

*Full Length Research Paper*

## Clues of production for the Neolithic Çatalhöyük (central Anatolia) pottery

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**Probable source materials and production technologies of neolithic pottery from Çatalhöyük were studied with micromorphological and archaeometrical methods, seeking to shed light on the established techniques and appropriate source material mixtures used by the inhabitants of the epoch (7500 yr BP) in contrast to the reputed idea of primitiveness of the neolithic pottery. The results revealed the use of reed chaff along with mud brick (sun-dried) fragments that may have been derived from brick-making. The application of the 'slip' represents a novel observation and the intention of the use of a dye that needs further confirmation. The presence of gehlenite and aluminum diopside are considered to be the evidence of reached temperatures of about 800°C and not over with short durations manifested by the presence of calcite. Stress phenomena along with the bent weed fragments may also manifest the practice in shaping of pottery, where the former may also reflect fluctuating firing temperatures. Thus, analytical and micromorphological data obtained herein can provide some guidelines on designating prehistoric Anatolian pottery to the archaeologist and potters working on the subject matter.**

**Key words:** Neolithic, pottery, traditional knowledge, archaeometry, micromorphology.

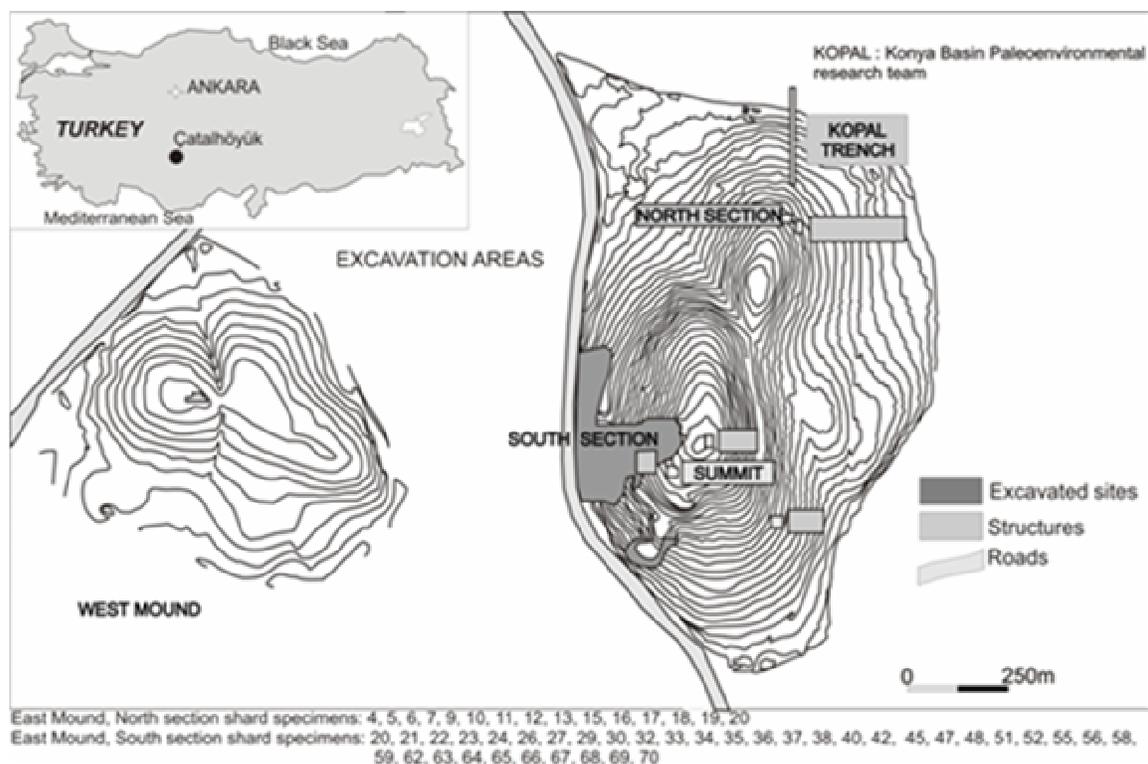
### INTRODUCTION

Recent archaeometrical studies, utilising chemical, mineralogical and micromorphological techniques in an archaeological context, have successfully revealed the type of raw materials used and details of the technology employed in the production of many types of ceramics found in Anatolia. These include artifacts of Hittite (Akça et al., 2009), Greek (Poblome et al., 2002), Seljuk and Ottoman (Kapur et al., 1998; Sakarya et al., 1990) origin that have survived the rigors of physical, chemical and biological degradation over several millennia. Moreover,

pioneering studies have been undertaken to determine the behavior of clay minerals against increasing firing temperatures and the determination of the levels of verifications as continuous and extensive in the reducing or oxidizing atmospheres of furnaces by the use of calcareous and non calcareous clays as the source materials (Maniatis and Tite, 1981). Studies of Peacock (1970) and Heimann and Maggetti (1981) on ancient ceramics by simple optical-petrographic methods have enabled the interpretation of the past furnace technologies and the formation of the peculiar matrix/temper fabric and high temperature minerals.

The production of ceramics in the Neolithic has commonly been thought to be achieved by coincidence. However, the determination of the micromorphological and

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**Figure 1.** The Çatalhöyük excavation and collection sites of shards (modified from <http://catal.arch.cam.ac.uk/catal/>).

and mineralogical features in such ceramics revealed a knowledge of the selection of raw materials of the Neolithic pottery. For example, ceramic ‘stress coatings/cutans’, commonly encountered around expanding pores in the ceramic matrix are indicators of the relatively slow development of pore-grain phases leading to the development of the repeated crescent-like features -the stress coatings-. Here the combination of both, that is the increase in temperature and the development of the gas phase in the pore, may probably cause the shrinkage of the finer ingredient of the matrix-the clay- around mineral grains originating from the source material and/or secondary high-temperature minerals (Kapur et al., 1998).

The progressive alteration and destruction of minerals in Hittite and Seljuk ceramics, such as the exfoliation and deformation of biotite cleavage planes and amphibole crystals, also appear to be indicators of high and rapidly rising firing temperatures (Sakarya et al., 1990). These processes are often associated with the development of high-temperature minerals such as pseudowollastonite and forsterite, as determined by X-ray diffraction (Sakarya et al., 1990).

The study reported here was designed to test whether a similar methodology, utilising a range of investigative tools, that is, particularly micromorphology coupled with mineralogy and chemistry, could help in elucidating the composition, source-materials and production technology

of neolithic ceramic materials. It thus represents a further extension of these archaeometrical investigations into the prehistoric era, as exemplified by the 7500 years-old early neolithic pottery (Hodder, 1999) (the upper age limit of the settlement in the site) found in excavations at the Neolithic site of Çatalhöyük, in central Anatolia, Turkey. Thus, the study aimed to elucidate the composition, source-materials and production technology of the Anatolian Neolithic pottery, which are among the pioneering samples of the Neolithic.

## MATERIALS AND METHODS

The Çatalhöyük Neolithic site was discovered by J. Mellaart in 1958 and initially excavated by the British Institute of Archaeology at Ankara. Today, Çatalhöyük, located near Çumra (Figure 1), is being excavated since 1993 by an international team of archaeologists, led by Prof. Ian Hodder from Stanford University, in order to shed more light on the people that inhabited the site. The site is composed of 2 mounds - the west and the eastern - where the latter is the concern of this paper attempting to complement the archaeological studies with knowledge on the ancient technology reflected in the recovered pottery. A total of 50 shards were selected at particular sites along with the ceramic experts of the excavation project for analysis from an initial collection of 70 samples obtained from the north and south sections of the east mound (höyük, in Turkish) at the Çatalhöyük site (Figure 1). Shards numbered from 4 to 20 were collected from the floors and walls of dwellings and from ditch infills of levels v, vi and vii in the northern part of the site. Shards 21 to 70 were collected from the floors,

**Table 1.** Details of the shard specimens studied.

Sample	Area	Level	Contexts	Shard part
<b>Analytical Fabric: Group 1</b>				
4	North	VI-V	Floor	Body
13	North	VI-V	Building fill	Rim
17	North	VII-VI	Floor make up	Body
19	North	VII-VI	Building fill	Base
20	North	VII-VI	Building fill	Base
23	South	VII	Foundation cut fill	Rim
26	South	VII	Midden	Rim
30	South	VII	Midden	Rim
33	South	VII	Wall	Base
36	South	VIII	Midden	Body
40	South	VIII	Midden	Base
42	South	VIII	Midden	Rim
47	South	VIII	Midden	Rim
48	South	VIII	Midden	Body
52	South	VIII	Fill	Rim
56	South	IX	Midden	Base
58	South	IX	Midden	Body
59	South	IX	Midden	Rim
62	South	IX	Bin fill	Body
63	South	IX	Building fill	Rim
64	South	IX	Wall	Rim
68	South	X	Hearth base	Base
69	South	X	Scoop fill	Rim
<b>Analytical Fabric: Group II</b>				
5	North	VI-V	Floor	Base
11	North	VI-V	Building fill	Base
22	South	VII	Foundation cut fill	Rim
45	South	VIII	Midden	Base
51	South	VIII	Fill	Rim
65	South	IX	Platform makeup	Body
67	South	X	Floor	Rim
70	South	XI	Floor	Rim
<b>Analytical Fabric: Group III</b>				
7	North	VI-V	Fill between walls	Rim
10	North	VI-V	Building fill	Body
12	North	VI-V	Building fill	Rim
15	North	VI-V	Fill between walls	Rim
21	South	VII	Foundation cut fill	Body
27	South	VII	Midden	Body
29	South	VII	Arbitrary (mixed)	Base
34	South	VII	Floor	Rim
<b>Analytical Fabric: Uniques</b>				
6	North	VI-V	Building fill	Body
9	North	V-IV	Pit fill	Body
16	North	VII-VI	Building fill	Body
18	North	VII-VI	Building fill	Body
24	South	VII	Midden	Rim
32	South	VII	Fill	Body
37	South	VIII	Midden	Base
38	South	VIII	Midden	Rim
66	South	IX	Building fill	Base

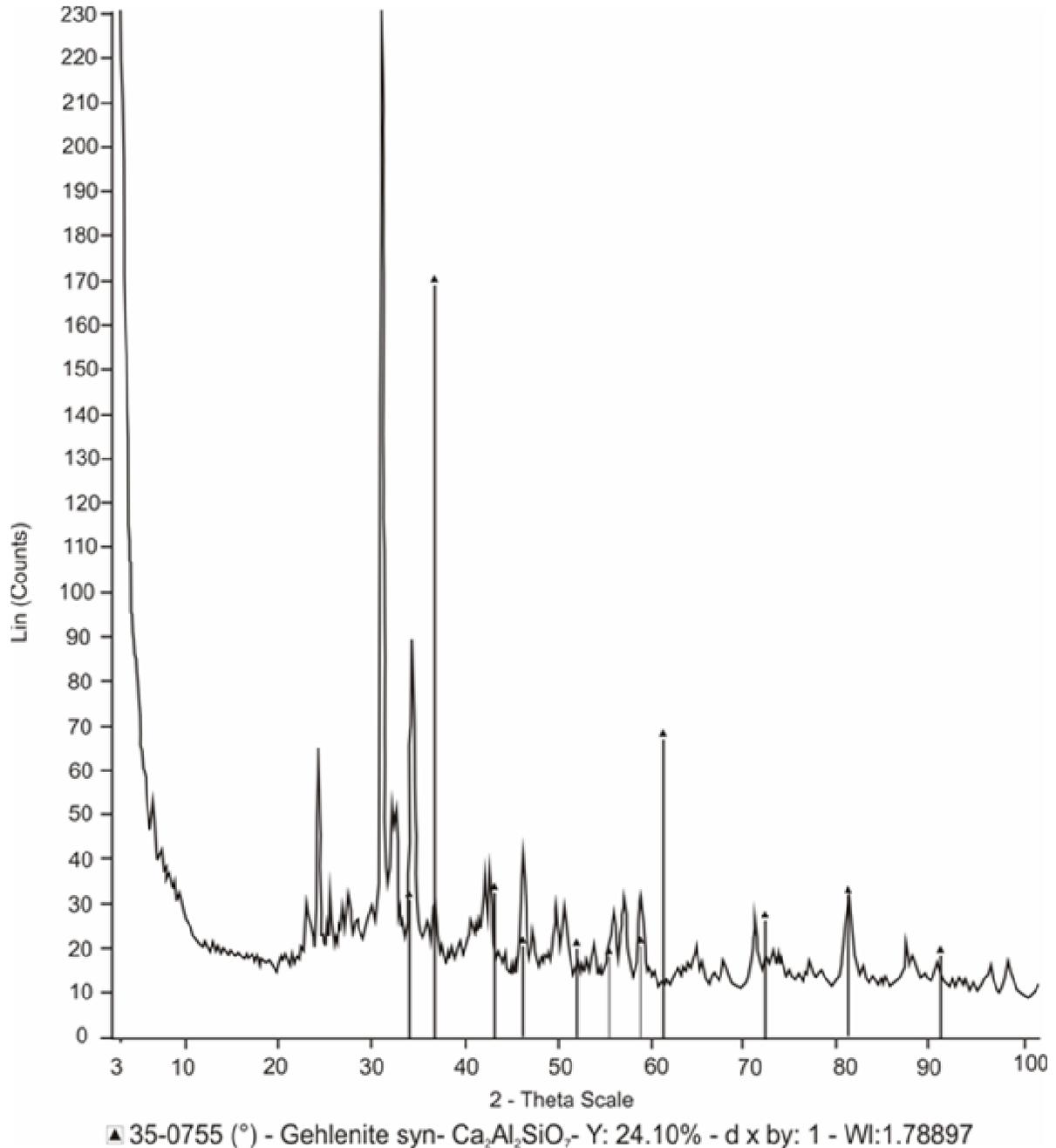
walls, midden deposits and infills of the foundations of warehouses and dwellings within levels vii, viii, ix and x in the southern part of the east Mound (Figure 1) (Table 1).

Conventional archaeological inspection was employed by the naked eye and stereo-microscopic observations for obtaining details of form, texture and porosity, color (Munsell Soil Color Charts), temper/chaff and degree of firing, together with estimation of the proportions and distribution of coarse and medium size minerals/grit, shaping/smoothness, and hardness according to the recording guidelines presented in the prehistoric ceramic research group occasional papers 1 and 2 (PCRG, 1995). X-ray diffraction analysis of the minerals was also merged into a combined in Table 2 to complement the description of the shards of the study bearing the shortcomings of their degraded Neolithic morphology compared to the ease in the typological characterization of shards of the later periods.

Petrographic thin sections of the shards were prepared for polarized-light microscopy according to the methods of FitzPatrick (1993) by impregnating the surfaces of optically flat-cut samples with a polyester cristic resin, using Logitech equipment and final hand-grinding to 30  $\mu\text{m}$  thickness. These thin-sections were interpreted according to the protocols of PCRG (1995) and Stoops (2003). Selected shards were investigated using a Philips XLS-30 scanning electron microscope (SEM) equipped with DX-4 EDAX system. The mineralogical analysis (qualitative) in the ceramic samples was undertaken by means of a Philips PW 1130/90 x-ray diffractometer with Cu-K $\alpha$  radiation, using the methods recommended by Jackson (1979). The fragments were ground to approximately 50  $\mu\text{m}$  size, placed in suspension in distilled water then settled on to glass slides, to create oriented slides of the ceramic constituents. The slides were then scanned in the x-ray diffractometer over the 15 - 40 degrees ( $2\theta$ ) range (Jackson, 1979) to identify both primary minerals and those produced at high temperatures as relative abundances. Part of the ground samples were also saturated with Mg<sup>++</sup> and glycolated for the determination of the basal spacing of the probable clay mineral (phyllosilicates) crystals (3 - 15 degrees- $2\theta$ ) that may have survived (with partly collapsed crystal structure) the open-air firing of the Neolithic (Jackson, 1979).

Selected specimens (No's. 24 and 69) were scanned from 2.2 to 102.2 -  $2\theta$  at 180 s at each 4 positions of the area detector, with Co-K $\alpha$  radiation generated at 40 KV and 20 MA for the justification of the presence of the high temperature minerals gehlenite and aluminum diopside. The determination of gehlenite (The four strongest reflections for gehlenite are at 2.84, 3.06, 1.75, 2.43 Å) in the selected specimens by the Co-K alpha radiation may seem to be confusing and problematic due to the overlapping of the 2.84Å reflection of calcite, which is the same for gehlenite. However, if it is looked closely at the diffractogram in Figure 2 (of specimen 24), the intensity at 2.84Å reflection is relatively high if it was solely coming from calcite. Theoretically for calcite, the intensity at 2.84 should be 3% of the most intense peak (3.03Å). In sample 24, the intensity at 2.84Å is 34% relative to 3.03 indicating contribution from mineral(s) other than calcite and most probably the presence of gehlenite. Moreover, the following reflections are indicative for the presence of gehlenite - 2.84, 3.72, 3.06 (masked by calcite's 3.03 peak), 2.71 and with several peaks at 2.39 - 2.43, 2.19, 2.03 Å units. These reflections are also recognizable in the other sample (No. 69), although weaker in this sample compared to 24. Similarly the strongest peak of diopside was probably masked by the major peak of calcite (Fig. 3), but the other peaks in the diffractogram, although weaker in sample 69 than sample 24, may be indicative of its presence.

Accordingly, the identification of these ones was done primarily through matching X-ray peaks with standard patterns in the powder diffraction database. The elemental analysis of the slipped specimens was conducted by means of an ICP (Perkin Elmer Optima 2100 DV ICP-OES).



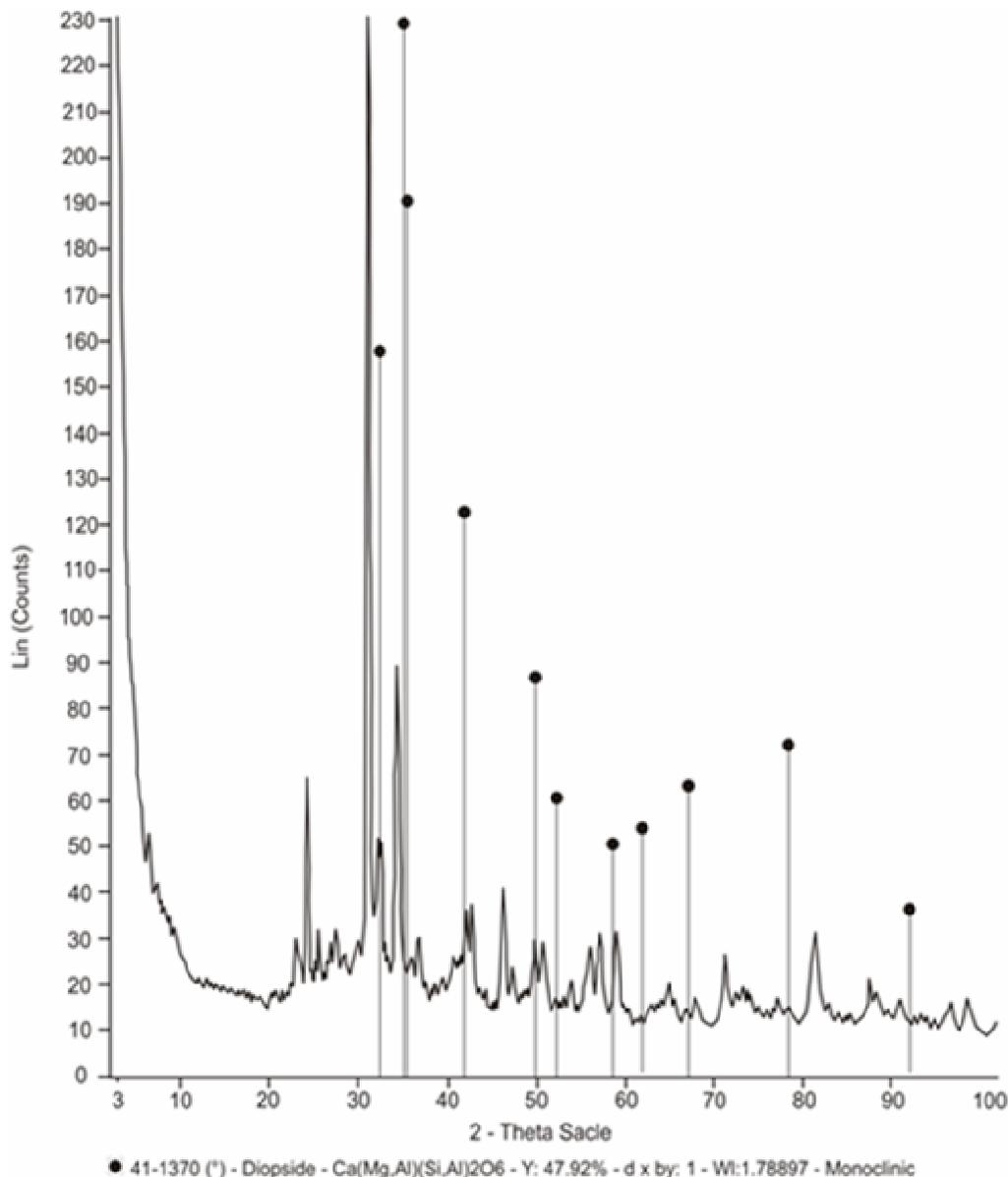
**Figure 2.** X-ray diffraction of Specimen 24 with standard diffraction pattern of gehlenite.

## RESULTS AND DISCUSSIONS

Preliminary inspection of the suite of selected specimens suggested that the major distinguishing morphological features included the content, size and levels of oxidation of chaff and to a lesser extent, the mineral grain size and color of the pot-core. According to these temper/fabric criteria 4 categories (groups) were identified, group i is characterized by abundant chaff displaying variable levels of oxidation, together with a relatively coarse mine-

ral grain size and spongy texture; Group II samples are structurally and mineralogically similar to group i but chaff is absent, group iii samples also lack chaff but are harder, with more variable grain size and core color; the unique group is characterized by absent to rare chaff content (small fragments) and finer, more uniform mineral textures (Table 1).

The micromorphology of thin sections and X-ray diffraction analyses reveal that the dominant mineral in all 4 groups of the Çatalhöyük pottery and the corresponding

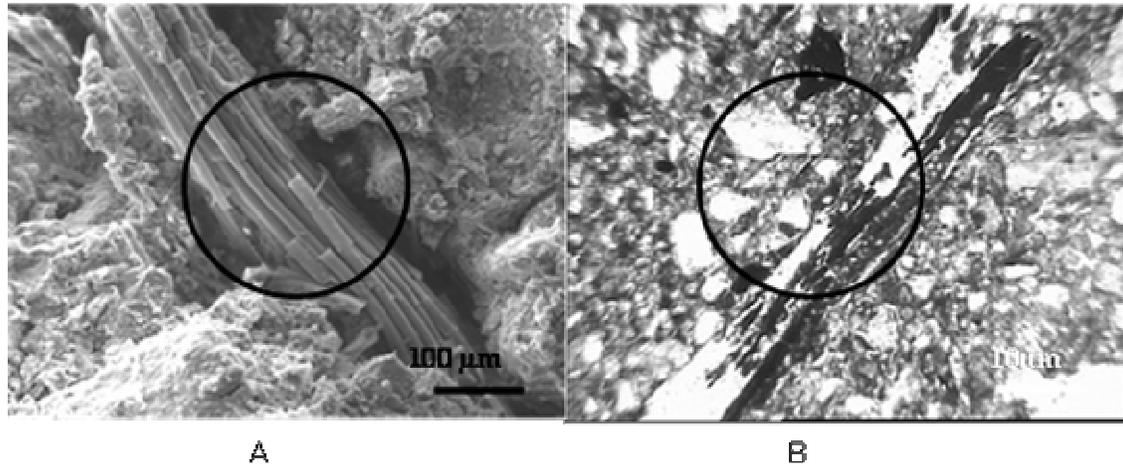


**Figure 3.** X-ray diffraction of Specimen 24 with standard diffraction pattern of aluminum diopside.

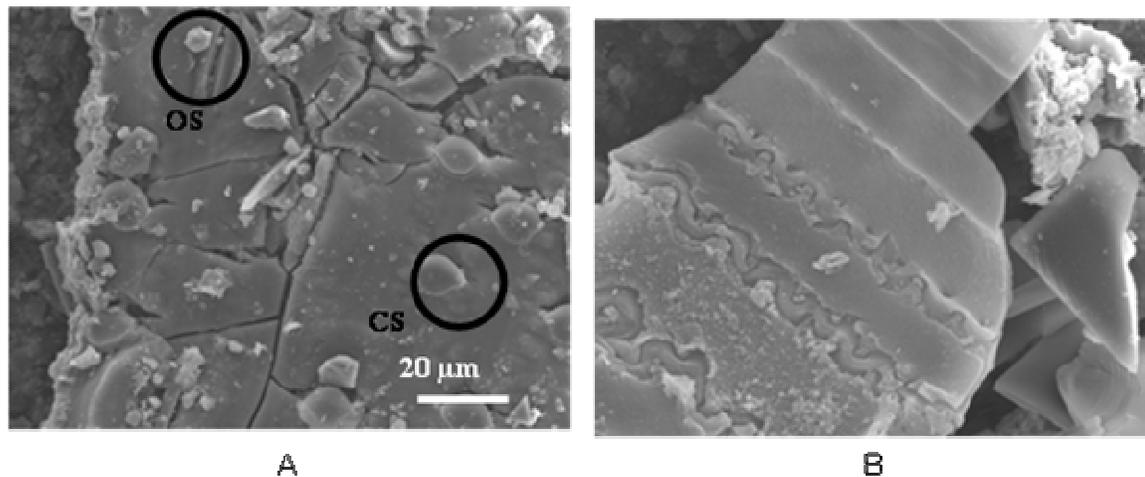
x-ray reflections in Cu-K $\alpha$  2- $\theta$  is quartz followed by calcite, plagioclase feldspar (anorthite- $\text{CaAl}_2\text{Si}_2\text{O}_8$ ), phyllosilicates (in clayey matrix-in thin section and as welded/aggregated, thus, collapsed clay mineral crystal structures after firing-in SEM images-Figure's 4b and 10), subordinate micas (biotite-in thin section) and amphiboles and pyroxenes (in thin section) (Table 2). The x-ray reflections in Co-K $\alpha$  for gehlenite ( $\text{Ca}_2\text{Al}_2\text{SiO}_7$ ) and aluminum diopside ( $\text{Ca}(\text{Mg,Al})(\text{Si,Al})_2\text{O}_6$ ) determined as the dominant but trace high-temperature minerals indicated an oxidizing firing atmosphere and a firing temperature of about 800°C but of short duration (as being typical of the fuel materials -straw and/or wood- used at that period at open-air firing) (Figures 2 and 3) in the presence of

quartz, plagioclase and especially calcite as documented by Maggetti (1981). The calcite content includes both source materials, mainly shell fragments from typical lacustrine mollusks, but including locally abundant clasts of nodular calcite and a few pieces of older marine limestones.

Thin sections and SEM images of the samples also revealed the presence of abundant plant debris, mainly composed of short strands of chaff and reed (*Phragmites* sp.), with epidermal tissue (Figure 4) as well as open and closed stomatal guard cells (Figure 5), up to 1 - 2 mm in length, demonstrating the use of the raw material sources of the ancient central Anatolian wetlands, such as the reed marshes, that gradually replaced the lake environ-



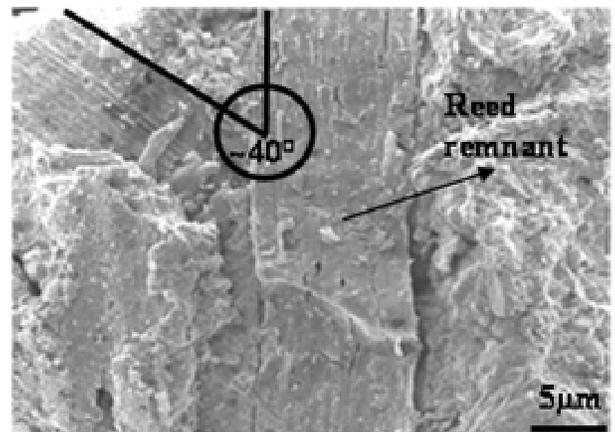
**Figure 4.** (A) Cellular structure of partly oxidized reed stem (thin section, plane polarized light); (B): epidermal tissue of *Phragmites sp.* (SEM). Both from Group I shards.



**Figure 5.** The open (OS) and closed (CS) stomatal guard cells (A) and epidermal tissue (B) of *Phragmites australis* remnants in specimen 56 (SEM image).

ments of the earlier Holocene (Roberts, 1983). The chaff exhibited varying levels of oxidation and some of the elongate fragments appear to have been bent and broken, probably during the throwing and hand shaping of the pots (Figure 6). Pollen of *Phragmites australis* was also observed in the same material (Figure 7) and interpreted as proxies of the reed marsh, that is wetland environment. In addition, small fragments of tempers have been observed as added elements in some pottery samples indicating the awareness on the value of increasing the durability of the pottery products by incorporating pre-fired fragments of relatively higher resistance compared to the clay source.

The quartz contents of the Groups i, ii and uniques samples appear more uniform compared to group iii (Table 2). Similarly, the average amount of calcite is generally higher in the group i samples (Table 2).



**Figure 6.** Broken reed remnants with ca. 42° angle, ascribed to shaping of the specimen 56 (SEM image).

**Table 2.** Qualitative analysis of the specimen minerals by XRD and morphological descriptions. Q: Quartz, C: Calcite, P: Plagioclase, A: Anorthite, G: Gehlenite, D: Al-Diopside.

Sample No.	Minerals	Morphological description
<b>GROUP I</b>		
4	Q, C, P/A, G, D	Fine loose; fine to medium uniform porosity; 10YR6/3(Pale brown); common fine chaff temper and very fine grits; non-uniform colors; smoothed; soft.
13	Q, C, P/A	Moderate loose spongy; dense fine uniform porosity; 10YR5/2(Grayish brown); common fine chaff temper and very fine uniform grit; mottled surface; smoothed; soft.
17	Q, C, P/A, G, D	Moderate to coarse grainy; fine dense non-uniform porosity; 7.5YR6/4(Light brown); common fine to moderate chaff and common fine uniform grits; uniform color; smoothed; soft to moderate.
19	Q	Moderate compact; dense fine uniform porosity; 7.5YR6/4(Light brown); common fine uniform chaff temper and fine grit; non-uniform color; roughly smoothed; soft.
19a	Q	Moderate grainy loose; moderate dense fine porosity; 10YR7/3(Very pale brown); common fine uniform grit; uniform color; smoothed; soft.
23	Q, C, P/A, G, D	Coarse loose spongy; dense fine to medium porosity; Gley 1 3/N (Very dark grey); common fine to medium chaff temper and fine grit; uniform color; roughly smoothed; soft.
26	Q, C, G, D, P/A	Fine to medium grainy; dense very fine homogenous porosity; Gel 1 4/N(Dark grey); common fine non-uniformly distributed grit; uniform colour;
30	Q, C, P/A, G, D	Fine grainy loose spongy; fine dense porosity; 10YR6/3(Pale brown); common fine uniform chaff temper and fine grits; uniform color; smoothed; soft
33	Q, C, P/A	Moderate to coarse; moderate to coarse dense porosity; 10YR6/2(Light brownish gray); common fine uniform grit and coarse random chaff temper; mottled; moderate smoothness; soft.
36	Q, P/A	Very coarse; moderate to coarse dense porosity; 5YR4/4(Reddish brown); common fine to moderate chaff temper and fine grit; uniform color; moderately smoothed; moderate to soft hardness.
40	Q, C, P/A	Fine grainy, loose; rare fine pores; 10YR6/3(Pale brown); common very fine chaff temper and fine homogenous grit; uniform colour; fine smoothed surface; soft.
42	Q, C, P/A	Fine to moderate loose grainy spongy; fine uniform porosity; 10YR6/3(Pale brown); common fine grit and very fine chaff temper; non-uniform color; smoothed surface; soft.
47	Q, C, P/A, G, D	Coarse to moderate grainy; frequent fine uniform porosity; 7.5YR5/4(Brown); common fine to moderate rare coarse chaff temper and common fine grit; uniform color; smoothed surface wavy interior; soft to moderate hardness.
47a	Q, C, P/A, G, D	Moderate spongy; dense fine uniform porosity; 10YR6/4(Light yellowish brown); common fine to moderate uniform chaff temper and very fine common grit; non-uniform color; smoothed; soft.
48	Q, C, P/A, G, D	Moderate spongy; dense fine to moderate mostly uniform occasionally coarse pores; 10YR6/4(Light yellowish brown); common fine grit and fine to moderate uniform chaff temper; non-uniform color; roughly smoothed, moderate hardness.
52	Q, C, P/A, G, D	Coarse loose spongy; dense fine to moderate uniform rarely coarse porosity; 10YR3/1(very dark gray); common fine to moderate uniform and moderate to coarse chaff temper and common very fine grit; uniform color; smoothed; soft.
56	Q, C, P/A	Fine compact; moderate uniform porosity; 10YR6/4(Light yellowish brown); common fine chaff temper and common fine uniform grit; uniform color with few mottles; smoothed; moderate hardness.

Table 2. Continued

59	Q, P/A, G, D	Fine to moderate compact; dense fine uniform porosity; 10YR6/3(pale brown); common fine to moderate chaff temper and common fine uniform grit; non-uniform color; finely smoothed with wavy interior; moderate hardness.
58	Q, C, P/A	Fine grainy loose spongy; dense fine uniform porosity; 2.5Y6/3(Light yellowish brown); common fine grit and common very fine chaff temper; non-uniform color; moderately smoothed; soft.
62	Q, C, P/A, G, D	Moderate loose, spongy; dense fine to moderate, rarely coarse porosity; 10YR6/3(Pale brown); common fine uniform grit and fine to moderate non-uniform chaff temper; non-uniform color; finely smoothed; soft.
64	Q, P/A	Moderate somewhat compact; dense fine to moderate uniform porosity; 10YR6/3(pale brown); common fine uniform grit and common fine to moderate chaff temper; non-uniform color; moderately smoothed; soft to moderate hardness.
63	Q, C, P/A, G, D	Moderate somewhat compact; dense fine to moderate uniform porosity; 10YR6/3(pale brown); common fine uniform grit and common fine to coarse chaff temper; non-uniform color; moderately smoothed; soft to moderate hardness.
68	Q, C, P/A, G, D	Coarse loose spongy; dense fine to coarse porosity; Gley 1 3/1(very dark gray); common fine to moderate uniform grit (volcanic minerals?) and moderate to coarse chaff temper; uniform color; roughly smoothed, wavy; moderate hardness.
69	Q, C, P/A, G, D	Fine loose; fine to medium uniform porosity; 10YR6/3(Pale brown); common fine chaff temper and very fine grits; non-uniform colors; smoothed; soft.
<b>GROUP II</b>		
5	Q, P/A	Medium sandy, compact; random porosity; 7.5YR2/1 (Black); common fine-medium grit (calcite); smoothed; soft.
11	Q, C, G, D	Fine-medium loose porous, 7.5YR5/4 (Brown), black core, common fine grit (calcite and Q), fine smoothed, soft.
22	Q, C, P/A	Fine-medium compact; moderate random porosity; 10YR5/2 (Grayish brown); mottled surface; common fine grit and sea shells; fine smoothed; moderate hardness.
45	Q, C, P/A, G, D	Medium, compact, porous, N3/1 (Dark gray), mottled surface, common fine medium grit, frit and sea shells, fine smoothed, moderately hard.
51	Q, C, P/A	Fine, compact very fine sandy texture, 10YR6/3 (pale brown), black core, common fine grit and frit (?), wavy surface finish, moderately hard.
65	Q, P/A	Fine, compact, random pores, 5YR5/6 (Yellowish Red), common very fine grit, soft, frit (?), very fine smoothed, soft.
67	Q, C, P/A, G, D	Fine-medium, medium random pores, 10YR6/3(Light yellowish brown), common homogenous grit, fine smoothed, moderately hard.
70	Q, C, P/A, G, D	Fine-medium, loose, random pores, 10YR6/4(Light yellowish brown), common fine various grit, sea shells, very fine smoothed surface, soft-moderate hard.
<b>GROUP III</b>		
7	Q, P/A	Moderate grainy; moderate to fine rare non-uniform porosity; 10YR4/2(Dark grayish brown); common fine grit; uniform colour; moderately smoothed surface; soft
10	Q, C, P/A	Moderate compact; frequent fine to moderate pores; 5YR3/2(Dark reddish brown); common fine to moderate grits; mottled surface; fine smoothed; moderate hardness.

**Table 2.** Continued

12	Q, P/A	Fine to moderate, loose; dense fine homogenous porosity; 7.5YR4/3(Brown); common fine to moderate grit; fine smoothed; moderate to soft hardness.
15	Q, C, P/A, G, D	Fine to moderate; moderate dense fine porosity; 7.5YR3/2(Dark brown); moderate fine grit; fine smoothed; moderate to soft hardness; uniform colour.
21	Q, C, P/A	Medium grainy loose; dense fine to medium porosity; 7.5YR5/6(Strong brown); common fine to moderate grit; smoothened interior; very soft; mottled, non-uniform colour
27	Q, C, G, D, P/A	Fine to medium grainy; dense very fine homogenous porosity; Gley 1 4/N (Dark grey); common fine homogenous grit; uniform color; moderate to soft.
29	Q, P, G, D	Fine to medium, loose; dense fine uniform porosity; 7.5YR5/4(Brown); common, fine uniform grit; non-uniform colour; soft to moderate hardness.
34	Q, C, P/A, G, D	Fine-medium loose, porous, 2.5GY2/1 (Black), black core, homogenous color, common fine grit, chaff temper, fine smoothed, moderately hard.
<b>UNIQUES</b>		
6	Q, C, P/A	Medium loose spongy; homogenous pores; 7.5YR6/6(Reddish yellow); very common fine-medium; homogenous chaff temper and, grit (mica and calcite?); moderately smoothed; soft.
9	Q, C, P/A	Moderate, compact, rare pores, 10YR3/1(Very dark grey), Common fine to coarse white grit (quartz?), fine smoothed, moderate hardness.
16	Q, C, P/A	Fine, moderately compact; very fine homogenous porosity; 10YR5/4(Yellowish brown); common, very fine, homogenous grits and homogenous chaff temper; fine smoothed surfaces; soft.
18	Q, C	Very fine compact; homogenous very fine porosity; 10YR4/2(Dark grayish brown); without grit (refined?); fine smoothed; moderate hardness; mottled surface.
24	Q, G, D	Coarse, loose, spongy, grainy; dense, fine homogenous porosity; 10YR6/4(Light yellowish brown); common, fine-medium rare coarse grit; mottled surface; roughly smoothed; soft.
32	Q, P/A	Fine grainy, compact; rare fine pores; 10YR6/4(Light yellowish brown); Common fine chaff temper and fine homogenous grit; uniform colour; fine smoothed surface.
37	Q, C, P/A	Fine medium grainy, loose; dense, fine homogenous porosity; 10YR6/4(Light yellowish brown); common fine chaff temper and common fine grit; well-oxidized core; fine smoothed surface; soft.
38	Q, C, P/A	Moderate, loose grainy; fine-moderate rare porosity; 10YR6/3(Pale brown); common fine moderate rarely coarse chaff temper; fine common grit; non-uniform colors; fine smoothed; soft
66	Q, C, P/A, G, D	Coarse, very loose, dense fine moderate porosity (coarsest piece); 7.5YR5/4(Brown); common coarse grits; uniform surface coloring; fine smoothed surface; soft.

However, this mineral is absent from about one-quarter of the samples, which may be attributed either to its absence in the source materials (for example, if these were volcanic formations) or to conversion of original calcite to high-temperature minerals such as gehlenite and aluminum diopside (as it is with samples 24, 29 and 59) despite the probability of decomposition to secondary pro-

ducts like calcite in the presence of fine-grain clays after burial (Heimann and Maggetti, 1981). The presence of quartz and calcite, that is, at the carbonate-silicate interfaces/reaction rims, during the ancient open-air firing process are characterized by relatively high firing temperatures of about 700 - 800 °C (Heimann and Maggetti, 1981), which is in contrast to the Roman and

Seljuk/Ottoman kilns, reaching much higher temperatures during the production of historical ceramics, such as of Roman sigillata and the Iznik tiles (Tite, 1989). There was no significant difference in the pattern of feldspar contents between the

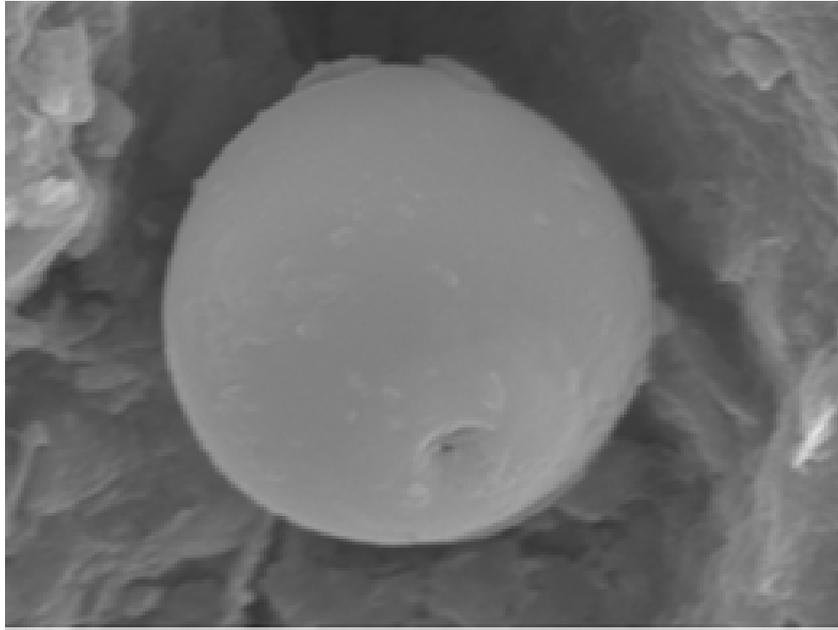


Figure 7. *Phragmites australis* pollen in pore space of specimen 56 (SEM image).

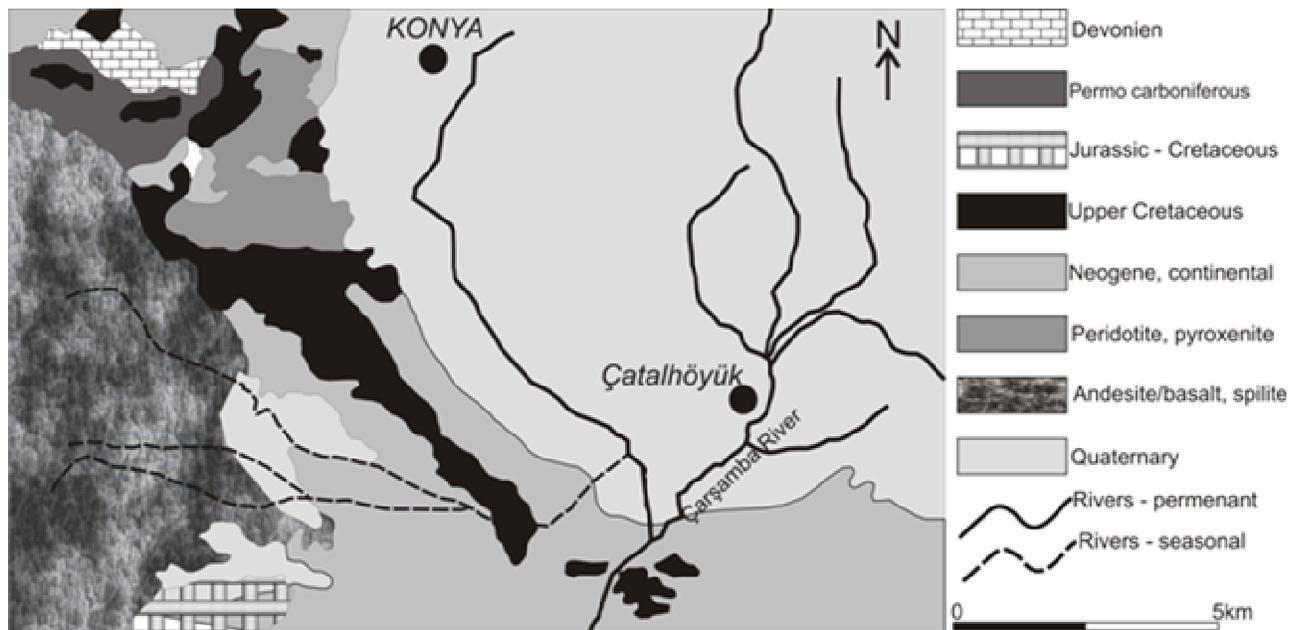
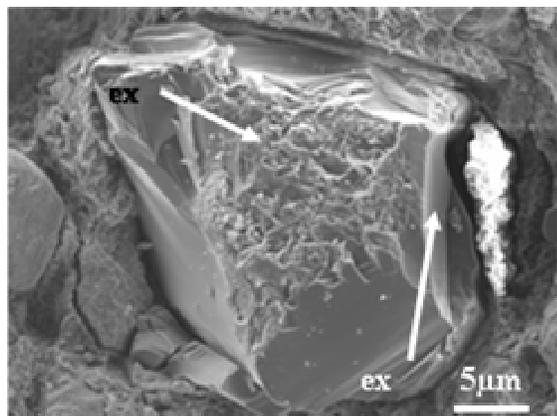


Figure 8. The geology of the study site (modified from Blumenthal, 1951).

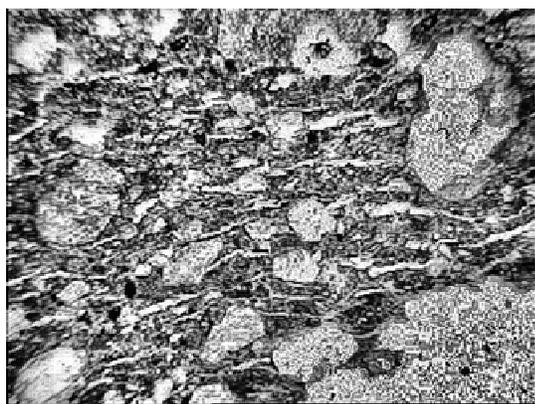
Groups, although individual samples yield higher values (Table 2). The rarer ferromagnesian minerals (biotite, amphiboles, pyroxenes, olivines) along with rock fragments, especially basalts, suggest the use of a variety of source materials including igneous (volcanic) and metamorphic formations (Figure 8) (Deer et al., 1975), in addition to the (contemporary) lacustrine /alluvial sediments rich in smectite and illite (detected in the paleoenvi-

ronmental study of the Konya-Çatalhöyük areas by Roberts (1983) and the phosphorous and clay mineral studies undertaken by Akyol and Demirci (2000) on the systematically collected soil samples of the Çatalhöyük excavation site).

The mixture also included the coarser sand-sized particles of the river Çarşamba with their content of molluscan shells of the late pleistocene shallow lake, the an-



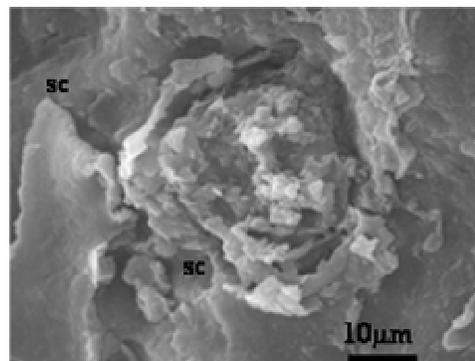
**Figure 9.** Exfoliated (ex = exfoliated planes) pyroxene in matrix of specimen 70 (SEM image).



**Figure 10.** Preferred orientation of fractures within specimen 15 (Plane polarized light).

cient Konya lake. This lake presumably dried up during the Würm period due to the decreasing precipitation and increasing evaporation and subsoil drainage as stated by Roberts (1983). The detection and confirmation by XRD analysis of calcite and its frequent co-occurrence with the 'trace' amounts of gehlenite and aluminum diopside is of particular significance since these are sensitive indicators of high firing temperatures (up to 850 and 875 °C) (Stein, 1984) (Table 1).

Micromorphological observations, such as the partial to complete destruction, exfoliation along cleavage planes and distortion of grains of biotite, amphibole, pyroxene and plagioclase-anorthite (Figure 9), provide further evidence of high firing temperatures during production of the Çatalhöyük pottery. Another important micromorphological observation is the presence in a few shards (e.g. 19, 47, 48) of a relatively thin (up to 100 μm thick), finer-grained external layer, adhering to a coarser matrix or 'body'. This external layer closely resembles the 'slip' or outer coating of more recent ceramic products.



**Figure 11.** Stress coatings (sc) in specimen 56 (SEM image).

Chemical differences between the body and slip layers confirm that the Çatalhöyük potters were among the first to use materials with slightly different composition and grain-size to achieve some type of surface treatment for further applications of a dye inexistent today, and that was not determined in the thin sections (Table 3).

Specimens 19 and 19a are chemically distinctive from the majority of the specimens studied, due to their lower Ca contents and the higher amounts of Na, Zn, Cr and Fe. Moreover, the coating (slip) of specimen 19 (sample 19a) also appears to be formed from a slightly different mixture of raw materials, with higher contents of Zn, Na, Mn and Fe and lower amounts of Ca than the body. The higher Na contents of the coating may reflect a more refined technique involving the application of a more clay-rich mixture to the surface of the pot sample. However, specimen 47 and its coating (47a) display minor but distinct differences in mineralogy (Table 2) and texture but are closely comparable in elemental composition (Table 3).

Other samples display color differences between the surface layer and the core (body) but these reflect surface oxidation of the pots, since the color contrast is not matched by micromorphological differences. It is likely that such oxidation has been caused by rather poorly controlled/non-uniform firing in the Çatalhöyük open-air fires. Preferred orientations (parallel to pot surfaces) of both mineral constituents and stress and temperature-induced fractures can be seen in the thin-sections and SEM images of several samples (Figure 10) and probably reflects the shaping methods (also indicated by the broken/bent weed fragments in the pot matrices) adopted by the Çatalhöyük potters and the relatively rapid firing processes they adopted.

Stress coatings, concentric cracks/adhesion phenomena developing on aggregate-clay mineral interfaces/reaction rims (Figure 10) were similar to those found in Seljuk ceramics, as reported by Kapur et al. (1998) and observed in the more clay-rich parts of the matrix of some specimens (Figure 11). These features probably developed

**Table 3.** The elemental composition of the specimens (by Group) (%).

	No	Zn	Cr	Cu	K	Mn	Fe	Ca	Na	Mg	Al
GROUP I	4	0.009	0.006	0.003	1.17	0.04	2.62	5.01	1.82	0.91	2.85
	13	0.006	0.006	0.003	1.03	0.02	2.32	5.07	1.43	0.80	2.62
	17	0.007	0.005	0.002	0.94	0.04	2.16	6.14	1.44	0.91	2.66
	19	0.010	0.010	0.004	1.46	0.05	4.60	0.19	2.02	1.38	4.42
	19a	0.012	0.010	0.003	1.63	0.07	4.97	0.14	2.61	1.42	4.91
	20	0.007	0.004	0.003	1.05	0.03	2.15	3.58	1.50	0.78	2.52
	23	0.008	0.008	0.002	0.91	0.03	2.25	5.52	1.50	0.86	2.37
	26	0.009	0.005	0.003	0.95	0.04	2.70	4.39	1.69	0.84	3.71
	30	0.009	0.009	0.001	1.03	0.04	2.40	5.59	1.48	0.86	2.77
	33	0.009	0.006	0.002	0.67	0.04	1.96	3.66	1.14	0.90	2.07
	36	0.009	0.009	0.003	0.82	0.04	2.15	0.23	1.11	0.70	3.94
	40	0.009	0.005	0.003	1.11	0.03	2.38	5.40	1.55	0.83	2.74
	42	0.007	0.005	0.003	0.79	0.03	2.13	5.96	1.36	0.89	2.30
	47	0.007	0.008	0.001	0.95	0.04	2.66	4.65	1.26	0.78	2.91
	47a	0.007	0.005	0.0007	0.86	0.06	2.19	3.46	1.50	0.72	3.00
	48	0.009	0.008	0.001	1.07	0.03	2.72	4.67	1.67	0.91	3.61
	52	0.008	0.005	0.003	1.04	0.03	2.52	4.53	1.64	0.76	2.81
	56	0.008	0.003	0.002	0.81	0.03	2.12	6.03	1.17	0.86	1.73
	58	0.006	0.005	0.001	0.74	0.06	2.47	3.94	1.05	0.77	3.22
	59	0.007	0.002	0.002	0.91	0.02	2.78	0.03	1.76	0.48	4.15
62	0.010	0.006	0.001	1.16	0.02	2.25	5.48	2.02	0.84	2.70	
63	0.008	0.008	0.003	0.76	0.02	1.63	5.36	1.39	0.67	2.04	
64	0.007	0.004	0.003	1.04	0.04	3.04	0.07	1.52	0.50	4.05	
68	0.009	0.005	0.002	0.71	0.01	2.16	6.94	1.08	0.81	2.98	
69	0.009	0.009	0.002	1.05	0.04	2.95	5.47	1.95	0.97	4.31	
GROUP II	5	0.007	0.005	0.002	0.95	0.04	2.63	5.01	1.42	0.45	4.06
	11	0.007	0.003	0.003	1.07	0.03	2.70	0.03	1.87	0.52	4.76
	22	0.007	0.004	0.003	0.69	0.02	2.10	4.94	1.11	1.38	1.97
	45	0.007	0.007	0.002	0.81	0.03	2.36	3.10	1.18	0.78	3.07
	51	0.008	0.006	0.001	1.14	0.03	2.67	6.94	1.83	0.82	3.61
	65	0.005	0.002	0.002	1.00	0.1	2.46	0.02	1.81	0.41	3.33
	67	0.006	0.006	0.002	0.74	0.02	2.03	7.62	0.94	0.67	2.24
	70	0.008	0.002	0.002	0.62	0.01	1.90	5.58	0.95	0.71	1.66
GROUP III	7	0.007	0.004	0.002	2.32	0.02	5.17	0.04	3.01	0.43	3.88
	10	0.008	0.005	0.003	0.84	0.05	3.38	0.28	1.12	0.67	2.93
	12	0.006		0.002	0.74	0.03	2.70	0.03	1.87	0.52	4.76
	15	0.008	0.003	0.002	0.95	0.04	2.50	0.02	1.53	0.48	5.00
	21	0.008	0.003	0.003	1.00	0.02	2.42	1.74	1.45	0.72	2.91
	27	0.009	0.007	0.002	0.95	0.03	3.16	0.20	1.60	0.49	4.73
	29	0.006	0.005	0.002	1.09	0.04	3.16	0.02	1.94	0.45	6.82
	34	0.010	0.006	0.003	1.31	0.02	3.20		1.60	1.00	3.50
UNIQUES	6	0.006	0.009	0.001	0.78	0.04	2.39	3.90	1.07	0.74	3.10
	9	0.008	0.009	0.002	0.91	0.01	2.49	20.83	1.26	0.43	2.73
	16	0.007	0.003	0.002	0.94	0.04	2.16	6.14	1.44	0.91	2.66
	18	0.009	0.010	0.004	1.46	0.05	4.60	0.19	2.02	1.38	4.42
	24	0.009	0.007	0.003	1.10	0.03	2.24	5.36	1.77	0.79	3.07
	32	0.006	0.003	0.002	1.03	0.03	3.01	0.06	1.60	0.55	4.21
	37	0.008	0.005	0.002	1.58	0.04	2.44	4.93	2.31	0.94	3.13
	38	0.009	0.006	0.004	1.07	0.02	2.42	7.03	1.57	0.84	2.26
	66	0.008	0.004	0.003	1.21	0.03	2.94	1.53	1.89	0.82	3.89

during abrupt (increasing) and erratic temperature changes associated with the open-air firing and most probably the repeated/periodic welding of the smectite/illite-rich groundmass ultimately separated to several platelets. The use of open-air firing has been a common practice in Anatolian pottery production like other contemporary sites elsewhere (Maniatis and Tite, 1981).

## Conclusions

Previous studies on Neolithic potteries supposed a primitive production technology and associate production to fortuitous findings. However, our study indicates that the use and selection of the raw materials (both inorganic and organic) and firing methods are comparable to techniques of the Bronze Age, Hittite, Roman and Seljuk cultures of Anatolia (Sakarya et al., 1990; Kapur et al., 1998, Akça et al., 2009). These techniques reveal that throughout the history of this settlement, the Çatalhöyük potters possessed considerable skill on the use of the local sources of raw materials and were aware to attain relatively high temperatures (ca 800°C) in their open-air firing places for better production.

The use of reed chaff in many of the pots is an aspect of scientific interest, and may well derive from mud-brick making, where chaff (straw) was used from the earliest times to bind the clay during the sun-drying process (Çambel and Knutstad, 1997). Coincidentally, the presence of this readily flammable material in the pot-clay may also have promoted the attainment of high temperatures (ca. 800°C) during firing for relatively short periods. This is also indicated by the trace amounts of gehlenite and aluminium diopside, whereas longer periods of higher temperatures would have otherwise completely oxidized the chaff and could have developed qualitatively and semi-quantitatively better defined and enhanced peaks of high temperature minerals in the X-ray diffraction scans. The incorporation of fragments, derived from mud brick (consisting of coarser fragments/ minerals in fine matrix), also suggests awareness in these Neolithic potters of the values of pottery durability obtained by readily available coarse grain material (pre-use leftovers) other than quartz.

If confirmed with further studies, the identification of the probable 'slip or -like' layers in the Çatalhöyük pots represents a novel observation in Neolithic earthenware that emphasizes the technological and aesthetic awareness of ancient Anatolian inhabitants. The different characteristics of the slip layers (some compositionally different from the body, others differing only in texture) suggests a degree of experimentation amongst successive generations of Çatalhöyük artisans and the intention to form a base for the dye ([www.catalhoyuk.com](http://www.catalhoyuk.com)).

While details of the firing technology employed by these Neolithic potters remain obscure, the stress coatings observed in the body of some of these shards provide clear evidence that the pots were subject to relatively

abrupt changes in temperature during firing and pre-firing shaping practices. Moreover, the variable levels of oxidation of chaff fragments and the relatively low amounts of gehlenite and aluminium diopside in most samples, along with the presence of calcite, attest to the problems encountered by the Çatalhöyük potters in maintaining relatively high but inconsistent/fluctuating temperatures (around 800°C) of short duration in their open-air firing process. Finally, the micromorphological, mineralogical and chemical data obtained within this study outline the Neolithic pottery technology that may be used as a reference database by the archaeologist studying on pottery in Anatolia and environs.

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