PETROGRAPHIC AND CHEMICAL CHARACTERIZATION OF POTTERY PRODUCTION OF THE LATE MINOAN I KILN AT HAGHIA TRIADA, CRETE*

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Pottery from the Late Minoan I kiln at Haghia Triada in the Mesara Plain, southern Crete, was analysed by a range of techniques, comprising thin-section petrography, scanning electron microscopy, X-ray diffraction, X-ray fluorescence and neutron activation analysis. The project characterizes the ceramic fabrics and probable raw materials, correlates paste recipes with shape, reconstructs the firing conditions of the kiln and establishes a chemical reference group, taking into account post-burial alteration and contamination. Comparison of the reference group formed with that from the neighbouring, broadly contemporary, kiln at Kommos shows an unexpected differentiation of the two kilns.

INTRODUCTION

From the early application of chemical analysis to archaeological ceramic provenance in the Aegean, 'reference groups' have played an important role (Jones 1986; Mommsen *et al*. 1991; Buxeda i Garrigós *et al*. 2001). Whether we emphasize the relative compositional homogeneity of certain types of argillaceous deposit (Hein *et al*. 2004) or the repetition of choice by ancient potters who belonged to specific traditions (Day *et al*. 1999; Whitbread 2001), the difficulties in separating ceramic groups of different provenance are clear.

In the Aegean it has been common practice for 'reference groups' to be produced from the analysis of ceramic types considered on archaeological grounds to have been produced locally at a specific site. Whilst such an assumption was often correct, there are plentiful examples where the sources of major classes of pottery were found to be far from sites where they were found in numbers (Whitelaw *et al*. 1997; Day and Wilson 1998; Cosmopoulos *et al*. 1999). For obvious reasons, in the identification of local groups, the analysis of wasters or pottery associated with kilns (Fillières *et al*. 1983) is often considered important. In Minoan Crete for the period up to Late Minoan I, there have been very few kiln structures available for consideration, although Late Bronze Age examples are now known (e.g., Tomasello 1996; Shaw *et al*. 2001, 20–2).
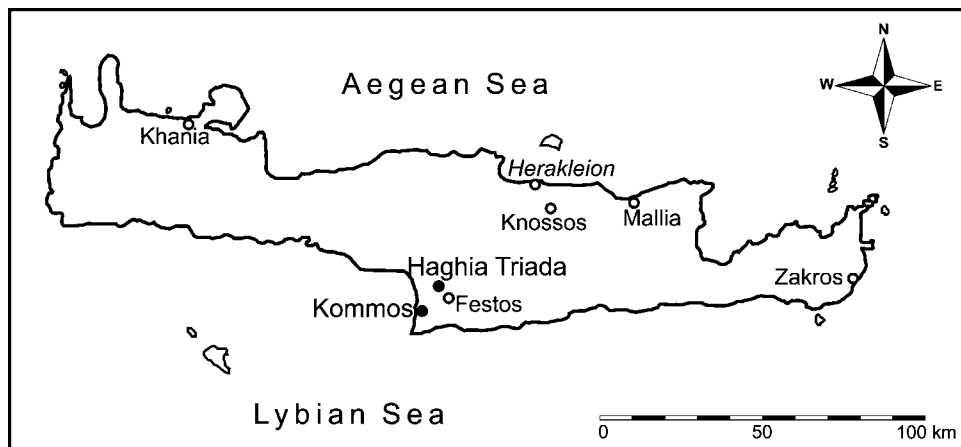
Figure 1   *A map of Crete, showing the sites mentioned in the text.*

While it has been demonstrated that wasters from kiln sites specifically may be susceptible to post-burial alteration and contamination (Buxeda i Garrigós 1999; Buxeda i Garrigós *et al.* 2001), the discovery of a ceramic kiln with associated pottery is a find of great importance, providing as it does a ceramic resource of certain provenance. Beyond composition, it can be valuable in developing an understanding of the technological practice and craft organization at a specific place and time (Whitbread *et al.* 1997; Shaw *et al.* 2001). Here, our emphasis is on the characterization of ceramic production at a Minoan kiln site in Southern Crete (Fig. 1). This is a crucial area for our understanding of Minoan pottery production and especially for the distinction of the composition of products of the Mesara Plain, which seem to have played an important role in life during the Cretan Bronze Age.

THE KILN AT HAGHIA TRIADA, CRETE

The Haghia Triada kiln was discovered by Levi in 1976 and dated to the Late Minoan I, around the mid-second millennium BC (Levi and Laviosa 1986; Tomasello 1996). It is of the channel type, which was common during the early part of the Late Bronze Age in Crete (Shaw *et al.* 2001, 20–2), of very similar design and date to its near-neighbour, the Kommos kiln, which lies only a few kilometres away and has been published elsewhere (Shaw *et al.* 2001). It comprises probably the largest and best-preserved example in Crete although, in contrast to the Kommos kiln, it has only a little associated pottery. Figures 2 (a) and 2 (b) show the kiln as excavated and its reconstruction from Di Vita *et al.* (1984).

The chance to analyse the products of this substantial kiln is even more important, as it provides the possibility of comparing the products of two neighbouring kilns in an area where there existed the repetition of clay recipes based on sand-tempered clay bodies. Analytical work so far has shown that this tradition obscures efforts to provenance products on a micro-scale within the Mesara Plain (Day *et al.* 1999).

In applying mineralogical, petrographic, chemical and microstructural analyses of the pottery products, we have a number of aims concerning ceramic production technology and ceramic characterization within the Mesara Plain and central Crete more generally:
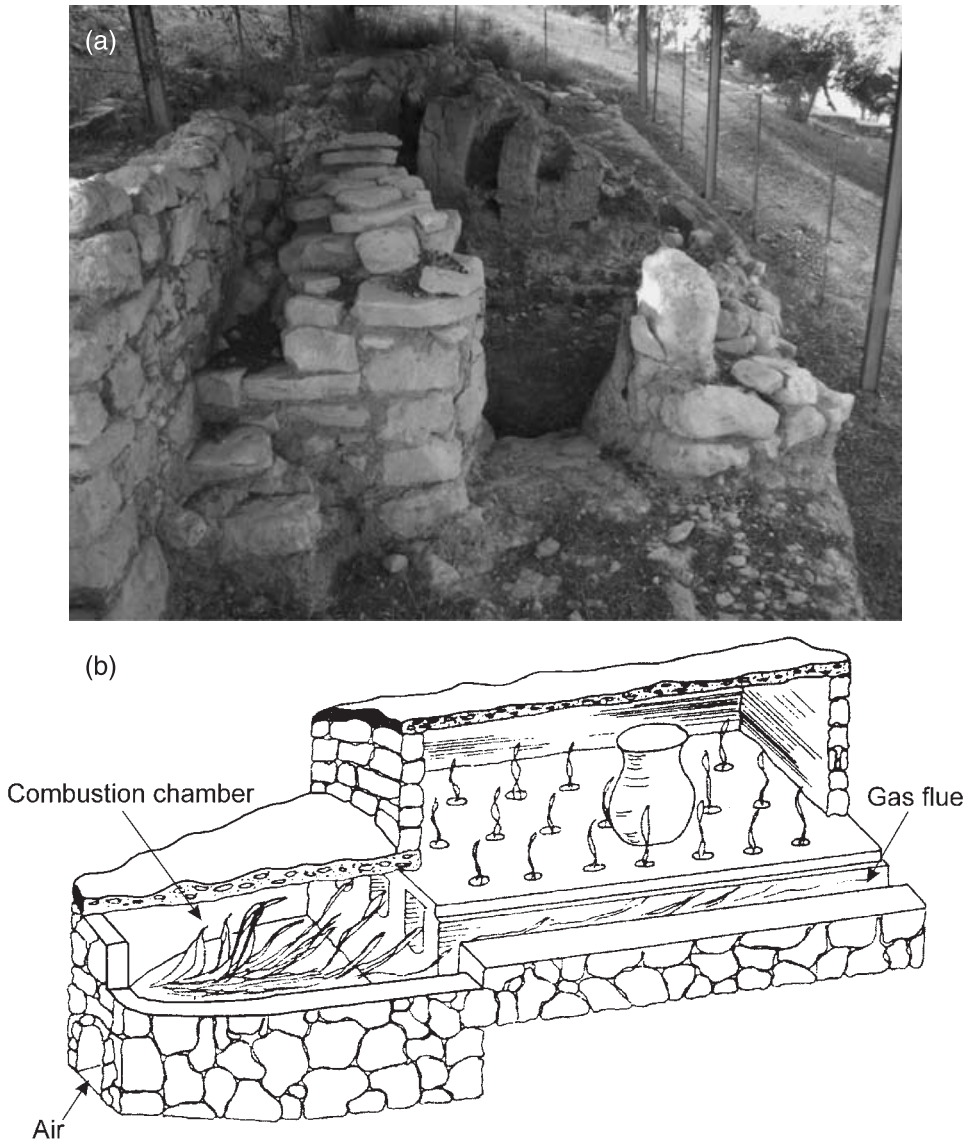
Figure 2 *The kiln at Haghia Triada (a) and its reconstruction (b) (from Di Vita et al. 1984, fig. 277).*

• to identify the raw materials exploited (clays and tempers) and to indicate their possible source within the local area;
• to characterize and group the pottery in petrographic terms, relating this to stylistic groups;
• to collect information on the production technology used at the kiln (firing temperature, probable addition of tempers, processes of clay mixing, etc.);
• to investigate any post-burial alterations that could have affected the overall chemical composition;

• to form a 'reference group' for the production of pottery at this kiln site during Late Minoan I;
• to make a comparison between these results and those obtained from the kiln at Kommos.

SAMPLE SELECTION

Of the material recovered during the excavation of the Haghia Triada kiln, 52 sherds were chosen for examination. These are dated to the Late Minoan IB and were selected to represent the wide range of fabrics, from fine to coarse, and the range of produced shapes, from conical cups to storage and cooking vessels. Some of the vessels analysed have light slips and/or reddish-brown painted decoration. The full range of samples taken is presented in Table 1.

With the exception of a few samples whose shape could not be determined, all the others were assigned to the following typological classes: conical cups, jars, jugs, cups, bowls, amphorae, basins, one-handled cups, deep bowls, storage jars and cooking vessels. Some, but not all, of the sherds analysed were noticeably over-fired and characterized as 'wasters'.

ANALYTICAL METHODOLOGY

All samples underwent macroscopic description, recording aspects such as grain size and colour of the ceramic body, using Munsell Soil Colour Charts. Inclusions and voids were recorded, as well as details of surface modification and decoration (Table 1). Petrographic thin-section analysis was carried out on a polarizing microscope, following the description system proposed by Whitbread (1995). This facilitates the detailed characterization of microstructure, groundmass and inclusions.

The micromorphology and vitrification microstructures of the samples were examined by scanning electron microscopy (SEM), at the Department of Earth Sciences, University of Messina. The microstructures of all samples were studied from carbon-coated, fresh fracture surfaces. The degree of vitrification and equivalent firing temperatures were then assessed following the procedure described elsewhere (Maniatis and Tite 1981; Kilikoglou 1994).

Mineralogical analyses by X-ray diffractometry (XRD) and geochemical analyses by X-ray fluorescence (XRF) were performed at the Department of Geological Sciences, University of Catania. For XRD, a Siemens D 5000 diffractometer was used and spectra were taken from 4 to 100° 2Θ, using a step-size of 0.02° and a step-time of 10 s. For XRF, a Philips PW 2404/00 was used to measure the major and minor elements. Finally, neutron activation analysis (NAA) was also performed on the samples, primarily to determine trace element composition. Samples and standards were irradiated at the swimming pool reactor of NCSR 'Demokritos', at a thermal neutron flux of 3×10^{13} n cm^{-2} s^{-1}. Seven days after irradiation, the samples and standards were measured for Sm, Lu, U, Yb, As, Sb, Ca, Na and La, and 20 days after irradiation for Ce, Th, Cr, Hf, Cs, Tb, Sc, Rb, Fe, Ta, Co and Eu.

PETROGRAPHIC ANALYSIS

Examination of the samples suggests that four different fabrics are present in the kiln assemblage (Figs 3–6), one of which is fine grained while the other three are coarse. These four petrographic groups are presented and described below (for abbreviations, see Whitbread 1995).

From the comparison between the petrographic groups and typological–stylistic data, a clear correlation between the paste used for the vessels and the size/shape of the pot emerges,

Sample	Typological class	Fabric	Colour	Inclusions	Voids	Surface	Thickness (cm)
HTR-C01	Conical cup	Fine	10 YR, 7/4 Very pale brown	Absent	Few; $\Phi < 1$ mm	Smooth	0.4
HTR-C02	Conical cup	Fine	10YR, 8/4 Very pale brown	Few, red–brown, rarely white; $\Phi < 1$ mm	Common; Φ variable up to a few mm; orientated parallel to the margins	Smooth	Variable from 0.3 to 0.7
HTR-C03	Conical cup	Fine	7.5 YR, 8/6 Reddish yellow	Rare, white; $\Phi < 1$ mm	Very rare; $\Phi < 1$ mm	Smooth	0.5
HTR-C04	Conical cup	Fine	10 YR, 8/4 Very pale brown	Common, brown, rarely white; $\Phi < 1$ mm	Few; $\Phi < 1$ mm	Smooth	0.5
HTR-C05	Conical cup	Fine	7.5 YR, 8/6 Reddish yellow	Few, white; $\Phi < 1$ mm	Common; $\Phi < 1$ mm	Smooth	0.5
HTR-C06	Conical cup	Fine	10 YR, 8/4 Very pale brown (slightly darker in the core)	Common, reddish-brown $\Phi < 1$ mm	Common; Φ variable up to a few mm	Smooth	0.4
HTR-C07	Conical cup with thin walls	Fine	10 YR, 8/4 Very pale brown	Absent	Few; $\Phi < 1$ mm; orientated parallel to the margins	Smooth	0.3
HTR-C08	Conical cup	Fine	5 YR, 7/6 Reddish yellow	Absent	Common; Φ variable up to a few mm	Smooth	0.5
HTR-C09	Unpainted cup	Fine	10 YR, 7/4 Very pale brown (slightly darker in the core)	Absent	Very few; $\Phi < 1$ mm	Smooth	0.4
HTR-C10	Small-mouthed jar (?) with remains of reddish-brown paint	Fine	10 YR, 7/4 Very pale brown	Few, brown; $\Phi < 1$ mm	Few; Φ variable up to a few mm; orientated parallel to the margins	Smooth	0.4
HTR-C11	Closed vessel (jug or jar) with remains of probable spiral decoration in reddish-brown paint	Fine	10 YR, 7/4 Very pale brown	Few, brown; $\Phi < 1$ mm	Few; Φ variable up to a few mm; orientated parallel to the margins	Smooth	0.3

Table 1   *Continued*

Sample	Typological class	Fabric	Colour	Inclusions	Voids	Surface	Thickness (cm)
HTR-C12	Small jar with remains of probable spiral decoration in brown paint	Fine	10 YR, 6/4 Light yellowish brown	Few, brown; $\Phi < 1$ mm	Few; $\Phi < 1$ mm	Smooth	0.5
HTR-C13	Medium-sized closed vessel (jug or jar) with remains of probably spiral decoration in reddish-brown paint	Fine	7.5 YR, 8/6 Reddish yellow	Few, brown; $\Phi < 1$ mm	Few; $\Phi < 1$ mm	Smooth	Variable from 0.4 to 0.6
HTR-C14	Small jar with remains of a horizontal-banded decoration in brown paint	Fine	10 YR, 8/4 Very pale brown	Few, brown; $\Phi < 1$ mm	Few; $\Phi < 1$ mm	Smooth	0.3
HTR-C15	Base of closed vessel (jug or jar); probably overall reddish-brown slip	Fine	7.5 YR, 6/6 Reddish yellow (red in the core)	Absent	Few; $\Phi < 1$ mm	Smooth	0.8
HTR-C16	Rim of small jar with horizontal-banded decoration in dark brown paint	Fine	10 YR, 7/4 Very pale brown	Absent	Few; $\Phi < 1$ mm	Smooth	0.3
HTR-C17	Large two-handled bowl decorated with reddish-brown paint on the handle and with horizontal band of same under rim	Partly fine and partly coarse	7.5 YR, 8/6 Reddish yellow (red in the core)	Absent in the fine portion; frequent, brown colour, in the coarse portion; Φ variable up to a few mm	Few; $\Phi < 1$ mm	Slightly rough	Variable from 0.4 to 0.8
HTR-C18	Base of unpainted closed vessel (small amphora?)	Fine	5 YR, 6/6 Reddish yellow (slightly lighter in the core)	Absent	Few; Φ variable up to a few mm; orientated parallel to the margins	Smooth	0.8
HTR-C19	Handle and shoulder of unpainted jar	Fine	7.5 YR, 7/8 Reddish yellow (red in the core)	Few, white and brown; $\Phi < 1$ mm	Few; $\Phi < 1$ mm	Smooth	0.8

HTR-C20	Rim of a small basin with brown painted band on the rim; remains of decoration on the body and brown slipped interior	Fine	5 YR, 6/6 Reddish yellow	Absent	Few; $\Phi < 1$ mm	Smooth	0.5
HTR-C21	Rim of jug (?) with a horizontal band in reddish-brown paint	Fine	5 YR, 7/6 Reddish yellow	Rare, brown; $\Phi < 1$ mm	Common; Φ variable up to a few mm; orientated parallel to the margins	Smooth	0.5
HTR-C22	Body fragment of closed vessel (jug ?) with spiral decoration in reddish-brown paint	Fine	5 YR, 7/6 Reddish yellow	Rare, brown; $\Phi < 1$ mm	Common; $\Phi < 1$ mm	Smooth	0.3
HTR-C23	Rim of large vessel (pithos?) with fugitive reddish-brown paint	Coarse	7.5 YR, 6/6 Reddish yellow	Frequent, white, brown and dark grey colour; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Smooth	1.3
HTR-C24	Shoulder of a closed vessel (jug?) with remains of horizontal band in brown paint	Coarse	10 YR, 6/4 Light yellowish brown	Frequent, white and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Smooth	0.6
HTR-C25	Body fragment of closed vessel with remains of decoration in reddish paint	Coarse	7.5 YR, 7/6 Reddish yellow	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Rough	0.7
HTR-C26	Rim of a unpainted 'pot a' fleurs'	Coarse	7.5 YR, 7/4 Pink	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm; slight orientated parallel to margins	Rough	0.5
HTR-C27	Body fragment of closed vessel with vertical banded decoration in brown paint	Coarse	10 YR, 7/3 Very pale brown	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Rough	0.8
HTR-C28	Shoulder and neck of a closed vessel (jug?) with remains of fugitive decoration in reddish-brown paint	Coarse	10 Y, 7/4 Very pale brown	Frequent, brown; Φ variable up to a few mm; slight orientation parallel to margins	Few; $\Phi < 1$ mm	Rough	0.6

Table 1   *Continued*

Sample	Typological class	Fabric	Colour	Inclusions	Voids	Surface	Thickness (cm)
HTR-C29	Base of closed vessel (jug?); unpainted	Fine	10 YR, 8/4 Very pale brown	Absent	Few; $\Phi < 1$ mm	Slightly rough	0.4
HTR-C30	Body fragment of closed vessel with remains of a vertical banded decoration, and other motifs in reddish-brown paint	Coarse	7.5 YR, 8/4 Pink	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm; slight orientation parallel to margins	Slightly rough	0.6
HTR-C31	Body fragment of large closed vessel (pithos?) with remains of brown to reddish-brown decoration	Coarse	7.5 YR, 7/4 Pink	Frequent, brown and dark grey, rarely white; Φ variable up to a few mm	Few; Φ variable up to a few mm	Rough	1.0
HTR-C32	Body fragment of closed vessel with horizontal-band decoration in reddish-brown paint	Coarse	7.5 YR, 6/4 Light brown (greyish in the core)	Frequent, brown and dark grey; Φ variable up to a few mm; orientated parallel to margins	Few; $\Phi < 1$ mm; orientated parallel to margins	Slightly rough	0.6
HTR-C33	Neck of a unpainted jug	Coarse	2.5 YR, 7/2 Light grey (rosy in the core)	Frequent, white, brown and dark grey; Φ variable up to a few mm; slight orientation parallel to margins	Few; Φ variable up to a few mm; slight orientation parallel to margins	Slightly rough	0.7
HTR-C34	Jar rim with traces of reddish-brown paint	Coarse	7.5 YR, 6/4 Light brown	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm; orientation parallel to margins	Slightly rough	0.6
HTR-C35	Thick-walled vessel with traces of brown painted decoration	Coarse (with a layer of fine clay on the walls)	10 YR, 6/3 Pale brown (greyish in the margins)	Frequent, white, brown and dark-grey; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	1.2

HTR-C36	Rim of large vessel with traces of ?horizontal band in fugitive brown paint	Coarse	10 YR, 6/6 Brownish yellow (greyish in the core)	Frequent, white, brown and black; Φ variable up to a few mm	Common; Φ variable up to a few mm	Rough	1.2
HTR-C37	Handle of unpainted large amphora/jug	Coarse	10YR, 7/3 Very pale brown	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Ext. surf. rough, int. surf. smooth	0.7
HTR-C38	Base of a large basin; unpainted	Coarse	7.5 YR, 6/6 Reddish yellow (slightly darker in the core)	Frequent, brown and dark grey; Φ variable up to a few mm	Common; Φ prevalently < 1 mm	Rough	1.5
HTR-C39	Neck and shoulder of probable oval-mouthed amphora with traces of brown painted decoration over light slip	Coarse	10 YR, 6/4 Light yellowish brown	Frequent, brown and dark grey, rarely white; Φ variable up to a few mm	Few; Φ prevalently < 1 mm	Rough	0.7
HTR-C40	Base and lower part of closed vessel (small jug?) with a light slip and remains of a reddish-brown decoration	Coarse	7.5 YR, 7/6 Reddish yellow	Frequent, brown and dark-grey, rarely white; Φ variable up to a few mm; orientated parallel to the margins	Few; Φ prevalently < 1 mm; orientation parallel to the margins	Ext. surf. smooth, int. surf. rough	1.0
HTR-C41	Rim of small pithos with relief rope band and light slip	Coarse	7.5 YR, 6/6 Reddish yellow	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Rough	1.0
HTR-C42	Body fragment of pithos with wavy relief rope pattern, with light slip	Coarse	2.5 YR, 5/2 Greyish brown	Frequent, white and dark grey; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to the margins	Rough	1.2
HTR-C43	Rim and upper part of a cooking pot, unpainted	Coarse	7.5 YR, 5/4 Brown	Frequent, brown, rarely white and dark grey; Φ variable up to a few mm	Common; Φ variable up to a few mm; slight orientation parallel to margins	Rough	1.5
HTR-C44	Foot of an unpainted cooking pot	Coarse	5 YR, 5/6 Yellowish red	Frequent, white, brown and dark grey; Φ variable up to a few mm	Few; Φ variable up to a few mm	Rough	0.7

Table 1 *Continued*

| Sample	Typological class	Fabric	Colour	Inclusions	Voids	Surface	Thickness (cm)
HTR-C45	Body fragment of cooking pot with slip	Coarse	7.5 YR, 5/4 Brown	Frequent, brown, rarely white; Φ variable up to a few mm	Few; Φ prevalently < 1 mm	Rough	1.2
HTR-C46	Foot of a cooking pot with slip	Coarse	7.5 YR, 5/6 Strong brown	Frequent, brown and dark grey; Φ variable up to a few mm	Few; Φ prevalently < 1 mm	Rough	Not definable
HTR-C47	Body fragment of an over-fired closed vessel (waster)	Coarse	5 Y, 4/1 Dark grey	Frequent, brown and white; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	Variable from 0.5 to 0.7
HTR-C48	Body fragment of an over-fired closed vessel (waster)	Coarse	2.5 Y, N5/ Grey	Frequent, white; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	0.7
HTR-C49	Body fragment of an over-fired closed vessel (waster)	Coarse	10 YR, 4/2 Dark greyish brown	Frequent, white and brown; Φ variable up to a few mm	Frequent; Φ variable up to a few mm	Rough	Variable from 0.5 to 0.7
HTR-C50	Body fragment of an over-fired closed vessel (waster)	Coarse	2.5 YR, N6/ Grey – light grey	Frequent, white; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	0.7
HTR-C51	Base and body of an over-fired closed vessel (waster)	Coarse	2.5Y, N5/ Grey	Frequent, white; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	Variable from 0.5 to 0.8
HTR-C52	Body fragment of an over-fired closed vessel (waster)	Coarse	5 Y, 6/1 Grey – light grey	Frequent, white; Φ variable up to a few mm	Frequent; Φ variable up to a few mm; slight orientation parallel to margins	Rough	0.5
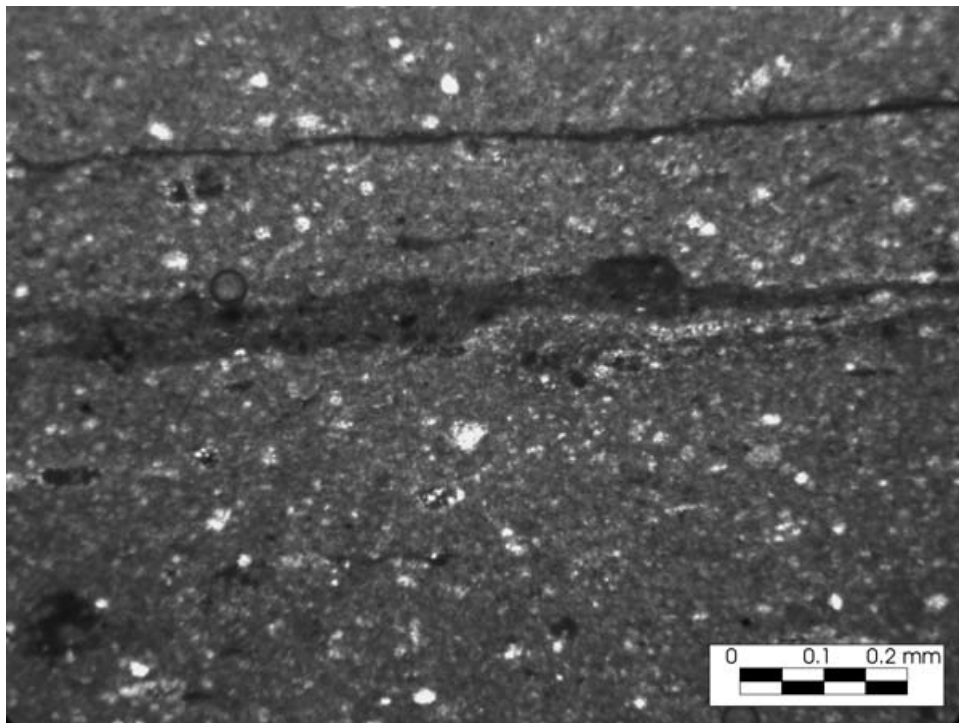
Figure 3   *A photomicrograph (plane polarized light) of the sample HTR-C07 belonging to fabric Group 1. Illustrated in the centre of the photo are red, elongate segregations, common in the first group.*

as has been observed previously by Shaw *et al.* (2001) for the Kommos kiln assemblage. In general, the smaller vessels are associated with finer fabrics, while the larger ones have higher proportions of aplastic inclusions, as shown in Figure 7. This may be accounted for by the fact that the larger vessels are prone to greater mechanical stresses in their use (Kilikoglou *et al.* 1998). However, certain vessel shapes, such as jugs and jars, exhibit both paste types. No relationship emerged between the optical activity of the groundmass (taken to be indicative of firing temperature) and the presence/absence of painted decoration.

The aplastic inclusions found in the course of thin-section petrography are compatible with the range of geological deposits in the broader local area (see discussion in Shaw *et al.* 2001, 118):

Group 1: fine fabric (Fig. 3) (HTR-C01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 29)

I Microstructure
(a) Few to very few voids, sometimes partly or totally filled with secondary calcite. Predominant to dominant mesovoids (vughs and vesicles), common to very few macrovoids (prevalently vughs, at times linear); few to very rare megavoids (vughs and linear) and microvoids (vesicles); (b) the micromass appears to have an orientation parallel to the vessel margins, rarely also voids and Acf; (c) unimodal grain-size distribution; (d) the inclusions are open-spaced.
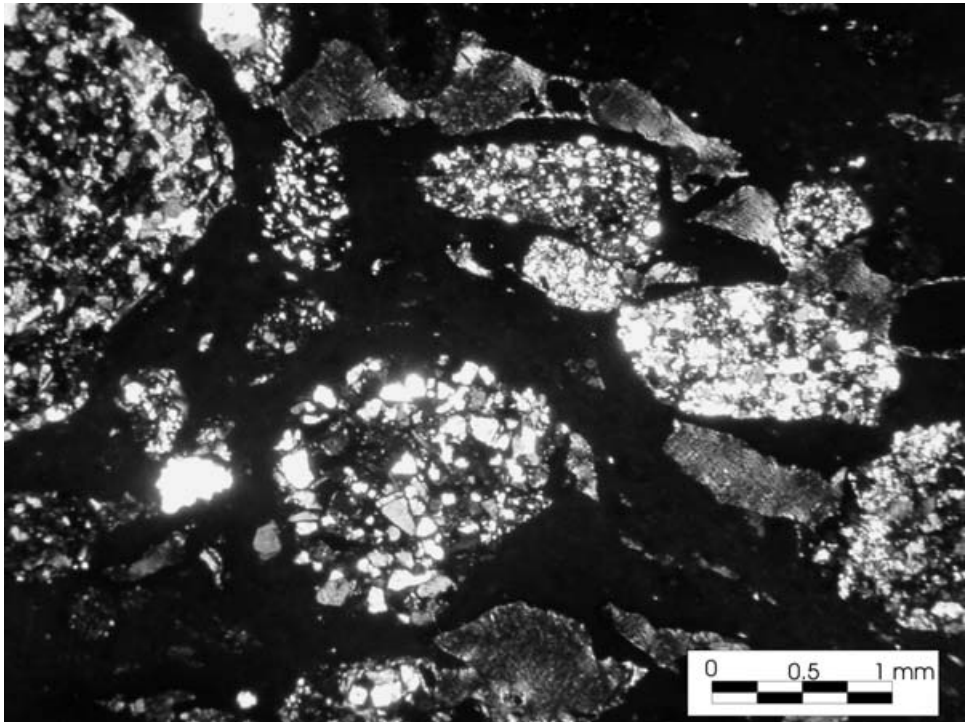
Figure 4 *A photomicrograph (crossed polars) of the sample HTR-C51 belonging to fabric Group 2. Numerous large inclusions of quartzarenite and quartzite can be observed. The micromass is totally vitrified, as it is a waster.*

II Groundmass
(a) Homogeneous to heterogeneous, depending on the section; (b) the colour in PPL is generally brown to greyish-brown, rarely reddish-brown; (c) the optical activity of the groundmass varies from being high to medium-low—where the core of the section is enriched in (secondary) calcite, it gives the appearance of optical activity, while the margins are often inactive; (d) the b-fabric is generally crystallitic, often striated, rarely globular-speckled or strial.

III Inclusions
c:f:v$_{10\mu m}$: 3:90:7 to 20:65:15 (< 2.4 mm)
The grains are moderately to well-sorted.
(i) Composition and frequency:
Predominant to dominant: prevalently monocrystalline quartz sr. to sa.
Frequent to few: biotite and muscovite mica and carbonate rock fragments (sr. to sa), some of the latter altered to secondary micritic calcite (with frequent reaction rims).
Few to rare: feldspar, plagioclase feldspar, metamorphic rock fragments sr., (quartz–biotite schist to gneiss, quartzite, amphibolite gneiss), chert sa., quartzarenite sr., amphiboles and opaques.
Rare to very rare: serpentine aggregate and volcanic rock fragments sr. (porphyritic with plagioclase phenocrysts and sometimes serpentine deriving from the transformation of the ferric minerals in a red–brown and totally fired matrix).
There are also frequent microfossils, some of which have decomposed during the firing process.
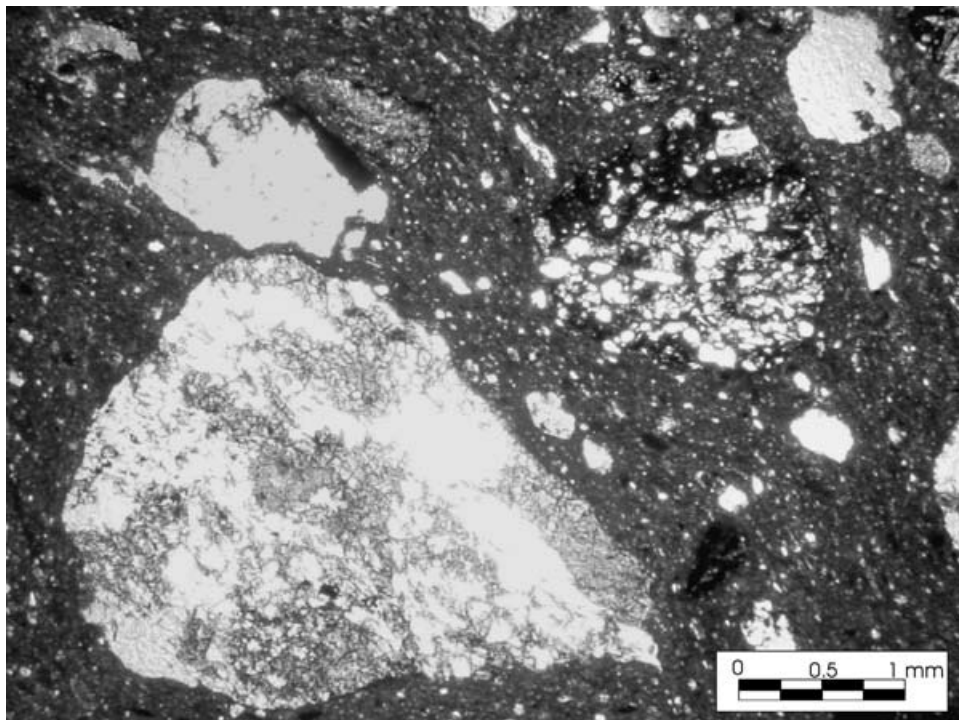
Figure 5 *A photomicrograph (crossed polars) of the sample HTR-C25 belonging to fabric Group 3. Most aplastic inclusions are < 1 mm in size and comprise mostly rock fragments and quartz.*

IV Textural concentration features

Tcf: absent to 5% of the total field. Prevalently clots of a light-coloured clay (probably richer in carbonates) with clear boundaries.

V Amorphous concentration features

Acf: 2–10% of total field. Predominantly pure (at times impregnative) nodules of amorphous material variable in size; rare segregations parallel to the vessel margins. The colour is red in both PPL and XP.

Notes: Several samples have probable evidence of clay mixing, which appears as streaks or clots of either calcareous clay in a red clay or vice versa.

Group 2: coarse fabric with frequent quartzarenite and quartzite (Fig. 4)
(HTR-C23, 42, 48, 50, 51 and 52)

I Microstructure

(a) Frequent to common voids. Predominant to frequent macrovoids (vughs and linear), common to few mesovoids (vughs and vesicles) and megavoids (vughs and linear), few to absent microvoids (vesicles); (b) slight orientation of voids parallel to the vessel margins

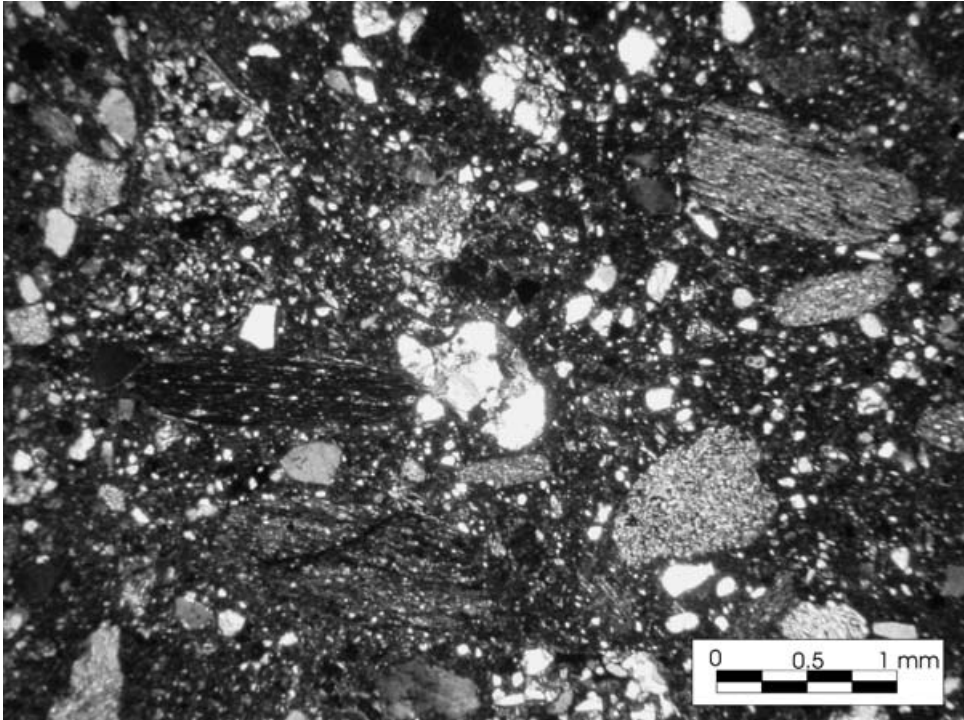Figure 6   *A photomicrograph (crossed polars) of the sample HTR-C36 belonging to fabric Group 4. The aplastic inclusions, prevalently rock fragments and quartz, show a bimodal grain size distribution, with the maximum size being ~ 4 mm.*
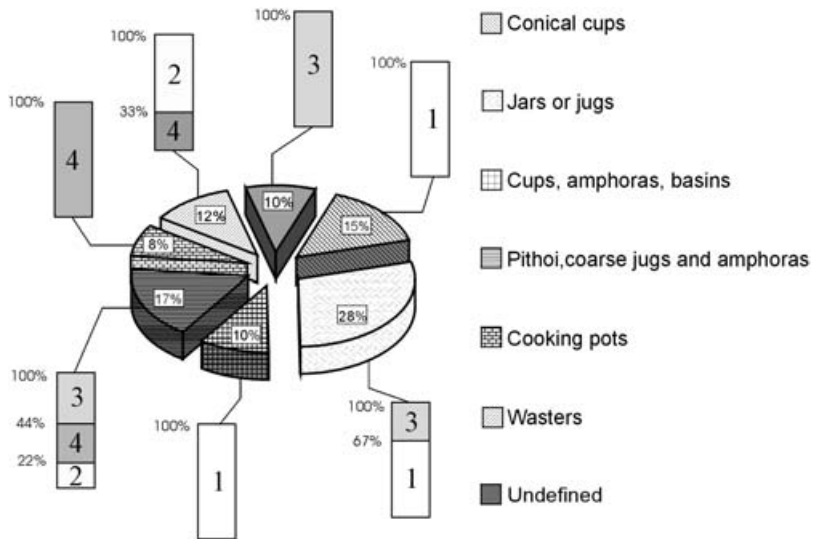

Figure 7   *The frequencies of the different fabrics within the studied typological classes. Numbers in the bars refer to the fabric groups present in each shape range.*

—micromass and inclusions appear to be randomly orientated for the most part; (c) bimodal grain-size distribution; (d) the inclusions are single-spaced to double-spaced in the coarse fraction and open-spaced in the fine fraction.

II Groundmass
(a) More or less homogeneous depending on the section; (b) the colour in PPL is generally dark brown, and grey in the over-fired samples (HTR-C48, 50, 51 and 52); (c) the micromass is optically inactive.

III Inclusions
c:f:v$_{10\mu m}$: 25:35:40 to 40:30:30 (< 3.6 mm)
The grains are poorly to very poorly sorted.
Composition, frequency and roundness:
(i) Coarse fraction (Φ > 0.125 mm):
Predominant to dominant: monocrystalline quartz a. to sa.
Dominant to frequent: quartzarenite fragments r. to sr.
Common to few: polycrystalline quartz, a. to sa., chert sr., quartzite fragments, sa. to sr.
Few to very few: feldspar (some altered to sericite), a. to sa. and sa. plagioclase.
Very few to rare: biotite schist and semi schist, both sa. to sr.; sr. siltstone.
Rare to very rare: carbonate rock fragments altered to secondary micritic calcite (with frequent reaction rims) sr., volcanic rock fragments (porphyritic with plagioclase phenocrysts and sometimes serpentine deriving from the transformation of the ferric minerals in a red–brown and totally transformed matrix), sr., serpentine aggregate, amphiboles, biotite mica, phyllite, spinel (hercynite) and opaques.
(ii) Fine fraction (10 μm < Φ < 0.125 mm): very scarce in the over-fired samples.
Predominant: monocrystalline quartz.
Rare to very rare: micas (biotite), feldspar, plagioclase feldspar, chert.

IV Textural concentration features
Tcf: generally absent.

V Amorphous concentration features
Acf: 3% of total field. Predominantly pure nodules of amorphous material; red in both PPL and XP. Absent in over-fired samples.

Notes: In the over-fired samples, most inclusions exhibit strong alteration due to the high temperature of firing.

Group 3: coarse fabric with frequent rock fragments (Fig. 5)
(HTR-C24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 35, 37, 39 and 40)

I Microstructure
(a) Common to few voids. Predominant to common mesovoids (vughs and vesicles), common to few macrovoids (vughs), rare to absent microvoids (vesicles) and megavoids (vughs); (b) subparallel orientation of voids, at times of micromass and inclusions; (c) bimodal grain-size distribution; (d) the inclusions are open-spaced to double-spaced (at times single-spaced) in the coarse fraction and open-spaced in the fine fraction.

II Groundmass
(a) Homogeneous to heterogeneous, depending on the section; (b) brown to greyish-brown (rarely reddish-brown) in PPL; (c) the optical activity is generally medium–low, with the exception of the samples HTR-C32 and HTR-C40, which are optically highly active; (d) the b-fabric is crystallitic, sometimes striated or stipple speckled.

III Inclusions
c:f:$v_{10\mu m}$: 25:65:10 to 40:45:15 (< 4.4 mm)
The grains are poorly sorted.
Composition, frequency and roundness:
(i) Coarse fraction (Φ > 0.125 mm):
Dominant to common: monocrystalline quartz, a.; sandstone, sa. to sr.
Common to few: polycrystalline quartz, a.; metamorphic rock (biotite or biotite–muscovite schist to gneiss), sa.; amphibolitic gneiss, sr.; quartzite, sa.
Few to rare: feldspar, a. to sa.; plagioclase feldspar, sa. to a.; chert, sa. to sr.; phyllite, sa.; schist, r.; siltstone, r. to sr.; volcanic rock, almost totally altered by firing; carbonate rock, altered to secondary micritic calcite (with frequent reaction rims), sr.
Rare to very rare: micas (biotite and muscovite), amphiboles, epidote, serpentine aggregate, spinel, opaques.
(ii) Fine fraction (10 μm < Φ < 0.125 mm): scarce.
Predominant to frequent: monocrystalline quartz.
Common to few: micas (biotite and muscovite).
Very few to rare: feldspar and amphiboles.
Rare to very rare: plagioclase feldspar, chert and opaques.

IV Textural concentration features
Tcf: 2–10% of total field. Prevalently clots of light-coloured clay (probably richer in carbonates) and with clear boundaries; rare clots of a dark-brown clay with less frequent inclusions.

V Amorphous concentration features
Acf: 2–10% of total field. Predominantly pure nodules of amorphous material, variable in size; rare impregnative segregations.

Notes: Several samples show probable evidence of clay mixing, which appears as streaks or clots of either calcareous clay in a red clay or vice versa.

Group 4: coarse fabric with dominant quartz (Fig. 6)
(HTR-C36, 38, 41, 43, 44, 45, 46, 47 and 49)

I Microstructure
(a) Common to few voids. Dominant mesovoids (vughs and vesicles), common to few macrovoids (vughs), very few to rare megavoids (vughs), rare to very rare microvoids (vesicles); (b) rare slight orientation of voids and micromass (due to the orientation of the micas); (c) bimodal grain-size distribution; (d) the inclusions are double-spaced to single-spaced either in the coarse fraction or in the fine fraction.

II Groundmass
(a) Generally homogeneous; (b) brown in PPL (at times reddish), grey in over-fired samples (HTR-C47 and 49); (c) the optical activity varies from being absent to high, depending on the section; (d) the b-fabric is crystallitic.

III Inclusions
$c:f:v_{10\mu m}$: 30:50:20 to 50:25:25 (< 3.6 mm)
The grains are very poorly sorted.
Composition, frequency and roundness:
(i) Coarse fraction ($\Phi > 0.125$ mm):
Dominant: monocrystalline and polycrystalline quartz a. to sa.
Frequent to common: quartzarenite, sa. to sr.; metamorphic rock (biotite or biotite–muscovite schist to gneiss) sa. to sr.
Few to very few: feldspar, a.; plagioclase feldspar sa. to r.; chert, sr.; phyllite, sa.; schist, sr.; quartzite, sr. to sa.; amphibolitic gneiss, sr. to sa.; volcanic rock (almost totally altered through firing) r.
Rare to very rare: siltstone, r.; carbonate rock altered to secondary micritic calcite (with frequent reaction rims), sr.; micas (biotite and muscovite); amphibole, epidote, serpentine aggregate, spinel (hercynite?), opaques.
(ii) Fine fraction (10 μm $< \Phi < 0.125$ mm):
Predominant: monocrystalline quartz.
Common to few: micas (biotite and muscovite).
Very few to rare: feldspar, plagioclase feldspar, chert and opaques.
Rare to very rare: amphiboles, epidote.

IV Textural concentration features
Tcf: 2–5% of total field. Prevalent clots of clay generally impoverished of inclusions and with clear boundaries. Absent in the over-fired samples.

V Amorphous concentration features
Acf: 2–5% of total field. Predominantly pure (at times impregnative) nodules of amorphous material variable in size (generally small).

Notes: In the over-fired samples, the majority of inclusions display alteration due to the high temperature of firing.

MICRO-MORPHOLOGICAL ANALYSES BY SEM

Micro-morphological analysis by scanning electron microscopy has proven a most useful technique in the characterization of ceramic technology, often in conjunction with energy-dispersive X-ray analysis for compositional information. Examination of the fresh fracture of a ceramic under the SEM allows for an assessment of the micro-morphology of the groundmass (Tite *et al.* 1982), thereby allowing an evaluation of the degree of vitrification reached by the ceramic during the firing. Additional information can be gained on the materials used in surface modification and their manipulation. Here we will concentrate on the information that SEM analyses, in combination with petrographic and geochemical–mineralogical data, can provide in order to determine equivalent firing temperatures. For this purpose, the comparative vitrification stages established by Maniatis and Tite (1981) for calcareous and non-calcareous clays were used.

Table 2 *Scanning electron microscopy results for the 15 representative samples. IV, initial vitrification; V, extensive vitrification; CV, continuous vitrification*

Sample	Firing atmosphere	CaO (%)	Body vitrification	Firing temperature (°C)
HTR-CO1	0	14.47	V	850–1050
HTR-C17	0	14.52	V	850–1050
HTR-C18	0	7.99	V	850–1050
HTR-C22	0	12.36	IV	800–850
HTR-C28	0	10.77	IV	800–850
HTR-C29	0	13.13	V	850–1050
HTR-C30	0	10.29	V	850–1050
HTR-C33	R	13.33	V	850–1050
HTR-C36	0	1.93	V	850–950
HTR-C42	0	8.00	V	850–1050
HTR-C44	0	1.49	V	850–950
HTR-C48	0	6.73	CV	1050–1100
HTR-C49	R	2.51	CV	900–1000
HTR-C51	0	6.16	CV	1050–1100
HTR-C52	0	8.98	CV	1050–1100

A summary of the SEM analysis of 15 representative samples is presented in Table 2, where it is clear that the majority displayed extensive vitrification, as illustrated in Figures 8 (a) and 8 (b), where a representative microstructure of a calcareous (a) and another of a non-calcareous (b) paste are shown. The level of Ca content, in combination with the extent of the glassy phase in the microstructures and a consideration of firing atmosphere, suggest equivalent firing temperatures of between 850°C and 1050°C for calcareous clays and between 900°C and 950°C for non-calcareous clays. However, there are a small number of samples that exhibit a lower degree of vitrification, probably due to their different placement in the kiln (Fig. 8 (c)). The over-fired pottery shows a continuous vitrification and no structure is visible in the SEM examination (Fig. 8 (d)). In this case, equivalent firing temperatures of above 1100°C can be assumed.

MINERALOGICAL ANALYSES

Spectra obtained by XRD were examined in qualitative terms for the identification of the phases present in each sample. Then, in order to obtain the weight fractions of each phase, a quantitative elaboration of the same spectra was carried out using a calculation software (GSAS) based on the Rietveld method, which recently has been applied successfully to the quantitative mineralogical composition of ceramic materials (Viani *et al*. 1999). In addition, a known quantity of an internal standard (corundum NIST 676) added to each sample also provided an estimate of the weight percentage of the amorphous fraction (combined Rietveld–R.I.R. method; see Gualtieri 2000).

The average weight percentages of each phase in the four groups and the relative standard deviations are reported in Table 3. The qualitative and quantitative data display a substantial diversity among the four groups (Fig. 9). The samples belonging to petrographic Group 1 show a greater amount of high-temperature Ca-silicates (gehlenite and diopside), with lesser
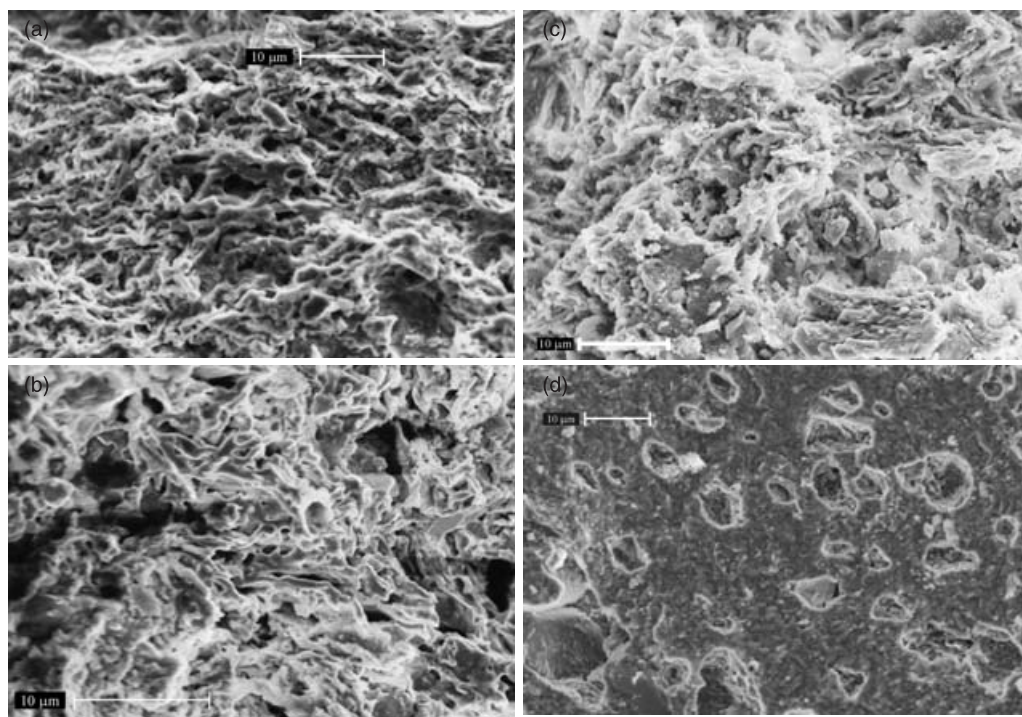
Figure 8   *SEM photomicrographs of (a) a calcareous fabric (HTR-C29), showing extensive vitrification; (b) a non-calcareous fabric, showing extensive vitrification (HTR-C36); (c) sample HTR-C22, to demonstrate the initial vitrification microstructure; and (d) an SEM photomicrograph of an over-fired sample (HTR-C51), where a continuous vitrification, accompanied by the development of isolated bloating pores, can be observed.*

Table 3   *The average mineralogical composition (wt%), obtained by the adapted Rietveld method, and the related standard deviations of the four fabrics. Qz, quartz; Pl, plagioclase; Kf, alkaline feldspar; Di, diopside; Cc, calcite; Gh, gehlenite; He, hematite; Ms, muscovite; Amph, amphibole; Wa, wairakite; Hr, hercynite; Fo, forsterite; Cb, cristobalite; Am, amorphous*

		Qz	Pl	Kf	Di	Cc	Gh	He	Ms	Amph	Wa	Hr	Fo	Cb	Am
Group 1	Average	17.0	8.7	3.4	36.2	4.3	2.1	0.9	3.1	0.1	0.2	0.0	0.0	0.0	24.0
	St. dev.	3.7	2.4	1.5	6.7	2.6	2.6	0.4	1.9	0.2	0.6	0.0	0.0	0.0	2.3
Group 2	Average	35.7	8.6	2.1	12.9	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.9	0.9	37.7
	St. dev.	0.6	1.8	0.8	4.1	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.4	0.7	5.1
Group 3	Average	25.4	9.3	2.9	29.9	1.8	0.9	1.0	1.5	0.2	0.5	0.0	0.0	0.0	26.6
	St. dev.	1.9	1.5	1.0	10.3	2.8	2.0	0.5	2.2	0.5	1.2	0.0	0.0	0.0	3.4
Group 4	Average	34.8	13.2	3.3	1.1	0.5	0.0	1.4	3.8	1.4	0.0	2.6	0.0	0.0	37.9
	St. dev.	1.9	1.8	1.9	1.9	1.4	0.0	1.0	3.4	1.0	0.0	2.5	0.0	0.0	3.3
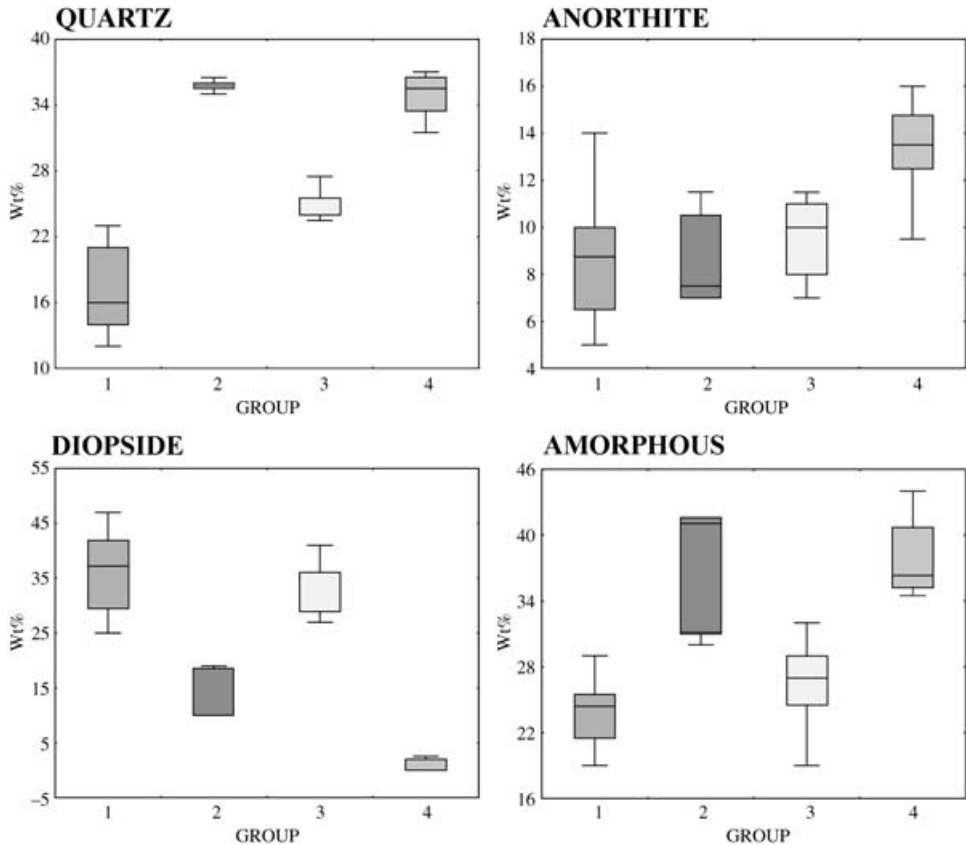
Figure 9 *Box-whisker diagrams of the mineralogical compositions of the different fabrics obtained by XRD.*
The boxes limit the first and the second quartiles, while the horizontal line represents the median. The vertical lines
contain the compositional interval.

amounts of quartz (due to the scarcity of inclusions) and amorphous phases (whose develop-
ment is inhibited by the formation of silicates). In contrast, the ceramics of Group 2 are
characterized by low percentages of diopside and a high content of both quartz (due to the
prevalence of quartz inclusions) and amorphous phase. Group 3 displays amounts of the
respective phases that could be characterized as intermediate to those of Groups 1 and 2.
Group 4 shows high quartz and amorphous phases, similar to Group 2, but differs from the
latter in the absence of diopside and the higher content of anorthite.

The presence/absence and abundance of high-temperature phases confirm the indications
from SEM concerning the temperatures reached inside the kiln, as the presence of diopside
and/or anorthite has been shown to indicate firing temperatures not lower than 950–1000°C
(Grim 1968; Mazzoleni and Pezzino 2001). The co-presence of calcite and diopside in some
samples is due to the secondary deposition of calcite during burial, either through re-precipitation
of carbonate inclusions, or through allochthonous contamination (Cau *et al.* 2002).

The combined XRD and SEM data, therefore, indicate relatively high-firing temperatures,
with some variability through a few low-fired fragments and a number of over-fired wasters,
as was expected.

Figure 10 *The ternary system SiO_2–$(CaO + MgO)$–Al_2O_3, showing the main mineral phases formed during firing. Triangles, Group 1; stars, Group 2; squares, Group 3; circles, Group 4.*

XRF ANALYSES OF MAJOR AND MINOR ELEMENTS

Major and minor elements were analysed by XRF in order to check whether the petrographic groups already formed present any differences, especial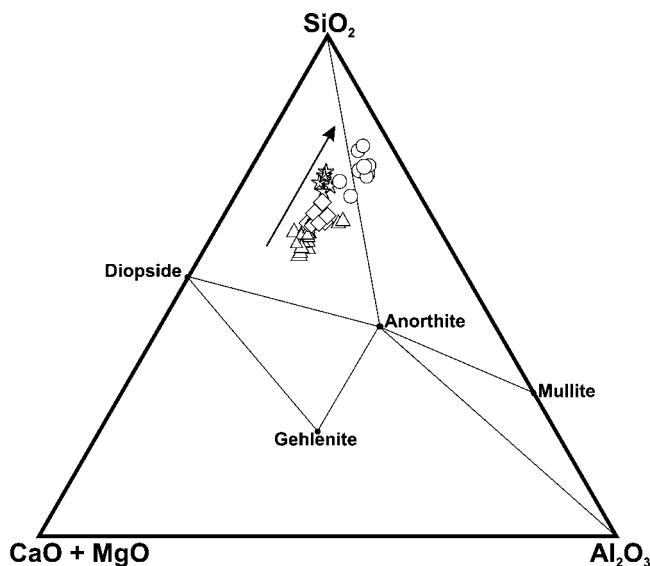ly in major elements. The data are reported in Table 4. It should be noted that while the differences among the first three petrographic groups are mainly related to the content of SiO_2, samples of the fourth group are clearly distinguished from the rest by the high contents of SiO_2, Al_2O_3 and Fe_2O_3, and low CaO and MgO. More specifically, Group 1 has lower SiO_2 and higher CaO (which accounts for the abundant presence of diopside, as well as gehlenite and anorthite). Conversely, Group 2 shows high SiO_2 (due to quartz inclusions) and relatively low percentages of CaO, which may account for the rare presence of diopside. Likewise, the high percentages of SiO_2, as well as the very low contents of CaO and MgO in the ceramics of Group 4 are related to the absence of diopside and the presence only of anorthite as a high temperature Ca-silicate.

Such observations find resonance in the vessel types in Group 4, which is dominated by cooking vessels. The thermal requirements during their use are often taken to be conducive to the choice of non-calcareous quartz-tempered clays, which aids the resistance to repeated exposure to high temperatures (Picon 1992; Agodi *et al*. 1998; Tite and Kilikoglou 2002). The chemical data also confirm the intermediate nature of Group 3 in terms of its content of SiO_2 and CaO.

The substantial difference between the cooking pots (Group 4) and those of the other three groups is illustrated by plotting the same data in the ternary system SiO_2–$(CaO + MgO)$–Al_2O_3 (Noll 1978; Heimann 1989) (Fig. 10). All the samples fall within the compositional triangle quartz–diopside–anorthite, with the exception of the Group 4 samples which, being poorer in CaO and MgO and richer of Al_2O_3, fall in the area quartz–anorthite–mullite. In the same diagram, the trend indicating the progressive increase in frequency of inclusions from Group 1 to Group 4 is demonstrated with an arrow.

Table 4   *Concentrations of major (in %) and minor (in ppm) elements determined by XRF and relative standard deviations for all the analysed samples*

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	V	Zn	Rb	Ba	Sr
Group 1															
HTR-C01	54.43	0.76	14.17	6.99	0.12	6.71	14.47	0.75	1.49	0.11	125.59	93.75	51.00	1051.77	342.16
HTR-C02	53.57	0.71	14.63	6.92	0.09	5.64	16.56	0.23	1.56	0.09	141.78	81.50	59.14	2121.78	462.85
HTR-C03	56.17	0.75	14.71	6.92	0.12	6.18	12.94	0.38	1.72	0.10	124.58	101.12	69.00	1269.26	416.29
HTR-C04	52.15	0.77	15.88	7.52	0.09	5.92	16.37	0.08	1.12	0.09	170.64	88.92	20.09	2963.57	349.57
HTR-C05	55.32	0.65	12.55	6.00	0.11	5.90	17.08	0.55	1.76	0.09	105.16	91.24	63.29	742.87	474.43
HTR-C06	51.85	0.75	14.99	7.24	0.10	6.50	17.08	0.11	1.28	0.10	146.56	73.13	22.83	2107.97	304.99
HTR-C07	50.61	0.74	15.32	7.66	0.10	8.46	15.84	0.02	1.16	0.10	172.80	85.24	23.87	2472.42	290.77
HTR-C08	54.92	0.72	13.82	6.83	0.12	6.90	13.97	0.52	2.10	0.09	126.74	95.70	77.74	626.47	390.00
HTR-C09	54.07	0.82	15.18	7.56	0.13	5.97	14.52	0.24	1.38	0.11	157.10	74.47	31.03	1936.32	298.89
HTR-C10	49.60	0.77	16.52	8.41	0.11	9.83	13.44	0.00	1.24	0.10	178.60	101.41	27.28	2270.83	250.54
HTR-C11	52.10	0.70	14.73	7.74	0.10	9.10	13.19	0.21	2.03	0.09	152.82	93.80	73.90	1199.77	296.11
HTR-C12	54.00	0.72	14.77	7.25	0.11	8.11	12.47	0.88	1.56	0.11	155.23	97.05	63.86	859.87	273.57
HTR-C13	52.32	0.73	15.64	7.67	0.11	9.04	12.17	0.26	1.97	0.09	158.98	104.77	78.78	1563.76	270.82
HTR-C14	50.87	0.79	15.37	7.90	0.10	7.97	15.71	0.08	1.11	0.10	163.25	80.98	18.64	2364.72	305.15
HTR-C15	54.89	0.99	18.22	9.19	0.16	6.97	7.77	0.25	1.43	0.13	184.98	116.53	43.86	3056.30	236.04
HTR-C16	53.92	0.68	13.90	6.79	0.11	7.08	14.89	0.69	1.83	0.10	147.74	90.96	57.71	773.15	334.22
HTR-C17	52.15	0.64	13.87	6.99	0.10	8.91	14.52	0.39	2.35	0.09	139.58	92.91	76.64	693.11	270.65
HTR-C18	54.96	1.04	18.18	9.28	0.17	6.23	7.99	0.30	1.73	0.12	166.93	112.89	58.41	2428.32	264.73
HTR-C19	52.04	0.67	14.77	7.38	0.11	9.51	12.60	0.94	1.88	0.10	150.83	104.76	94.39	383.14	271.62
HTR-C20	54.75	0.74	14.42	6.98	0.13	7.20	12.91	0.62	2.13	0.13	133.23	106.53	79.33	720.53	367.76
HTR-C21	53.04	0.72	15.10	7.38	0.09	8.55	12.29	0.43	2.32	0.09	159.45	104.13	95.72	901.69	289.00
HTR-C22	53.60	0.69	14.87	7.21	0.09	8.44	12.36	0.41	2.24	0.09	156.51	102.78	86.01	867.18	295.08
HTR-C29	51.35	0.69	14.84	7.57	0.10	9.85	13.13	1.01	1.35	0.10	153.79	101.12	52.38	631.04	219.47
Average	53.16	0.75	15.06	7.45	0.11	7.61	13.66	0.41	1.68	0.10	150.99	95.47	57.61	1478	316.29
St. dev.	1.71	0.09	1.27	0.74	0.02	1.38	2.42	0.30	0.39	0.01	19.08	11.31	24.24	834	68
Group 2															
HTR-C23	62.02	0.70	13.86	7.33	0.12	7.37	5.90	0.85	1.75	0.10	111.85	101.71	71.52	638.77	177.43
HTR-C42	60.08	0.69	13.79	7.14	0.12	6.94	8.00	0.99	2.16	0.09	118.73	101.06	95.19	327.45	209.64
HTR-C48	63.94	0.65	12.21	7.27	0.12	5.71	6.73	0.78	2.53	0.07	120.11	92.01	108.66	266.57	172.46
HTR-C50	61.81	0.68	12.69	7.28	0.11	5.92	8.24	0.71	2.49	0.07	120.92	92.34	104.62	263.82	196.28
HTR-C51	63.24	0.68	12.25	7.44	0.12	6.00	6.96	0.70	2.54	0.07	123.10	93.32	107.80	249.78	170.63
HTR-C52	61.22	0.70	12.71	7.42	0.12	6.50	8.18	0.79	2.29	0.08	129.24	92.76	97.83	308.05	190.95

Average	62.05	0.68	12.92	7.31	0.12	6.40	7.33	0.80	2.29	0.08	120.66	95.53	97.60	342	186
St. dev.	1.39	0.02	0.74	0.11	0.00	0.65	0.95	0.11	0.31	0.01	5.68	4.56	13.87	148	15

Group 3

HTR-C24	56.00	0.70	14.73	7.26	0.12	8.75	9.98	0.94	1.44	0.09	143.67	101.93	45.69	794.92	227.94
HTR-C25	57.93	0.74	14.75	7.37	0.12	6.47	9.85	0.50	2.19	0.09	140.18	94.83	92.92	768.25	322.35
HTR-C26	56.11	0.79	16.25	7.80	0.12	7.45	9.46	0.41	1.53	0.09	159.90	101.81	44.59	1815.04	251.20
HTR-C27	57.15	0.69	13.95	7.06	0.11	7.39	10.72	0.77	2.08	0.09	127.18	96.37	85.96	429.16	275.06
HTR-C28	57.01	0.74	14.56	7.65	0.14	7.32	10.77	0.29	1.43	0.10	155.61	93.95	43.13	1579.03	235.84
HTR-C30	57.32	0.72	14.22	7.20	0.12	7.30	10.29	0.67	2.07	0.09	140.55	97.77	76.30	632.76	243.06
HTR-C31	59.42	0.72	14.06	6.94	0.11	6.21	9.42	0.75	2.27	0.11	128.39	98.88	83.09	816.30	253.61
HTR-C32	56.23	0.77	15.79	8.15	0.14	7.02	8.92	0.53	2.34	0.10	140.77	120.66	119.98	444.18	345.49
HTR-C33	56.54	0.75	13.71	7.21	0.12	6.69	13.33	0.61	0.96	0.09	136.39	84.24	25.79	609.32	228.19
HTR-C34	55.58	0.74	15.31	7.98	0.13	8.98	9.09	0.38	1.68	0.13	156.27	96.26	69.80	1366.03	245.06
HTR-C35	55.95	0.80	14.39	7.81	0.12	8.16	10.00	0.82	1.83	0.12	134.04	116.70	68.73	520.15	246.17
HTR-C37	55.75	0.69	14.45	7.16	0.10	7.37	11.65	0.57	2.18	0.09	137.90	95.27	92.49	597.04	286.11
HTR-C39	55.50	0.68	14.35	7.07	0.10	7.47	11.99	0.67	2.09	0.09	137.85	96.88	94.87	585.04	304.43
HTR-C40	56.77	0.77	14.77	7.94	0.13	8.89	8.50	0.31	1.80	0.11	162.72	102.56	80.86	1484.36	217.90
Average	56.66	0.74	14.66	7.47	0.12	7.53	10.28	0.59	1.85	0.10	142.96	99.87	73.16	889	263
St. dev.	1.03	0.04	0.68	0.39	0.01	0.84	1.27	0.19	0.38	0.01	10.92	8.85	24.65	448	37

Group 4

HTR-C36	64.28	0.90	16.76	8.62	0.13	5.03	1.93	0.50	1.76	0.08	146.91	106.87	90.92	1528.52	128.90
HTR-C38	63.40	0.79	14.85	7.45	0.11	4.87	6.33	0.58	1.53	0.08	140.68	93.97	61.27	1207.78	205.02
HTR-C41	59.51	0.96	17.42	8.93	0.10	6.99	3.55	0.47	1.97	0.11	167.77	133.66	80.14	1712.20	127.21
HTR-C43	66.91	0.88	14.60	8.70	0.14	3.49	1.84	1.21	2.19	0.04	133.84	98.26	105.29	380.62	105.64
HTR-C44	63.93	0.95	17.45	9.37	0.13	3.43	1.49	1.03	2.17	0.05	144.25	96.90	104.40	417.92	100.00
HTR-C45	62.60	0.83	18.08	8.75	0.14	4.23	2.10	0.83	2.37	0.06	176.15	95.77	100.92	2038.58	191.59
HTR-C46	63.43	0.90	18.34	8.38	0.13	4.22	1.73	0.85	1.98	0.03	165.88	94.83	100.92	2002.06	137.01
HTR-C47	66.94	0.96	14.67	9.52	0.13	2.87	1.36	1.05	2.47	0.04	131.19	105.35	115.49	367.48	99.78
HTR-C49	62.22	1.21	16.51	9.52	0.16	3.16	2.51	1.84	2.78	0.09	168.61	110.42	102.81	370.51	128.61
Average	63.69	0.93	16.52	8.80	0.13	4.26	2.54	0.93	2.14	0.06	152.81	104.00	95.79	1114	136
St. dev.	2.17	0.11	1.39	0.62	0.01	1.19	1.48	0.40	0.36	0.03	15.89	11.86	15.33	692	36

TRACE ELEMENTS AND CHEMICAL VARIABILITY

Trace element analysis has been demonstrated to constitute a useful tool for studying ceramic provenance (Rice 1987; Mommsen *et al.* 1991; Mommsen 2001). Apart from four samples (HTR-C02, HTR-C35, HTR-C46 and HTR-C52), all samples were measured by NAA, the trace element compositions of which are presented in Table 5. In the same table the analytical error for each element is given, which is below 5% for the majority of them (Hein *et al.* 2002). The goal of the statistical analysis was to isolate and refine a reference group for pottery production at the Haghia Triada kiln and compare it to the one from the almost contemporary kiln of Kommos. In the statistical analysis performed here, the concentrations of As and Sb were excluded due to the very high natural variability, which is not necessarily related to clay sources, as well as those of Ta and Tb, due their relatively poor counting statistics and therefore relatively high error of determination.

As a first step, the variability within the data set has been investigated in order to ascribe its source either to the technological processes (selection of raw materials, preparation of the paste, firing conditions) or to unintentional alteration and contamination processes that take place during the successive phases of use and burial (Buxeda i Garrigós 1999).

The procedure applied here in order to assess the variability is the one used in the study of the Kommos kiln pottery (Shaw *et al.* 2001) and outlined by Buxeda i Garrigós *et al.* (2001). In order to do so, the variation matrix (Table 6) was first calculated using the nomenclature of Aitchison (1990) and Buxeda i Garrigós (1999). A relatively high value of the total variability ($v_t = 0.88$) emerged from the calculations, which does not correspond to a single production group (Buxeda i Garrigós and Kilikoglou 2003), as would be expected for material assumed to be produced at the same kiln site. However, a large part of the total variation is contributed by Na ($v_t/\tau_i = 28.5\%$), Cs ($v_t/\tau_i = 29.4\%$) and Rb ($v_t/\tau_i = 41.1\%$), while for the rest of the elements the v_t/τ_i values were much higher. It should be noted here that the lower the v_t/τ_i, the higher is the contribution of this particular element to the total variation (Buxeda i Garrigós and Kilikoglou 2003). The respective values for the rest of the elements are much higher, with U and Hf at 77% and 79% and the rest above 80%, with the highest being La (91%). The effect of Cs and Rb to group formation was tested by performing cluster analysis (S-Plus 2000) on the basis of the mean squared Euclidean inter-sample distance, using all elemental concentrations, except As, Sb, Ca, Th, Ta and Na. Prior to this, all elemental concentrations were expressed as logarithmic ratios over La, which was the element with the least variability and therefore the most probable to represent only the natural variability (Buxeda i Garrigós 1999). The dendrogram that resulted from this procedure is shown in Figure 11. The main feature here is the formation of a group at the top part of the dendrogram, which appears to be separated from the main body of the samples. The samples included in it (HTR-C07, 10, 06, 14, 04, 15, 18, 26 and 28) are the ones with the lowest Cs and Rb values, as well as K, which was not included in the cluster analysis as it was determined by XRF. However, there is no strong evidence to believe that the members of this group represent a different clay source from the main body of the samples, for several reasons: petrographically, they all belong to the main fine fabric (Group 1), which contains samples that are also stylistically the same; and, furthermore, the same phenomenon, partial leaching of alkalines in vitrified ceramics, was detected in the nearby almost contemporary kiln of Kommos (Buxeda i Garrigós *et al.* 2001). This different behaviour of Na, Rb and Cs, in combination with the fact that these three alkali elements are known to become mobile due to subsoil circulating fluids, makes them suspicious, and their variability is probably caused by conditions prevalent in the burial environment

Table 5 *Concentrations of trace elements (in ppm) determined by NAA and relative standard deviations for all the analysed samples. Ca, Na and Fe are expressed in wt%*

Sample	Sm	Lu	U	Yb	As	Sb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Tb	Sc	Rb	Fe	Ta	Co	Eu
HTR-C01	5.13	0.32	2.82	2.51	8.27	1.15	9.28	0.80	26.8	59.5	9.13	267	4.35	6.01	0.71	17.0	62.1	4.73	1.01	25.0	1.09
HTR-C03	5.43	0.34	2.85	2.70	9.73	1.17	8.74	0.62	28.3	64.1	10.00	248	4.59	5.08	1.10	17.6	77.2	4.94	1.12	27.5	1.15
HTR-C04	5.39	0.35	2.91	2.70	8.41	0.89	10.83	0.30	27.5	64.6	10.30	252	4.04	1.79	1.07	19.5	37.3	5.51	1.26	28.5	1.14
HTR-C05	4.84	0.30	2.67	2.35	7.19	0.90	11.53	0.67	25.6	57.0	8.21	239	4.12	4.61	0.67	15.0	72.5	4.22	0.97	24.3	1.03
HTR-C06	5.26	0.35	2.80	2.69	7.98	0.98	11.60	0.33	26.6	65.4	10.40	283	3.95	3.52	1.02	20.3	54.5	5.65	1.19	28.6	1.17
HTR-C07	5.17	0.38	2.79	2.83	8.84	0.88	11.55	0.26	26.1	65.4	11.50	339	4.26	2.22	0.88	23.1	42.5	6.43	1.17	32.1	1.12
HTR-C08	4.96	0.32	2.64	2.46	6.55	0.92	9.04	0.69	26.4	59.2	8.82	251	4.02	5.53	0.72	17.6	84.4	4.83	1.01	28.7	1.11
HTR-C09	5.16	0.37	3.37	2.72	9.66	1.10	9.92	0.45	25.7	62.8	10.20	257	4.43	4.19	0.71	18.8	61.3	5.38	1.13	25.3	0.99
HTR-C10	5.04	0.34	2.60	2.63	5.83	0.66	9.88	0.24	26.1	62.9	11.20	350	3.91	2.24	0.66	23.0	54.2	7.08	1.13	37.9	1.08
HTR-C11	5.26	0.37	3.04	2.75	6.08	0.80	10.27	0.43	27.9	67.6	11.50	347	3.87	6.26	0.70	23.5	104.0	6.51	1.19	38.6	1.14
HTR-C12	5.66	0.37	3.23	2.85	5.76	1.07	9.60	0.99	30.7	69.0	11.70	343	4.73	7.51	0.77	22.0	93.3	6.02	1.29	35.2	1.19
HTR-C13	5.49	0.36	3.13	2.79	5.76	0.84	9.28	0.47	29.4	68.2	10.90	341	3.93	5.81	0.78	22.8	105.0	6.11	1.02	37.6	1.14
HTR-C14	5.33	0.36	2.89	2.76	6.89	1.00	11.46	0.31	28.1	69.8	11.60	336	4.12	2.20	0.71	22.3	39.8	6.28	1.35	32.8	1.21
HTR-C15	6.26	0.37	3.18	3.03	6.43	1.01	5.00	0.52	32.3	78.9	12.40	384	4.93	2.38	0.85	22.5	55.3	7.21	1.42	38.3	1.32
HTR-C16	5.30	0.34	3.18	2.66	7.06	0.98	11.05	0.80	28.0	62.6	9.96	327	4.32	4.85	0.74	19.4	95.4	5.38	1.12	31.4	1.14
HTR-C17	4.76	0.33	2.43	2.49	5.79	0.76	10.50	0.51	26.6	58.5	9.61	321	3.49	6.73	0.63	20.1	96.4	5.47	0.91	33.0	0.98
HTR-C18	6.03	0.39	2.91	3.12	8.03	1.02	5.40	0.54	32.0	76.0	12.50	329	4.94	3.92	0.60	21.7	60.1	6.19	1.19	36.8	1.31
HTR-C19	5.00	0.35	2.58	2.69	4.29	0.82	9.58	0.91	27.9	58.6	10.30	340	3.83	7.60	0.63	21.6	94.5	5.69	0.95	36.8	1.07
HTR-C20	5.24	0.33	2.73	2.56	8.31	0.96	9.10	0.68	28.7	63.1	10.60	328	3.95	6.95	0.62	18.4	87.7	5.09	1.02	29.9	1.14
HTR-C21	5.10	0.35	2.84	2.63	6.70	0.91	8.83	0.54	27.6	59.8	9.57	345	3.79	6.78	0.57	21.0	101.0	5.57	0.97	35.1	1.07
HTR-C22	4.84	0.34	2.66	2.58	n.d.	0.83	9.03	0.52	26.6	57.1	9.80	325	3.70	6.37	0.79	20.5	93.8	5.42	0.88	33.9	1.02
HTR-C23	4.09	0.27	1.85	2.21	4.83	0.74	4.23	0.82	22.4	49.7	9.58	503	3.73	3.71	0.45	16.9	65.8	5.63	0.80	31.0	0.88
HTR-C24	4.57	0.30	1.99	2.47	n.d.	0.68	7.29	0.85	25.3	55.6	9.85	372	4.08	4.39	0.57	19.2	58.3	5.38	0.96	33.1	1.04
HTR-C25	4.85	0.34	2.63	2.52	n.d.	0.96	6.90	0.64	26.1	58.9	9.20	401	3.62	6.21	0.51	18.8	90.7	5.37	1.02	31.1	1.12
HTR-C26	4.74	0.38	2.97	2.66	5.24	0.88	6.79	0.55	26.7	58.9	10.80	407	3.89	2.54	0.67	19.5	58.1	6.21	1.02	32.7	1.10
HTR-C27	4.75	0.35	2.64	2.64	n.d.	0.85	7.63	0.77	26.1	58.6	10.10	349	4.08	6.30	0.79	19.2	95.0	5.43	1.03	32.2	1.07
HTR-C28	4.93	0.34	2.90	2.67	6.27	0.80	7.28	0.56	25.2	57.1	9.80	349	4.08	2.97	0.79	18.1	52.2	5.40	1.10	31.3	1.09
HTR-C29	5.26	0.36	2.66	2.86	6.35	0.89	10.24	0.97	28.8	62.1	10.20	330	3.89	7.58	0.77	22.5	78.1	6.01	1.12	36.6	1.18
HTR-C30	4.81	0.35	2.72	2.76	6.91	0.88	7.79	0.71	26.2	57.5	10.30	348	5.19	5.34	0.59	19.0	83.1	5.31	1.05	31.7	1.06

Table 5 *Continued*

Sample	Sm	Lu	U	Yb	As	Sb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Tb	Sc	Rb	Fe	Ta	Co	Eu
HTR-C31	4.86	0.33	2.73	2.63	6.68	0.92	6.67	0.81	25.9	59.4	8.81	363	4.13	5.49	0.60	17.9	92.3	5.09	1.09	29.7	1.13
HTR-C32	5.33	0.38	3.58	2.74	n.d.	1.24	6.84	0.62	29.3	63.8	10.70	302	4.10	8.97	0.59	19.8	115.0	5.85	1.04	34.3	1.18
HTR-C33	4.90	0.32	1.43	2.61	4.01	0.66	9.78	0.68	23.3	57.2	9.75	346	4.29	2.42	0.89	19.7	37.2	5.69	1.07	31.6	1.03
HTR-C34	5.10	0.37	2.55	2.73	5.99	0.64	6.34	0.57	27.7	58.6	9.65	325	3.85	4.97	1.08	20.7	81.9	5.76	0.77	33.4	1.09
HTR-C36	4.01	0.33	2.25	2.34	4.35	0.49	1.43	0.79	20.7	51.0	8.47	326	4.23	4.32	0.98	17.2	81.4	5.26	0.97	31.4	0.92
HTR-C37	4.77	0.35	3.09	2.63	5.46	0.82	8.25	0.67	26.3	56.0	9.64	305	3.53	6.76	0.83	20.1	101.0	5.45	1.02	31.4	1.05
HTR-C38	4.61	0.30	2.33	2.34	7.61	0.73	3.96	0.81	25.2	55.3	8.34	280	4.08	2.87	0.78	15.7	51.3	4.64	0.76	25.2	1.03
HTR-C39	4.73	0.35	3.12	2.61	5.59	0.81	8.42	0.73	26.4	55.6	9.50	294	4.07	6.72	0.67	20.0	103.0	5.39	n.d.	31.7	1.01
HTR-C40	4.50	0.32	2.33	2.50	6.24	0.51	5.25	0.57	25.8	51.9	9.31	322	3.57	3.95	0.67	18.3	74.8	5.22	1.11	31.5	0.97
HTR-C41	7.08	0.45	3.09	3.58	9.82	1.13	1.41	1.10	37.8	77.1	13.80	423	5.68	6.24	1.18	23.8	107.0	6.82	1.23	35.0	1.56
HTR-C42	5.05	0.36	2.82	2.67	4.22	0.76	6.29	0.98	27.5	60.3	10.20	420	3.86	6.91	0.74	20.5	111.0	5.66	0.89	33.5	1.07
HTR-C43	6.02	0.38	2.55	3.00	6.38	0.88	1.52	1.04	31.2	65.6	11.20	451	4.79	5.52	0.92	19.7	97.3	5.61	n.d.	29.6	1.41
HTR-C44	5.21	0.37	2.84	2.83	4.94	0.89	2.58	0.69	29.2	64.8	12.10	319	4.23	4.61	0.65	20.6	82.9	5.85	0.83	34.1	1.17
HTR-C45	5.75	0.39	2.63	2.77	9.21	0.94	1.66	1.03	29.1	62.0	11.10	400	4.35	5.30	0.77	20.1	97.1	5.89	0.94	29.0	1.21
HTR-C47	7.32	0.43	2.89	3.46	n.d.	0.96	1.21	1.06	35.1	68.7	12.30	416	5.12	5.85	0.97	23.1	111.0	6.37	1.06	34.4	1.59
HTR-C48	5.14	0.33	2.58	2.50	4.91	0.67	6.72	0.86	26.5	54.5	10.40	351	3.23	7.21	0.63	20.9	118.0	5.81	0.78	34.0	1.09
HTR-C49	6.14	0.46	2.88	3.51	5.14	0.87	1.75	1.56	32.4	68.4	10.30	261	4.99	6.20	0.84	23.1	96.9	5.80	1.39	34.1	1.38
HTR-C50	4.81	0.36	2.99	2.75	1.53	0.68	7.15	0.80	26.2	57.0	9.74	375	3.94	6.45	0.79	21.1	112.0	5.80	1.03	37.0	1.08
HTR-C51	4.26	0.35	3.04	2.41	5.02	0.61	6.50	0.74	24.1	51.6	8.22	352	3.31	6.73	0.92	19.9	120.0	5.49	0.75	32.3	0.93
Exp. error (%)	5.8	5.7	7.9	5.7	4.1	4.9	8.0	5.8	3.5	2.5	1.4	2.5	2.4	2.4	9.8	1.8	4.0	1.1	4.9	1.5	2.9

Table 6   *The variation matrix of the 48 individuals analysed by NAA*

|	Sm	Lu	U	Yb	Ca%	Na%	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe%	Co	Eu
Sm	0	0.0056	0.0225	0.0028	0.4702	0.1486	0.0017	0.0032	0.0062	0.0364	0.0086	0.1711	0.0105	0.1088	0.0122	0.0199	0.0014
Lu	0.0056	0	0.0167	0.0015	0.4652	0.1452	0.0046	0.0060	0.0074	0.0315	0.0104	0.1594	0.0058	0.0954	0.0080	0.0130	0.0057
U	0.0225	0.0167	0	0.0207	0.4092	0.1867	0.0183	0.0187	0.0253	0.0607	0.0308	0.1536	0.0244	0.0923	0.0275	0.0316	0.0241
Yb	0.0028	0.0015	0.0207	0	0.4649	0.1432	0.0026	0.0039	0.0054	0.0307	0.0069	0.1666	0.0060	0.1037	0.0079	0.0128	0.0030
Ca%	0.4702	0.4652	0.4092	0.4649	0	0.8281	0.4597	0.4292	0.4517	0.5079	0.4837	0.6162	0.4243	0.6202	0.4369	0.4227	0.4856
Na%	0.1486	0.1452	0.1867	0.1432	0.8281	0	0.1408	0.1705	0.1712	0.1445	0.1387	0.1230	0.1702	0.1109	0.1773	0.1631	0.1424
La	0.0017	0.0046	0.0183	0.0026	0.4597	0.1408	0	0.0035	0.0059	0.0331	0.0100	0.1551	0.0089	0.0960	0.0112	0.0155	0.0024
Ce	0.0032	0.0060	0.0187	0.0039	0.4292	0.1705	0.0035	0	0.0044	0.0364	0.0086	0.1832	0.0083	0.1197	0.0087	0.0157	0.0043
Th	0.0062	0.0074	0.0253	0.0054	0.4517	0.1712	0.0059	0.0044	0	0.0259	0.0122	0.1867	0.0062	0.1189	0.0047	0.0120	0.0073
Cr	0.0364	0.0315	0.0607	0.0307	0.5079	0.1445	0.0331	0.0364	0.0259	0	0.0386	0.1826	0.0267	0.1071	0.0197	0.0214	0.0337
Hf	0.0086	0.0104	0.0308	0.0069	0.4837	0.1387	0.0100	0.0086	0.0122	0.0386	0	0.1880	0.0201	0.1253	0.0186	0.0266	0.0087
Cs	0.1711	0.1594	0.1536	0.1666	0.6162	0.1230	0.1551	0.1832	0.1867	0.1826	0.1880	0	0.1676	0.0320	0.1901	0.1599	0.1721
Sc	0.0105	0.0058	0.0244	0.0060	0.4243	0.1702	0.0089	0.0083	0.0062	0.0267	0.0201	0.1676	0	0.1031	0.0027	0.0047	0.0117
Rb	0.1088	0.0954	0.0923	0.1037	0.6202	0.1109	0.0960	0.1197	0.1189	0.1071	0.1253	0.0320	0.1031	0	0.1160	0.0948	0.1086
Fe%	0.0122	0.0080	0.0275	0.0079	0.4369	0.1773	0.0112	0.0087	0.0047	0.0197	0.0186	0.1901	0.0027	0.1160	0	0.0052	0.0130
Co	0.0199	0.0130	0.0316	0.0128	0.4227	0.1631	0.0155	0.0157	0.0120	0.0214	0.0266	0.1599	0.0047	0.0948	0.0052	0	0.0198
Eu	0.0014	0.0057	0.0241	0.0030	0.4856	0.1424	0.0024	0.0043	0.0073	0.0337	0.0087	0.1721	0.0117	0.1086	0.0130	0.0198	0
τ_i	1.0295	0.9813	1.1631	0.9825	7.9755	3.1045	0.9693	1.0244	1.0514	1.3370	1.1359	3.0072	1.0013	2.1526	1.0595	1.0385	1.0438
v_i/τ_i	0.8587	0.9009	0.7601	0.8998	0.1108	0.2848	0.9121	0.8630	0.8409	0.6612	0.7782	0.2940	0.8829	0.4107	0.8344	0.8513	0.8470
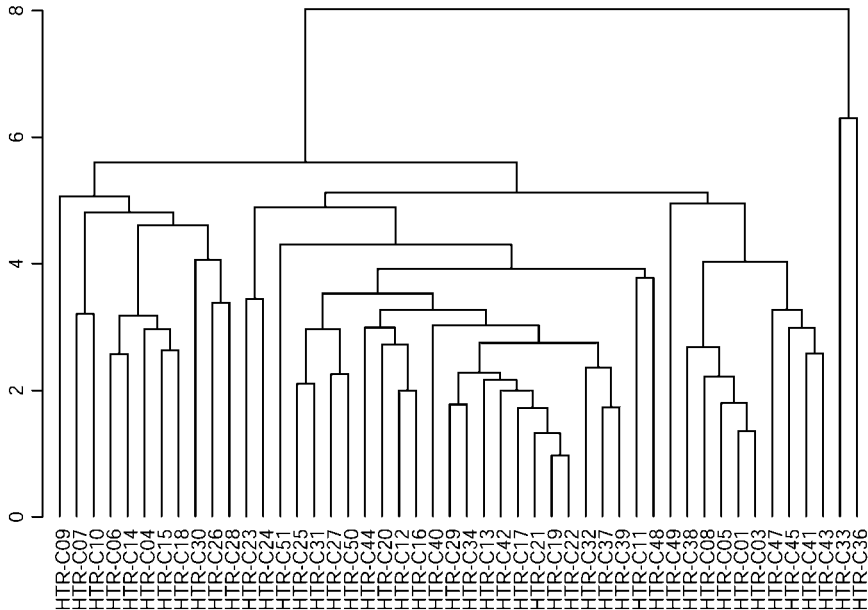
Figure 11 *A dendrogram produced by using all elements determined by NAA expressed as log-ratios over La, except for As, Sb, Ca, Tb, Ta and Na.*

(Shaw *et al*. 2001) or, to an extent, by the natural variability in the clay sources (Hein *et al*. 2004). Ca also exhibits a high contribution ($\nu_t / \tau_i = 11\%$), but in this case the variability is related to the presence of the samples belonging to the fourth group, produced with low- to non-calcareous clays. A small proportion of Ca variance is due to the secondary calcite detected in a large number of samples in variable amounts (see the Petrographic Analysis section).

A second variation matrix was thus calculated by excluding the affected elements (Na, Cs and Rb) and the non-calcareous samples (Group 4). The total variation obtained is now 0.14, which is clearly lower than before, thus indicating the use of raw materials of the same provenance for all the samples belonging to Groups 1, 2 and 3.

With the aim of isolating a reference group for the Late Minoan IB pottery production at Haghia Triada, which would represent the geochemical and technological signature, cluster analysis was performed on the neutron activation data, with the mean squared Euclidean distance used as inter-sample distance. The element concentrations were again log-ratio transformed with La as divisor, which presented the lowest variability in the data set. Due to their high variability the concentrations of the alkali elements were not used. In the dendrogram (Fig. 12), two well-distinguished clusters can be identified: the first one, with fewer samples, is represented by the non-calcareous fabric (Group 4), while the second, the main one, contains all the samples belonging to petrographic Groups 1, 2 and 3. In this specific case the reference group is represented by all the samples analysed, with the exception of those forming Group 4. In other words, it comprises the composition of the calcareous fabrics in the pottery series, from cups through jug/jars to storage jars. As is common in Minoan Crete, the cooking vessels (Group 4) are made from a quite different set of non-calcareous raw materials.

A comparison with the reference group of the nearby and almost contemporary kiln of Kommos, recently studied by Shaw *et al*. (2001), has been made in order to highlight compositional differences
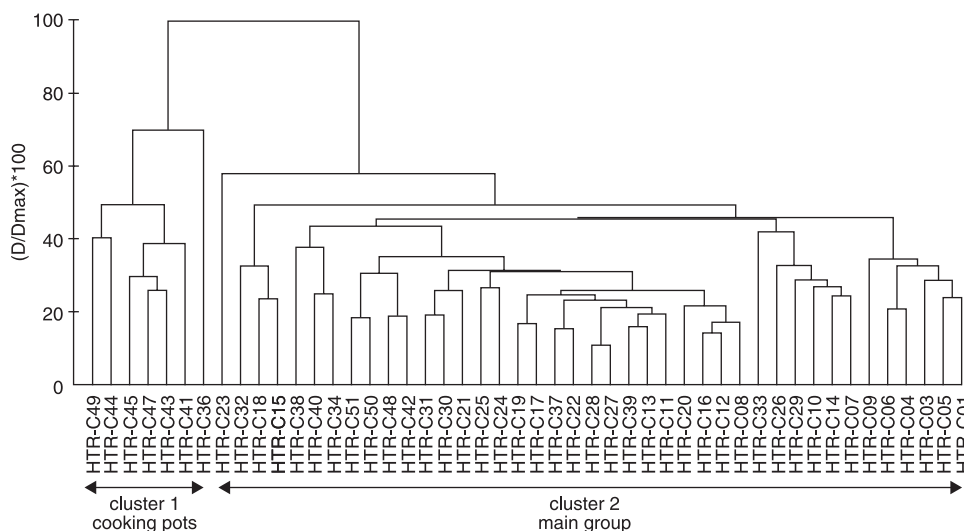
Figure 12 *A dendrogram produced by using all elements determined by NAA except for As, Sb, Tb, Ta, Na, Cs and Rb.*
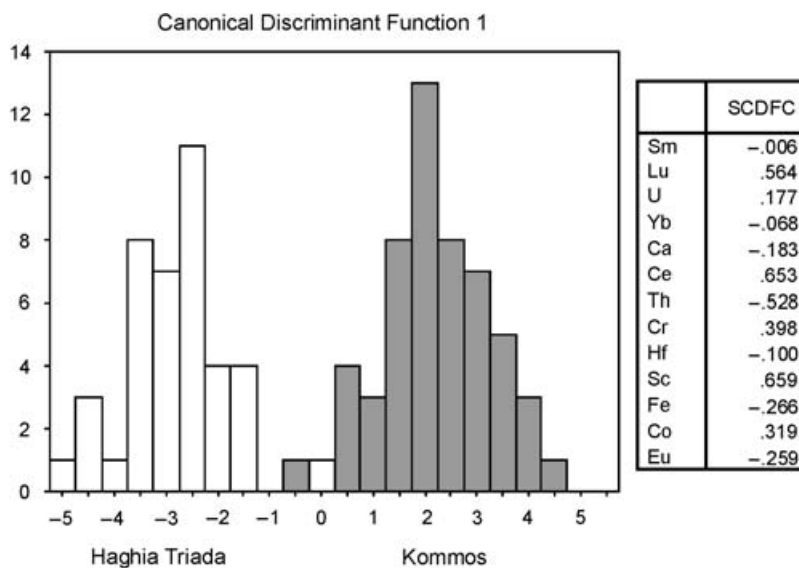

Figure 13 *The frequency histogram of canonical function 1. White rectangles refer to the Haghia Triada samples (N = 40), while the grey ones are those of the Kommos samples (N = 54). SCDFC, standardized canonical discriminant function coefficients.*

that could allow discrimination between the two production sites. It is apparent that this would be of great archaeological importance, as the two sites are close to each other in western Mesara, an area very well known for its extensive pottery production and the wide exchange of its products (Wilson and Day 1994; Day and Wilson 1998). For this reason, the reference groups of both sites were subjected to discriminant analysis by using the published data of Kommos kiln (Shaw *et al.* 2001). The separation of the two chemical groups is evident in the plot of Figure 13. Here

canonical function 1 has been used as a basis and all samples are presented in a histogram, forming two separable distributions. The one on the right comprises exclusively samples from the Kommos kiln, while the one on the left from Haghia Triada. Table 7 shows the average chemical composition of all elements determined by NAA and the respective standard deviations for the two reference groups. A substantial diversity in some element concentrations (i.e., La, Cr and Hf) is responsible for this separation, indicating the employment of different raw materials, despite the proximity of the two sites and the mineralogical similarity of base clay. This mineralogical similarity has often been taken to be responsible for the well-documented chemical similarity of the Neogene clays in central and eastern Crete (Hein *et al.* 2004).

CONCLUSIONS

With regard to production technology, the mineralogical and petrographic data indicate sophistication in the choice, manipulation and firing of a range of raw materials from the local area. As was shown at nearby Kommos (Myer and Betancourt 1990; Shaw *et al.* 2001, 118), there is clear evidence for the mixing of different clay-rich raw materials, both calcareous and low-to non-calcareous, to which sand temper was added. Beyond this, there are clear indications of the choice of different raw materials and combinations, according to the function of the vessel manufactured. The choice of calcareous clay, which fires a light colour, for the fine and table wares forms a tradition going back to the Early Bronze Age in this area. The dark-on-light decoration of the ceramics requires a light-firing body such as the one provided by these clays. The choice of raw materials extends to the temper added by potters, with quartz rich tempers forming a basic choice for the cooking vessels, which were based on non-calcareous clays.

In petrographic terms, the four different fabrics presented here display similarities with those found in the Kommos kiln (Shaw *et al.* 2001, 115–20, 139–55), indicating the use of similar resources available throughout the Mesara Plain and surrounding foothills. Indeed, so similar are their compositions that discrimination between the products of the two kilns would be very difficult. This relative homogeneity in the Mesara of available raw material, of potters' choices and therefore of their products has been recognized as a problem for some time (Shaw *et al.* 2001, 118–19, 131). Therefore, it appears that the present data can be used only for distinguishing the pottery produced in the Mesara area from those produced in other regions, and not to discriminate between the different ceramic production locations within the Mesara.

In contrast, preliminary consideration of the chemical data, especially those concerning the trace elements, allows discrimination between the products of the Haghia Triada and Kommos kilns. However, the compositional differences revealed by NAA between the ceramic products of these two kiln sites are very small, but at the same time can be detected by NAA. It is also apparent that because the base clay at both sites is of a similar type, the fine discrimination relies mainly on trace elements whose compositions are affected by aplastics (Hf and Cr). The picture of chemical similarity, whenever geologically similar base clays are involved, has been well documented for the wider area of central Crete (Hein *et al.* 2004). It has also been shown in the same work that these chemical similarities are dependent more on geology than geography.

The firing temperature estimates, obtained by different methods, confirm the high temperatures reached by these kiln types, in agreement with the determinations by Mazzoleni and Pezzino (2001) in their study of the coating materials of Phaistos and Haghia Triada Minoan kilns, and by Shaw *et al.* (2001) for the Kommos kiln pottery.

The integrated study of the ceramics found in the Late Minoan I kiln at Haghia Triada has successfully characterized its products in terms of petrography, mineralogy and chemistry.

Table 7 *The average concentrations of all elements determined by NAA and the respective standard deviations for the two reference groups of Haghia Triada and Kommos. Ca, Na and Fe are expressed in wt%*

	Sm	Lu	U	Yb	As	Sb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Tb	Sc	Rb	Fe	Ta	Co	Eu
Haghia Triada																					
Average	5.05	0.35	2.77	2.65	6.37	0.87	8.45	0.64	27.02	60.86	10.15	334	4.04	5.20	0.74	20.00	80.50	5.64	1.02	32.44	1.09
St. dev.	0.41	0.02	0.39	0.17	1.68	0.16	1.99	0.20	1.98	6.04	0.98	51	0.42	1.87	0.15	1.93	23.86	0.58	0.22	3.57	0.09
Kommos																					
Average	4.16	0.35	2.32	2.42	6.06	0.5	7.18	0.66	23.47	61.65	9.41	410	3.34	5.70	0.40	22.09	94.79	6.08	0.92	40.00	0.92
St. dev.	0.40	0.04	0.47	0.22	2.18	0.2	1.92	0.18	1.48	6.82	0.88	62	0.44	1.72	0.21	2.11	29.29	0.57	0.34	4.23	0.13

It forms a further step in the detailed study of key production locations and firing structures in the Minoan world that increases our understanding of Bronze Age ceramic technology and allows future allocation of provenance to these important classes of pottery.

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