 1996: 25-28) (Fig. 3).

The majority of the Kuruçay assemblage is characterized by dark gray and brown hand-made pottery. They are medium-to-well burnished and fired at low temperatures. The macroscopic evaluation of ceramics shows different colors at the cross-section and irregular breaks. The main ware groups identified as G and H wares were both medium and coarse textured pottery tempered with grit (e.g., calcite, chert, quartz) and organic materials (Duru 1996: 25-45). So far, a detailed chemical and mineralogical examination has not been conducted either on Kuruçay pottery or other comparative material.

This paper presents thin-section petrography, X-ray fluorescence (XRF), and X-ray diffraction (XRD) analyses of Kuruçay H-wares collected from levels 6A to 4. There are no H-wares recovered from levels 3A and 3, which might be related to a change/limitation in production facilitated by deep cups such as H-ware or a shift in populations as Duru (2016) suggested.

The reason for focusing on H-wares is two-fold: 1) to understand production technologies and raw material usage in such deep bowls; 2) to observe any (dis)continuation within different levels of the chalcolithic period. The results of this study will also contribute to establishing a pillar to understand the potential continuation of this production technology in the region because similar deep bowls were recovered in the early bronze age I (ca. 3400/3300–3000/2900 BCE) levels of other sites in Burdur plain and beyond such as Hacılar Büyük Höyük (Burdur),

Fig. 3. H-wares of Kuruçay (drawing by Burak Mutlutürk).

Beycesultan, and Hacımusalar Höyük (Elmalı, Antalya) (Fig. 1). Since only H-wares show typologically similar versions in the early bronze age, a pilot study is ongoing on this later period material.

2. Materials and methods

2.1. Materials

This study investigates a total of 21 ceramic sherds collected from primary contexts and a clay sample collected from levels 6A to 4 of Kuruçay (**Suppl. 1**). The late chalcolithic H-wares of Kuruçay are gray-colored, hand-made, and fired at low temperatures. Types generally include plates and deep bowls (Fig. 3).

The samples were selected from different archaeological layers. Four samples from level 4, two samples from level 5, 10 samples from level 6, and five samples from level 6A were considered for petrographic and chemical investigations. The only clay sample comes from level 6 (K6-2*), which is the only lump from the archaeological context. The sampling is based on the maximum number of available samples from each layer according to the rules and regulations of the Ministry of Culture and Tourism of Türkiye.

2.2. Methods

Petrographic thin section, XRF, and XRD analyses are used to illuminate the chemical composition and production technologies of the samples.

For petrographic thin-section analysis, all selected samples were prepared and examined under a Nikon LV100 Pol polarizing microscope at Istanbul Technical University, Faculty of Mines. The petrographic analysis aims to characterize raw materials, i.e., the rock and mineral fragments and fabric features used in pottery production. The petrographic analysis also illuminates certain technological aspects such as clay preparation techniques and firing temperatures of the pottery (Kibaroğlu et al., 2011).

For chemical characterization, major and minor element composition of the ceramic samples were determined by a Bruker S8 Tiger wavelength dispersive XRF (Rh X-ray tube, 4 kW) at Istanbul Technical University, Geochemical Research Institute. The internal and external surfaces of samples were cleaned with a tungsten dentistry tool before samples were ground to powder manually by using an agate mill. Press pellets were prepared for each sample. Standard major (Na_2O, MgO, Al_2O_3, SiO_2, P_2O_5, K_2O, CaO, TiO_2, MnO, and Fe_2O_3) and minor oxides (BaO, CoO, Cr_2O_3, NiO, Rb_2O, SrO, ZnO, ZrO_2) for ceramic studies are provided as wt% in **Suppl. 1. 1**. LOI (loss of ignition) and total calculated wt% are also listed. The LOI of the ceramic and clay samples was determined externally using 1 g of powder. This procedure is required because a large part of the volatile components mainly water and CO_2 of the clays disappear during firing and are no longer present in the resulting ceramics (Ottenburgs et al., 1993).

The XRF results were subjected to rigorous statistical analysis employing descriptive methodologies, including central tendency measures, bivariate plots, and boxplots (Kibaroğlu et al., 2011). To discern any potential variations between the samples obtained from disparate layers, a comparative analysis using non-parametric hypothesis tests namely Kruskal Wallis and Wilcoxon Sum Rank Tests was conducted (Salazar et al., 2020, Bray & Minc, 2020). To enhance the characterization of the samples based on their major chemical elements, Principal Component Analysis (PCA) was employed to reduce the dimensionality of the data (Baxter, 1994). This dimensionality reduction facilitated the identification of the most crucial underlying patterns and variations within the dataset, thereby enabling a more efficient interpretation of the chemical composition of the samples. A hierarchical cluster was applied to gain further insights into the potential associations between the samples. Similar applications of these methodologies are known in Madsen (1988), Tyers and Orton (1991), Baxter (2006), Vince (2011), Holmqvist et al. (2018), and Bellanger et al. (2021).

The results obtained through the application of the data analysis and visualizations were performed using the R free software environment (R Core Team, 2022). To ensure transparency and reproducibility of the research, the source code with the detailed instructions and commands used to perform the data analysis was made freely available in **Suppl. 2**.

For mineralogical characterization and to verify petrographic results, XRD analyses were conducted at the same institute with Bruker D8 Advance equipment. The analysis was conducted on dried samples ground to less than 75-μm grain size. Data were then collected over a 2θ range of 2°–70°, using a copper radiation source (Cu-Kα) at 40 kV and 40 mA. The XRD pattern was both manually and automatically matched with the mineral data through the use of Jade 5.0 software (MDI, California, USA) to identify the crystalline phases within the sample (see methodology in Dardeniz et al., 2021). All the results are provided in Table 1. K6-2* is the clay sample collected from level 6. The XRD graphs are provided in **Suppl. 3**.

3. Results

3.1. Petrographic thin section analysis

In the petrographic thin section analysis, grain sizes, pores, visual estimations of the grain size distribution, and fossil contents are observed (Fig. 4**a-h; Suppl. 4**). According to these parameters, the late chalcolithic H-ware from Kuruçay is made from medium or coarse fabrics. The colors of level 4 ceramics vary from light yellow–brown to black-brown under polarized light. All four samples from this level have small to medium cavities (i.e., vughs) inside their matrix. They are poorly (K4-3, K4-4) or moderately (K4-1, K4-2) sorted (Fig. 4a-b**; Suppl. 4 additional plate a**). Quartz inclusions are very fine and mostly subrounded. Calcite inclusion are micritic. K4-3 and K4-4 contain elongated fossil voids, the latter also includes shell fragments indicative of a lacunal/marine environment.

There are two samples from level 5 both of which look light black-brown under polarized light and deep-black brown under cross polarized light. The quartz and micritic calcite inclusions are very fine and sub-rounded indicating the use of a very fine clay. The thin section of K5-1 shows coarse calcite inclusions, and quartz and feldspar combination. The sample includes vegetal temper, sponge and gastropod shells (Fig. 4c**; Suppl. 4 additional plate b**).

Level 6 is architecturally the best-preserved level of Kuruçay. Ten samples from this level display clay matrixes varying from poorly sorted to (very) well sorted. All samples have pores of varying sizes. Their colors change from light yellow/red/black-brown to dark brown and black. Quartz and calcite inclusion are also not homogeneous. They change from medium to fine. K6-1, K6-7, and K6-9 contain shell fragments (Fig. 4f**; Suppl. 4 additional plate d**). Lithic fragments, which are different than quartz and calcite, are observed in the matrix of K6-5, K6-6, and K6-8 (Fig. 4e).

Five samples form level 6A color from light yellow, red, and black brown. Two are well sorted (K6A-1, K6A-3) and the rest is poorly sorted (Fig. 4g**, h**). Quartz grains show very fine size in the paste, whereas the grain size of micritic calcites changes from very fine to coarse. All analyzed ceramic sherds contain lithic fragment inclusions among which K6A-3 also contains sponge and gastropod void indicative of watery environments.

According to the petrographic thin section results, H-wares collected from levels 6 and 6A at Kuruçay demonstrate less homogeneous clay matrices with changing sorting degrees from coarse to fine. They mostly contain shell and lithic inclusions; the latter is not apparent in ceramic from the other levels. Levels 5 and 4 of Kuruçay demonstrate a change toward more homogeneous and finer clay preparation. The quartz and micritic calcite inclusions are fine-ground and mixed well in the clay paste.

Table 1
XRD results of 22 ceramic samples from Kuruçay Höyük. Abbreviations: Qz: Quartz, Cal: Calcite, Ab: Albite, Sa: Sanidine, Gp: Gypsum, Prg: Pargasite, Ms: Muscovite, Pprg: Potassic-pargasite, An: Anorthite, all An is (Na-rich, ordered), Kao: Kaolinite, Fprg: Ferro-pargasite, Mnt: Montmorillonite, Dol: Dolomite, Or: Orthoclase, Ill: Illite, Bt: Biotite; Prx: pyroxene; Amp: Amphibole; Fsp: Feldspar. All of the samples are ceramic except K6_2*, which is the clay sample.

S	Minerals														
Sample number	*Qz*	*Cal*	*Ab*	*Sa*	*Gp*	*Prg*	*Ms*	*Pprg*	*An*	*Kao*	*Fprg*	*Mnt*	*Dol*	*Or*	*Ill*
K4_1	+	+	+ (Ordered)	+	+	+	+								
K4_2	+	+		+			+	+	+						
K4_3	+	+	+ (Ordered)			+ (K-rich)	+		+	+			+		
K4_4	+	+				+ (K-rich)	+		+				+		
K5_1	+	+					+		+		+		+		
K5_2	+	+	+ (Ordered)				+		+		+		+		
K6_1	+	+	+ (Ca-rich, disordered)				+	+	+						
K6_2	+	+					+		+		+		+		
K6_2*	+	+	+ (Ordered)				+				+		+		+
K6_3	+						+		+		+				
K6_4	+	+					+		+		+		+		
K6_5	+	+					+		+		+		+		
K6_6	+	+				+ (K-rich)	++		+			+	+		
K6_7	+	+					+		+		+				
K6_8	+	+					+		+		+		+		
K6_9	+	+					+		+		+		+		
K6_10	+	+	+ (Ca-rich, disordered)				+		+		+	+	+		
K6A_1	+	+					+		+		+		+		
K6A_2	+	+					+		+		+				
K6A_3	+	+	+ (Ordered)				+		+		+		+		
K6A_4	+	+					+		+		+			+	
K6A_5	+	+					+		+		+		+		

3.2. XRF analysis

The XRF results display SiO_2, with an average content of approximately 33–55 %, representing a dominant component in the pottery. The average SiO_2 content is calculated to be 41.3 %, with a relatively high standard deviation of 6.1 %. This high standard deviation suggests a considerable variability in the SiO_2 content among the ceramic samples. K_2O shows an average range of approximately 2–5 %. Na_2O, with an average content of about 0.5–2.4 %, is characterized by an average to low representation in ceramics. MgO varies from low to high, approximately ranging from 1.85 % to 6.5 % (Table 2). This considerable variation in MgO content suggests diverse compositions among the pottery. In terms of the coefficients of variation, Na_2O, P_2O_5, and MgO are identified as having the most dispersed distributions. The coefficients of variation provide insight into the relative variability of the elements, and these three elements exhibit the highest variability among the major elements.

For the interpretation of the XRF analysis results and statistical analysis, only major elements are taken into consideration. The reason for the elimination of minor elements was due to their comparatively low representation in the dataset. The relatively limited presence of these minor elements in the samples might not yield sufficiently robust statistical outcomes due to potential data sparsity or noise. Consequently, the statistics of the minors were deemed less reliable or informative in this case. Otherwise, it is important to note that the trace elements are very useful for raw material characterization and provenance. Their existence and particular concentrations can provide important knowledge in the chemical study of ceramics (Maritan, 2023).

The selected ceramic assemblage exhibits specific characteristics as revealed by the descriptive statistics presented in Table 2. The major chemical elements in the ceramics display certain average and variability patterns. The descriptive statistics of the assemblage from Kuruçay highlight the prominent presence of SiO_2 and K_2O, the relatively low representation of Na_2O, and the wide range of MgO content. The high standard deviation of SiO_2 indicates substantial variability in its content, and the coefficients of variation point to the most dispersed distributions for Na_2O, P_2O_5, and MgO.

The Al_2O_3 levels vary between moderate to high concentrations shifting between ca. 7 % to 20 %. Similarly, the deviation in CaO is high changing from ca. 3.5 % to 25 %, the average being 17 % which reflects the dominance of micritic calcites, fossil or calcareous matrix in the composition. Fe values were detected between 4.2 and 7.5 %, which is considered low for major compositions (Kibaroğlu et al., 2011: 3079). High calcium concentrations relate to the calcareous affinity of clays which is common in the Burdur plain.

Bivariate and boxplots demonstrate the differentiation between distinctive levels. To further contextualize and validate the findings, the outcomes obtained from the bivariate plots were cross-referenced with the groups defined based on archaeological layers. During this cross-referencing process, two samples (K6-3, K6A-4: sample 9, 20 in **Suppl. 1** respectively) appeared as outliers in terms of CaO. Those are also confirmed as outliers in XRD results (**see: 3.3 XRD analysis;** Table 1). To ensure the integrity and reliability of the analysis, these two outliers were subsequently omitted from further statistical analysis.

Bivariate plots are used for Al, Fe, and Si vs. the other major elements. These plots aimed to explore potential areas of wide scattering in the compositional patterns, which might provide insights into the variability of the major element content. (Fig. 5, example output. For further plots refer to **Suppl. 2**).

The Kruskal-Wallis test (Kruskal & Wallis, 1952) was performed to scrutinize the major element composition between different levels within the late chalcolithic layers. The Kruskal-Wallis test is a non-parametric test used to compare the distributions of multiple groups when the data may not meet the assumptions of normality required for parametric tests (Salazar et al., 2020). The results indicate no statistically significant difference at a 95 % confidence level. This indicates no distinct variations differentiating sublevels from each other (Table 3).

These findings suggest that the pottery samples exhibit similar characteristics in major element compositions. The lack of significant differentiation in major element content indicates a certain degree of continuity or homogeneity in the material choices used in producing the ceramics across different levels, i.e., the use of similar clay from similar/same geological zones.

For exploratory analysis, the consecutive levels were grouped into two composite groups. Levels 4 and 5 were combined into one group (referred to as “K4 + K5″), and levels 6 and 6A were grouped (referred to as ”K6 + K6A“). This conservative grouping is based on archaeological interpretations (Duru, 2016) and aims to investigate potential differences in major element compositions between these two larger levels.

Subsequently, the Wilcoxon rank-sum test, also known as the Mann-

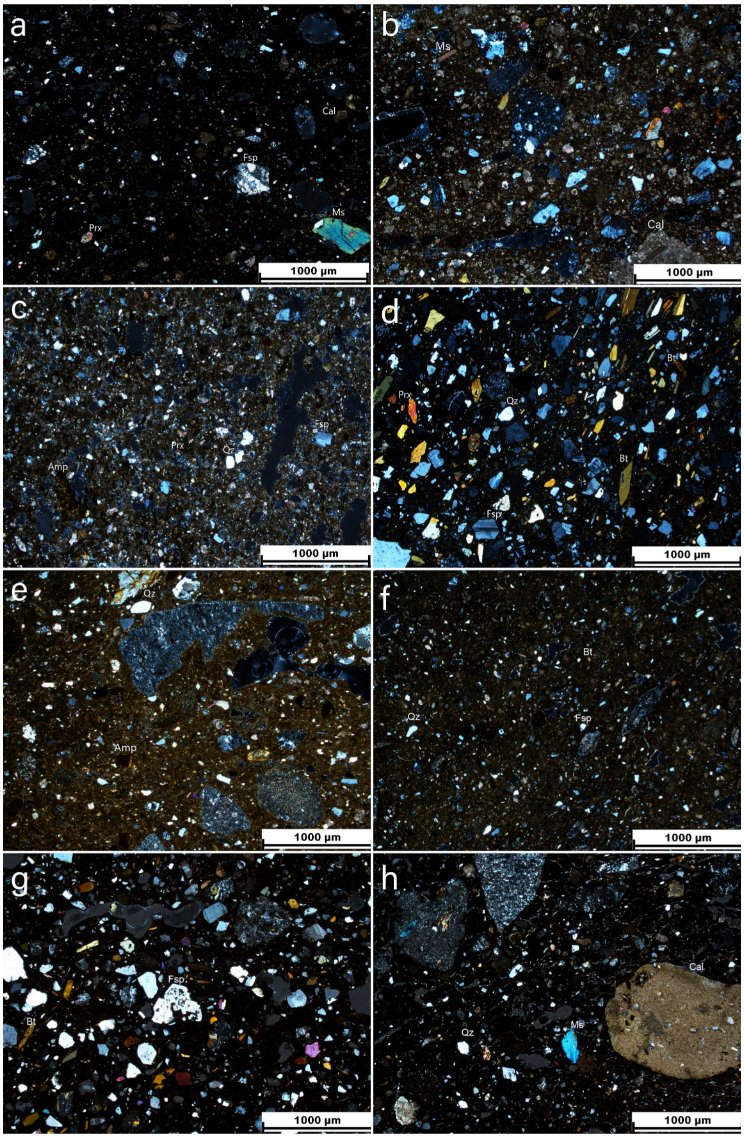

Fig. 4. Photomicrograph of thin sections of selected sherds showing the mineral contents of raw material. a) K4-2; b) K4-4; c) K5-1; d) K6-3; e) K6-8; f) K6-9; g) K6A-4; h) K6A-5. For abbreviations see Table 1.

Whitney *U* test (Mann & Whitney, 1947; Wilcoxon, 1945; Bray & Minc, 2020), was employed to examine whether this grouping revealed any statistically significant differences in major compositions between K4 + K5 and K6 + K6A. The results presented in Table 4, demonstrate that SiO_2, TiO_2, and Fe_2O_3 compositions were significantly different at the 95 % confidence level between K4 + K5 and K6 + K6A. The compositions of CaO and MnO were also found significantly different at the 90 % confidence level. Thus, K4 + K5 samples have significantly higher concentrations of SiO_2, TiO_2, MnO, and Fe_2O_3 whereas has a lower concentration of CaO compared to K6 + K6A. Rather than as single levels, the grouping of archaeological strata demonstrates a meaningful differentiation.

Despite the statistically significant differences in major element compositions between K4 + K5 and K6 + K6A, the bivariate plots did not display specific groupings among the samples that align with the designated phases (Fig. 6). To potentially uncover any hidden patterns, an additional approach was employed where the major elements Si and Al were combined into a new composite element. The samples were then replotted using this new composite element. Yet the results remained unchanged.

While the exploration of the data through bivariate plots is a valuable initial step in analyzing major element compositions, it is essential to recognize the complexity of archaeological materials. The integration of multiple analytical approaches, such as PCA, hierarchical clustering, or other multivariate techniques, may provide a more comprehensive understanding of the data and reveal any underlying patterns or relationships.

The PCA analysis resulted in the extraction of two dimensions that together accounted for 85 % of the total variance in the major element compositions (Fig. 7a). However, according to the results, despite considering all dimensions of the XRF analysis, no specific level samples aligned with the extracted dimensions (Fig. 7b).

As a complementary analysis, hierarchical clustering was conducted, setting aside the archaeological phases. The purpose of this clustering was to foster potential relationships among the samples and uncover any underlying structures that could provide valuable insights into the sample. The average-linkage method based on Euclidean distances of the samples was conducted. The dendrogram of the analysis in Fig. 8 revealed three groups. The first consists of two samples, which were the same outliers confirmed via petrography and XRD results. The remaining two groups do not exhibit a specific pattern in terms of their correlation with the archaeological phases. Nonetheless, hierarchical

Table 2
Descriptive statistics of the XRF results of H-wares.

	Level/Phase																				
	K4 (n = 4)				K5 (n = 2)				K6 (n = 10)				K6A(n = 5)				Total (n = 21)				
	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Coefficient of Variation (%)
Na_2O	0.58	1.08	0.87	0.23	0.70	0.84	0.77	0.10	0.58	2.37	0.96	0.51	0.59	2.39	1.04	0.76	0.58	2.39	0.94	0.50	53.02
MgO	4.64	5.66	5.00	0.45	6.02	6.93	6.48	0.64	1.87	7.98	5.34	1.56	1.85	6.34	4.84	1.84	1.85	7.98	5.26	1.43	27.09
Al_2O_3	7.11	9.52	8.81	1.14	7.85	8.61	8.23	0.54	6.71	19.77	10.11	3.61	7.26	19.53	10.71	4.99	6.71	19.77	9.82	3.43	34.92
SiO_2	34.54	44.46	37.96	4.59	35.43	37.09	36.26	1.17	32.79	55.26	42.46	5.96	37.48	55.58	43.65	7.45	32.79	55.58	41.30	6.10	14.76
P_2O_5	0.18	0.54	0.30	0.17	0.14	0.16	0.15	0.01	0.17	0.36	0.22	0.07	0.14	0.34	0.20	0.08	0.14	0.54	0.22	0.10	43.10
K_2O	2.58	3.06	2.87	0.23	2.26	2.67	2.47	0.29	2.20	4.92	2.92	0.76	1.96	4.97	2.88	1.23	1.96	4.97	2.86	0.77	26.89
CaO	18.17	21.90	20.32	1.56	19.63	19.79	19.71	0.11	3.54	25.07	16.16	5.72	3.59	23.31	15.81	7.47	3.54	25.07	17.21	5.46	31.75
TiO_2	0.49	0.71	0.55	0.11	0.58	0.62	0.60	0.03	0.51	1.04	0.73	0.17	0.54	0.77	0.65	0.08	0.49	1.04	0.67	0.15	21.93
MnO	0.09	0.15	0.11	0.03	0.11	0.11	0.11	0.00	0.09	0.17	0.13	0.02	0.11	0.14	0.12	0.01	0.09	0.17	0.12	0.02	17.48
Fe_2O_3	4.25	6.71	4.92	1.20	4.97	5.28	5.13	0.22	4.74	7.52	6.01	0.98	4.76	6.26	5.61	0.54	4.25	7.52	5.62	0.95	16.89

clustering provides insights into the similarities and differences in major element compositions among the samples.

To define the main characteristics of these clusters and identify any significant differences between them, the average wt% of each major element and sums of some major element groups (Al + Fe/Si, Si + Al, Mg + Mn + Fe) within each cluster were calculated. A pairwise comparison test was performed to quantify the significance of the differences between the clusters. This test enabled authors to identify statistically significant disparities in major element compositions among the clusters and provided a more comprehensive understanding of the variation in chemical compositions within the samples (Table 5).

Table 5 shows significant differences in major element concentrations between the 2nd and the 3rd cluster. The 3rd cluster exhibits significantly higher concentrations of Al_2O_3, SiO_2, TiO_2, MnO, and Fe_2O_3 compared to the 2nd. This suggests that ceramics in the 3rd cluster have higher major element contents compared to the 2nd. The 2nd cluster shows significantly rich CaO. It is important to note that the differences between the 1st cluster and the others are not considered in this analysis, as the 1st already represents the outliers and may not be directly comparable to the other clusters due to its distinct characteristics.

The distribution of the cluster members according to the levels is presented in Table 6 based on a Pearson Chi-Square Test. Yet, no significant relationship between the level and the cluster membership is identified. The resulting clustering could indicate that there were potentially two different clay sources in use during the late chalcolithic. Differences might be related to the diversity of clay deposits.

3.3. XRD analysis

XRD analysis confirms the existence of quartz and calcite in all of the ceramic samples. Aside from these minerals, all of the level 4 ceramics contain muscovite. Except for K4-1, the rest also contain sodium (Na) rich anorthite. K-rich pargasite and dolomite are comparatively common inclusions for level 4H-wares.

A similar structural pattern is visible in level 5 ceramics. The two samples from this stratum include muscovite, Na-rich anorthite, and dolomite. Both sherds include ferro-pargasite.

In the level 6 assemblage, muscovite and Na-rich anorthite still dominate. Pargasite is uncommon whereas ferro-pargasite and dolomite appear in all samples. Montmorillonite, which is a natural clay mineral, is only observed in two samples from this level (K6-6; K6-10). Montmorillonite, which decomposes at about 550–650 °C, indicates lower firing temperatures of this sample as well as heterogeneous exposure to fire. Similarly, illite, which is a type of high-quality clay mineral suitable for pottery, is only detected in the clay sample (K6-2*) recovered in level 6. The only clay sample shows superimposable results with the rest of the sample set. This suggests that K6-2* must be a remaining piece of clay brought to the site.

Level 6A ceramic sherds demonstrate a similar mineralogical pattern to level 6. Muscovite, sodium Na-rich anorthite, and dolomite are common inclusions. The only orthoclase-containing sample from Kuruçay is K6A-4 (Fig. 4g). Orthoclase is a common constituent of igneous rocks. The chemical composition of K6A-4 also demonstrates higher Al_2O_3, BaO, SrO, and low CaO values compared to the rest of the assembly. The closest chemical composition to this sample is detected in sample K6-3 (Fig. 4d).

4. Discussion

The late chalcolithic, hand-made H-wares of Kuruçay are made from coarse fabrics. Twenty-one samples collected from four sublevels of the late chalcolithic show both similarities and differences based on their chemical and mineralogical characteristics.

The existence of voids indicates the use of organic tempers. Among the assemblage, all samples contain quartz and micritic calcite which is

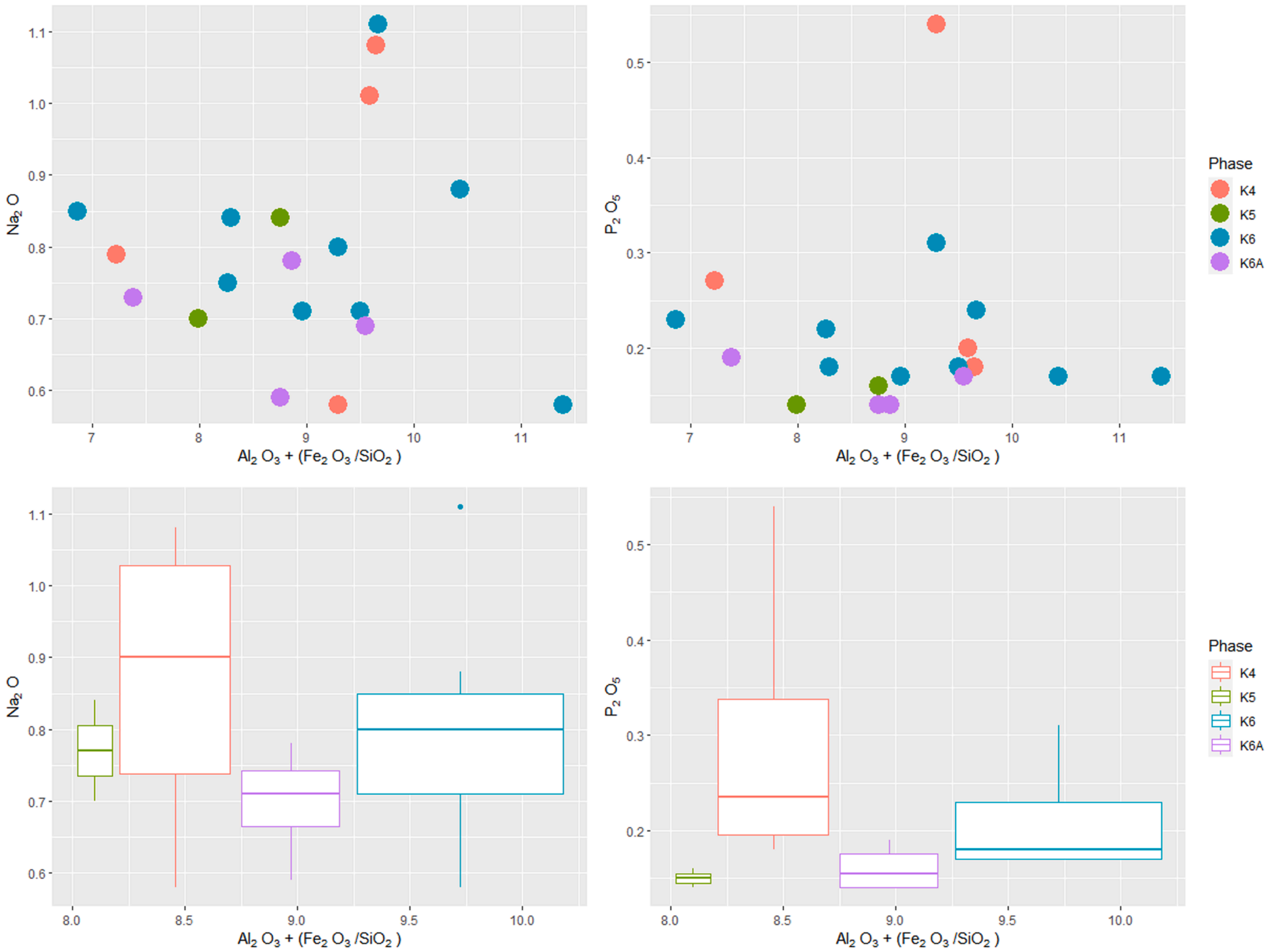

Fig. 5. Level-based bivariate and boxplots of the major oxides Al, Fe, and Si versus Na_2O and P_2O_5 (units in wt%).

Table 3
Kruskal-Wallis test results.

n = 21	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Test Statistic	0.872	3.136	1.605	5.118	6.631	2.452	3.736	5.677	4.108	4.405
df	3	3	3	3	3	3	3	3	3	3
Asymp. Sig. (2-tailed)	0.83	0.37	0.66	0.16	0.08	0.48	0.29	0.13	0.25	0.22

Table 4
Wilcoxon rank-sum test results.

		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Mean	K4 + K5	0.83	5.49	8.62	37.39	0.25	2.73	20.11	0.57	0.11	4.99
	K6 + K6A	0.99	5.17	10.31	42.86	0.21	2.91	16.05	0.70	0.13	5.87
Test Statistic		45.00	43.00	37.00	17.00	44.00	44.00	21.00	16.00	20.00	19.00
Asymp. Sig.		1.00	0.88	0.53	0.03	0.94	0.91	0.06	0.02	0.05	0.04

common in the region. Petrographic thin section and XRD analysis conducted by Dardeniz on the local stone quarries still exploited by the Burdur Provincial Administration (*Burdur İl Özel İdare*) shows calcite (i.e., crystallized calcium carbonate), dolomitic calcite, and fossils (published in Umurtak, 2023). The results superimpose with the local geological formations. The geology map of the research area (Fig. 9) clearly illustrates that Kuruçay is situated just northwest of an extensive lacustrine carbonate rock complex as well as other nearby sources of limestone (i.e., amorphous calcium carbonate) structures. Consequently, it is possible to state that the inhabitants took advantage of the nearby sources of calcite and fossils from lacustrine deposits.

Bioclast inclusions in the clay paste also demonstrate a relationship with watery environments such as Burdur Lake and Eski Göl (meaning Old Lake) (Fig. 4; **Suppl. 4**). In level 4, elongated fossil shells (K4-3, K4-4) and shell fragments (K4-4) are detected. In the next level, sample K5-1 contains vegetal temper, sponge inclusions, and gastropod shells. Shell

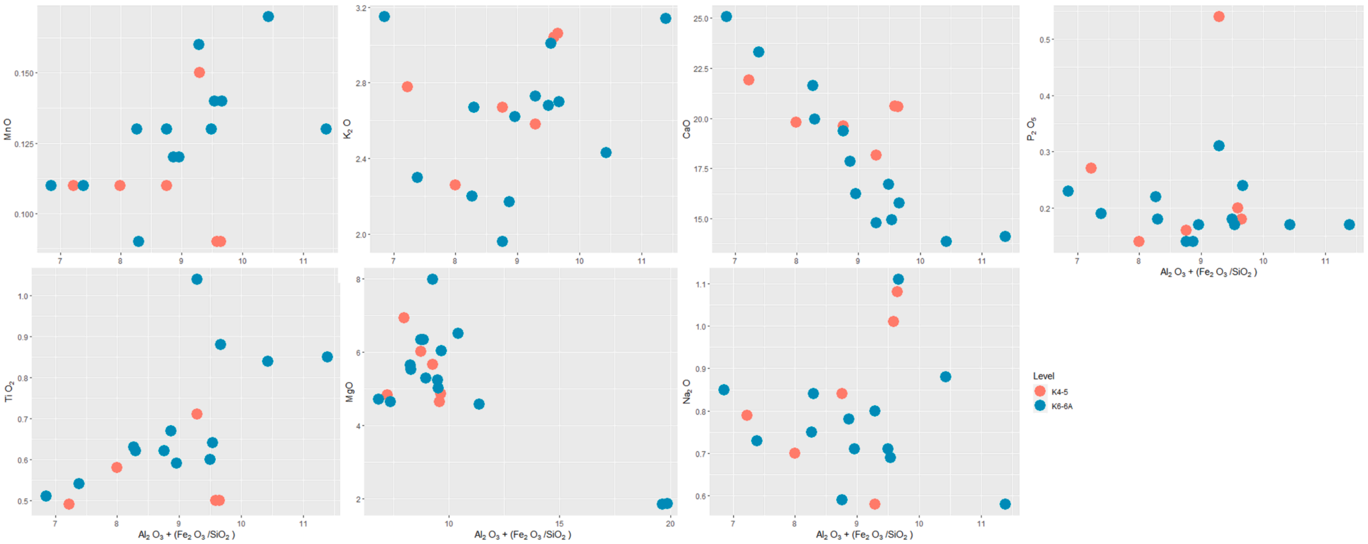

Fig. 6. Level-based bivariate plots of the major oxides (units in wt%).

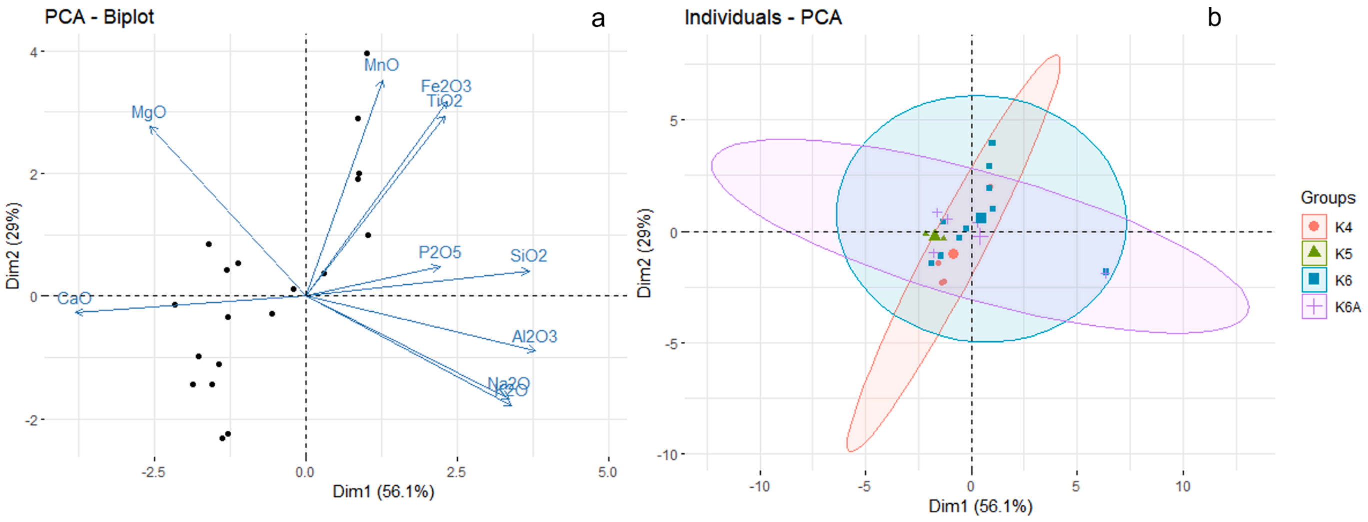

Fig. 7. PCA results from **a)** PCA scatter plot of two principal components (Dim1 and Dim2) of the selected element concentrations consisting of 21 samples **b)** The distribution of the samples from different levels according to the PCA dimensions. The ellipses on the plot represent potential group locations of the dimensions. In this representation, most of the pottery samples are clustered around the central area, indicated by the blue circle. This clustering suggests that the samples do not exhibit specific groupings based on the major element compositions.

fragments and sponge inclusions are also visible in K6-9 and K6-10. Sample K6A-3 from the earliest level of the late chalcolithic include sponge and gastropod shells. The existence of shells and gastropods indicates the continuous relation of the Kuruçay community with the lake. Among these inclusions, gastropod fossils are known from Eski Göl I and Eski Göl II (ca. 10,000 BP) periods (Görmüş et al., 2007). Eski Göl, which is now completely dry, was located close to the Burdur Lake which is experiencing a similar fate today due to climatic and environmental changes.

The XRF analysis and the detailed statistical evaluation of the compositions demonstrate similar characteristics for all the archaeological levels within the late chalcolithic. The lack of significant differentiation in major element content indicates a high degree of continuity or homogeneity in the material choices used in producing the ceramics across different levels.

While the results of several layers of statistical analysis indicate that the samples in the different archaeological layers do not show a distinct pattern or grouping based on their chemical composition, the cluster analysis yielded information on potentially different clay sources (Table 5).

A possible distinction between sublevels of late chalcolithic becomes possible with igneous rock lithic inclusions. Lithics in the clay paste are limited to levels 6A and 6, whereas later levels do not show a trace of lithics. Lithic fragments and their sizes also relate to the lack of paste preparation processes like levigation or sieving (Quinn, 2013: 154, 156). This confirms the low homogeneity of the clay matrix visible in these levels. In levels 5 and 4, no lithic inclusions are visible, and petrographic analysis demonstrates more homogeneous and finer clay preparation.

A recent survey conducted at the Burdur plain by the Sagalassos team investigated late chalcolithic sites and conducted petrographic research on the pottery (Vandam et al., 2019: 6). Accordingly, the late chalcolithic sites discovered throughout the survey share similarities in the material culture, including gray-brown colored, hand-made, low temperature fired, and burnished pottery. While the chronology of survey material should not be considered as secure as an excavation, Vandam et al., (2019: 6) note poorly sorted, coarse fabrics, with shell and grit inclusions supporting the petrographic results of this study.

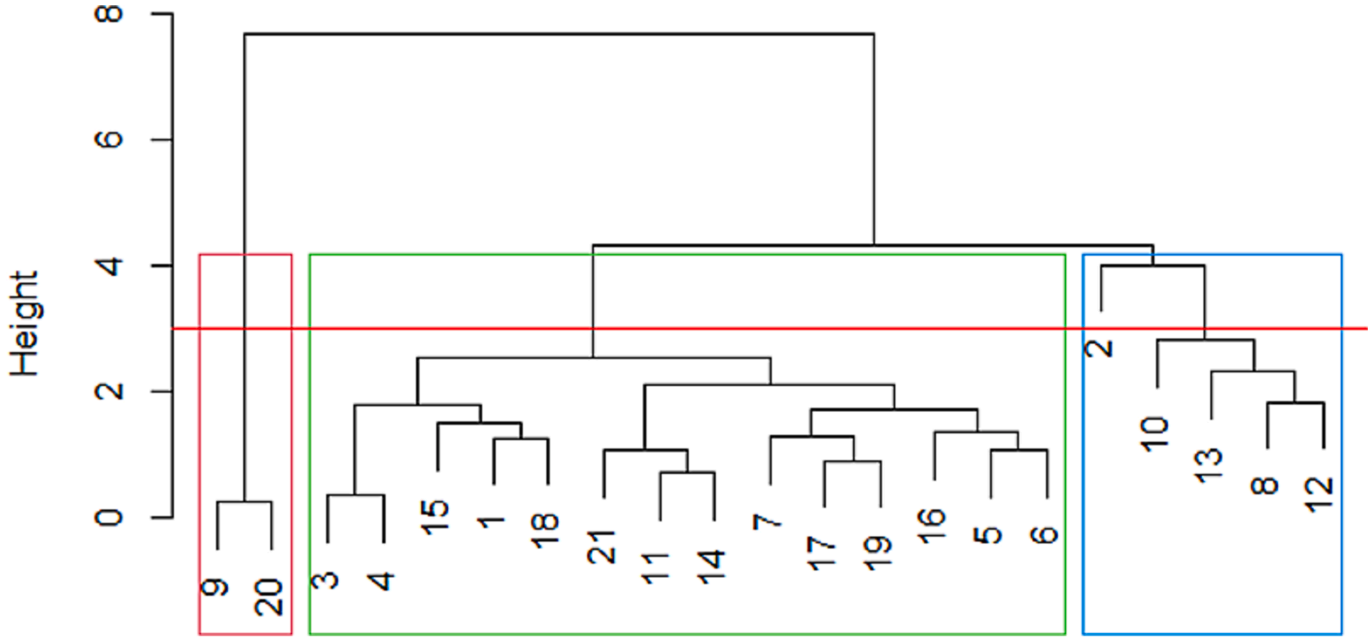

Fig. 8. Dendrogram showing average-linkage of the examined samples. Rectangles in different colors indicate different clusters.

Table 5
Pairwise comparison of the clusters. Results are based on two-sided tests assuming equal variances. For each significant pair, the key of the smaller category appears in the category with the larger mean. Significance level for upper case letters (A, B, C): 0.05.

Mean wt%	(A) Cluster 1	(B) Cluster 2	(C) Cluster 3
Na_2O	2.38 (BC)	0.79	0.79
MgO	1.86	5.43 (A)	6.15 (A)
Al_2O_3	19.65 (BC)	8.41	9.852 (B)
SiO_2	55.42 (BC)	38.53	43.392 (B)
P_2O_5	0.35 (B)	0.18	0.29
K_2O	4.946 (BC)	2.61	2.72
CaO	3.57	19.83 (AC)	15.33 (A)
TiO_2	0.77 (B)	0.58	0.864 (B)
MnO	0.12	0.11	0.15 (B)
Fe_2O_3	6.29 (B)	5.06	6.93 (B)
Al + Fe/Si	19.76 (BC)	8.54	10.01 (B)
Si + Al	75.07 (BC)	46.94	53.24 (B)
Mg + Mn + Fe	8.27	10.60	13.23 (AB)

Table 6
Level based frequencies. Chi-Square Test Statistic: 0.564, $p > 0.05$.

n = 21	Cluster 1	Cluster 2	Cluster 3
K4	0	3	1
K5	0	2	0
K6	1	5	4
K6A	1	4	0

5. Conclusions

The petrographic and chemical examinations of Kuruçay Höyük H-wares demonstrate a local production facilitated from at least two clay sources within proximity of the site including the lacunal environments of the Burdur Lake region.

The micritic calcites common in the late chalcolithic H-wares are part of the geological formation of the region (Fig. 9). The calcareous rocks are still exploited in the modern quarries within 10 km of proximity to Kuruçay. The existence of calcite but lack of vitrification based on macroscopic evaluation suggests firing temperatures lower than 850 °C. Existence of montmorillonite, a clay mineral decomposing around 550–650 °C, also supports this observation.

Kuruçay H-wares show chemical compositional homogeneity among the four sublevels of 6A to 4. This compositional concordance suggests that the raw clay sources used for the production should be located within the same/similar geographic location (Cultrone et al. (2001)). Sponge and gastropod inclusions identified via petrography show the exploitation of clay from lacustrine environments, the latter possibly suggests the Eski Göl area, which is almost 6 km to Kuruçay with crow flies. Hitherto the statistical evaluations possibly indicate the exploitation of at least two clay sources. Since the hierarchical clustering does not exhibit a specific pattern in terms of their correlation with the archaeological phases (Fig. 8), it hard to identify any relationship between clay sources at this stage of the research.

The only orthoclase-containing sample from Kuruçay is K6A-4 (Fig. 4g). While orthoclase is a common constituent of igneous rocks, it is a unique inclusion for the selected H-ware Kuruçay pottery. Taking the archaeological context of this sample into account, which was found in Building-8 of level K6A, this ware could be considered non-local. Although there is no clear evidence to refer to Building-8 as a temple/shrine, it is noticeable to have the only mineralogically exceptional sherd from this context. Except for the orthoclase inclusion, sample K6-3 (Fig. 4d) demonstrates a similar composition to K6A-4 thus these two samples cluster as a group. Archaeologically, this might suggest the seldom but continuous use of such non-local ceramics/clay.

While there is a continuity in the exploited clay sources, a change in clay preparation techniques is detected based on homogeneity in clay matrices and lithic inclusions. H-wares from levels 6A and 6 have heterogeneous clay matrices with coarse to fine. Diversity in their chemical compositions is higher and the existence of lithic inclusions must be due to the lack of paste preparation processes like levigation or sieving. In the later phases of the late chalcolithic, pottery from levels 5 and 4 is more homogeneous and displays a more accurate clay preparation with no lithic fragments. The quartz and micritic calcite inclusions are fine-ground and mixed well in the clay paste in levels 5 and 4. This shift in clay preparing technique could be due to the need for a quicker ceramic production in Level 6 which requires by-passing of some clay preparation steps. It could also indicate an attempt toward specialized ceramic production in levels 5 and 4. The excavations at the site yielded no indication of increasing specialization in other crafts at the later levels of

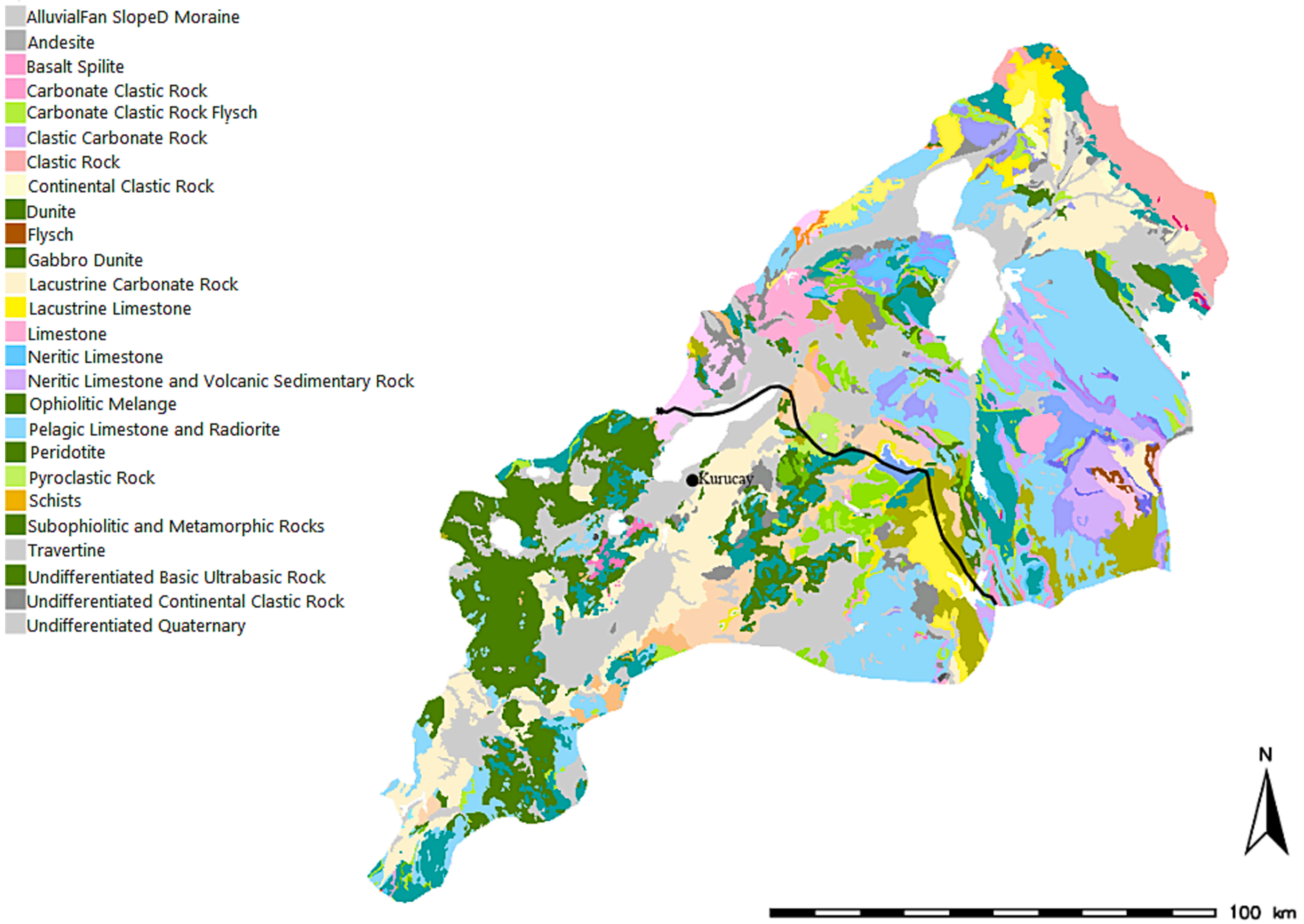

Fig. 9. Geological setting of the Burdur Lake region (map by Bülent Arıkan).

Kuruçay thus both of these hypotheses should be tested with further data; i.e., new excavations at the site and/or analytical data from contemporary archaeological settlements.

While H-wares disappear at the final late chalcolithic levels of Kuruçay (i.e., levels 3 and 3A), a similar type reappears during the early bronze age in the region. Analysis of similar wares from later periods will illuminate this question as the developments in the late chalcolithic period are seen as part of the early bronze age in the Burdur Lake region, which is also the case for the regional counterparts (Schoop 2011; Horejs, 2014; Vandam et al., 2019; Şahoğlu and Tuncel, 2014).

This study presented the first complete analytical data from the late chalcolithic pottery of Kuruçay. There is room for research on similar ware types recovered at the late chalcolithic and early bronze age of the region to understand the possible (dis)continuation of ceramic production technologies in broader southwest Anatolia.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All the data is presented as Supplementary including the R-code.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104304.

References

Baxter, M.J., 1994. Exploratory multivariate analysis in archaeology. Edinburgh University Press, Edinburgh.

Baxter, M.J., 2006. A review of supervised and unsupervised pattern recognition in archaeometry. Oxford Archaeometry 48 (4), 671–676.

Belfer-Cohen, A., Goring-Morris, N., 2014. The Upper Palaeolithic and Earlier Epi-Palaeolithic of Western Asia. In: Renfrew, C., Bahn, P. (Eds.), The Cambridge World Prehistory. Cambridge University Press, Cambridge, pp. 1381–1407. https://doi.org/10.1017/CHO9781139017831.088.

Bellanger, L., Coulon, A., Husi, P., 2021. Determination of cultural areas based on medieval pottery using an original divisive hierarchical clustering method with geographical constraint (MapClust). J. Archaeol. Sci. 132, 105431.

Bray, T.L., Minc, L., 2020. Imperial Inca-style pottery from Ecuador: Insights into provenance and production using INAA and ceramic petrography. J. Archaeol. Sci. Rep. 34, 102628.

Cultrone, G., Rodriguez-Navarro, C., Sebastian, E., Cazalla, O., Torre, M.J., 2001. Carbonate and silicate phase reactions during ceramic firing. Eur. J. Mineral. 13, 621–634. https://doi.org/10.1127/0935-1221/2001/0013-0621.

Dardeniz, G., Yıldırım, T., Yıldırım, C., Çiftçi, E., 2021. Techniques of blue, green, and white faience bead production used at the early bronze age central anatolian site of resuloğlu (Turkey). Archaeometry. 63, 327–342. https://doi.org/10.1111/arcm.12606.

Dietz, S., Mavridis, F., Tankosic, Z., Takaoglu, T. (Eds.), 2018. Communities in transition: The circum-Aegean area in the 5th and 4th Millennia BC, First Edition. Oxbow Books.

Düring, B.S., 2011. Millennia in the Middle? Reconsidering the Chalcolithic of Asia Minor. In: Steadman, S.R., McMahon, G. (Eds.), The Oxford Handbook of Ancient Anatolia. Oxford University Press, Oxford, pp. 796–812. https://doi.org/10.1093/oxfordhb/9780195376142.013.0036.

Duru, R., 1996. Kuruçay Höyük II: 1978–1988 Kazılarının Sonuçları Geç Kalkolitik ve İlk Tunç Çağı Yerleşmeleri. Türk Tarih Kurumu Basımevi, Ankara.

Duru, R., 2012. The Neolithic of the Lakes Region: Hacilar- Kuruçay Höyük- Höyücek - Bademağacı Höyük. In: Özdoğan, M., Başgelen, N., Kuniholm, P. (Eds.), The Neolithic in Turkey: Western Anatolia, vol. 4. Archaeology & Art Publications, Istanbul, pp. 1–65.

Duru, R., 2016. 'Tarım'dan 'Yazı'ya Burdur yöresi ve yakın çevresi'nin altıbin yılı (MÖ 8000- MÖ 2000). Batı Akdeniz Kalkınma Ajansı, Antalya.

Eslick, C., 1988. Hacılar to Karataş: Social organization in south-western anatolia. Mediterranean Archaeology. 1, 10–40. http://www.jstor.org/stable/24666552.

Fragnoli, P., Frangipane, M., 2021. Centralisation and decentralisation processes and pottery production at Arslantepe (SE Anatolia) during the 4th and early 3rd millennium BCE. World Archaeol. 53 (5), 834–861. https://doi.org/10.1080/00438243.2021.2015623.

Görmüş, M., Yağmurlu, F., Şentürk, M., Uysal, K., 2007. Jeolojik sentez: Burdur Gölü ve çevresi. I. Burdur Sempozyumu, Burdur, Turkey, pp. 558–568.

Hansen, S., 2014. The 4th Millennium: A watershed in European Prehistory. In: Horejs, B., Mehofer, M. (Eds.), Western Anatolia before Troy. Proto-Urbanisation in the 4th Millennium BC?: Proceedings of the International Symposium held at the Kunsthistorisces Museum Wien Vienna, Austria, 21-24 November 2012. Austrian Academy of Sciences Press, Vienna, pp. 243–260.

Holmqvist, E., Larsson, A.-M., Kriiska, A., Palonen, V., Pesonen, P., Mizohata, K., Kouki, P., Raïsänen, J., 2018. Tracing grog and pots to reveal neolithic corded ware culture contacts in the baltic sea region (SEM-EDS, PIXE). J. Archaeol. Sci. 91, 77–91. https://doi.org/10.1016/j.jas.2017.12.009.

Horejs, B., 2014. Proto-Urbanisation Without Urban Centres? A Model of Transformation for the Izmir Region in the 4th Millennium BC. In: Horejs, B., Mehofer, M. (Eds.), Western Anatolia before Troy. Proto-Urbanisation in the 4th Millennium BC?: Proceedings of the International Symposium held at the Kunsthistorisces Museum Wien Vienna, Austria, 21-24 November 2012. Austrian Academy of Sciences Press, Vienna, pp. 15–42.

Kibaroğlu, M., Sagona, A., Satir, M., 2011. Petrographic and geochemical investigations of the late prehistoric ceramics from Sos Höyük, Erzurum (Eastern Anatolia). J. Archaeol. Sci. 38 (11), 3072–3084. https://doi.org/10.1016/j.jas.2011.07.006.

Kruskal, W.H., Wallis, W.A., 1952. Use of ranks in one-criterion variance analysis. J. Am. Stat. Assoc. 47 (260), 583–621.

Madsen, T., 1988. Multivariate statistics and archaeology. In: Madsen, T. (Ed.), Multivariate Archaeology. Aarhus University Press, Aarhus, pp. 7–27.

Mann, H.B., Whitney, D.R., 1947. On a test of whether one of two random variables is stochastically larger than the other. Ann. Math. Stat. 18, 50–60.

Maritan, L., 2023. Ceramics: Chemical and petrographic analysis. reference module in social sciences. Elsevier. https://doi.org/10.1016/B978-0-323-90799-6.00020-3.

Ottenburgs, R., Jorissen, C., Viaene, W. 1993. Sagalassos Ware IV. Study of the clays. In: Waelkens, M. (Eds.), Sagalassos I. First General Report on the Survey (1986– 1989) and Excavations (1990–1991). Acta Archaeologica Lovaniensia Monographiae Leuven, pp.163–170.

Özdoğan, M., Başgelen, N., Kuniholm, P., 2012. In: The Neolithic in Turkey New Excavations & Research Vol 4, Western Turkey. İstanbul: Arkeoloji ve Sanat Yayınları.

Quinn, P.S., 2013. Ceramic petrography: The interpretation of archaeological pottery & related artefacts in thin section. Archaeopress, Oxford.

R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Salazar, A., Safont, G., Vergara, L., Vidal, E., 2020. Pattern recognition techniques for provenance classification of archaeological ceramics using ultrasounds. Pattern Recogn. Lett. 135, 441–450.

Şahoğlu, V., Tuncel, R., 2014. New Insights into the Late Chalcolithic of Coastal Western Anatolia: A View from Bakla Tepe, Izmir. In Horejs, B., Mehofer, M. (Eds.), Western Anatolia before Troy. Proto-Urbanisation in the 4th Millennium BC?: Proceedings of the International Symposium held at the Kunsthistorisces Museum Wien Vienna, Austria, 21-24 November 2012. Austrian Academy of Sciences Press, Vienna, 2014, 65-82 http://www.jstor.org/stable/j.ctv5vdd0s.7.

Tyers, P.A., Orton, C. R., 1991. Statistical analysis of ceramic assemblages, 117–20, British Archaeological Reports, International Series. In: Lockyear, K., Rahtz, S. (Eds.), Computer Applications and Quantitative Methods in Archaeology. Oxford, pp. 117 – 120.

Umurtak, G., 2020. Some remarks on the Early Bronze Age I defence system at Hacılar Büyük Höyük (Burdur, Turkey). Bulgarian e-Journal of Archaeology 10 (1), 33–54. https://be-ja.org/index.php/journal/article/view/be-ja-10-1-2020-33-54.

Umurtak, G., 2022. From the Neolithic to the end of Early Bronze Age: developments in the construction of entrance gates and city walls at settlements in Burdur (Turkey) and the surrounding region. Bulgarian E-Journal of Archaeology. 12 (1), 1–27. https://doi.org/10.57573/be-ja.12.1-27.

Umurtak, G., 2023. Observations on some finds with religious symbolism from the Early Bronze Age I settlemeny at Hacılar Büyük Höyük. Bulgarian e-J. Archaeology. 13 (1), 25–49. https://doi.org/10.57573/be-ja.13.25-49.

Vandam, R., Kaptijn, E., 2015. Living in the burdur plain, A diachronic reconstruction of human subsistence (6500–200 BC). In: Metin, H., Polat Becks, B.A., Becks, R., Fırat, M. (Eds.), Pisidian Essays in Honour of Hacı Ali Ekinci. Ege Publications, İstanbul, pp. 165–175.

Vandam, R., Mušič, B., Medarić, I., 2019. Contextualizing Kuruçay Höyük: Assessing the unexplored late Chalcolithic landscape near the beginning of early social complexity in SW Turkey. J. Field Archaeol. 44 (1), 1–18. https://doi.org/10.1080/00934690.2018.1558904.

Vince, A., 2011. Characterising French whiteware imports in britain and northwest Europe. In: Bocquet-Líenard, A., Fajal, B. (Eds.), A propos de l'usage de la production et de la circulation des terres cuites dans l'Europe du Nord-Ouest autour des XIVe-XVIe si'ecles, Actes des tables rondes du CRAHM. Publication du CRAHM, Caen.

Wilcoxon, F., 1945. Individual comparisons by ranking methods. Biometrics 1, 80–83.