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Vasiliki Valantou
(R.N. 1012201802011)

THESIS

Pottery analysis: A Technological Study of an Assemblage from Mycenaean Thebes.

SUPERVISING COMMITTEE:
- Prof. Nikolaos Zacharias
- Dr. Eleni Palamara

EXAMINATION COMMITTEE:
- Prof. Nikolaos Zacharias
- Dr. Eleni Palamara
- Dr. Vasilis Kilikoglou

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Abstract

Pottery fragments, as the commonest finding in archaeological excavations, can play an important role as a source of information regarding human activities and various aspects of culture. The study of pottery production in certain historic periods characterize the socio-cultural level of societies, as well as the environmental and material availabilities and constraints. On the other hand the identification of the raw material sources and production centers provides information about trade networks and cultural contacts. Furthermore, by employing archaeometric analytical techniques, valuable information can be gained about issues of manufacturing technology and the provenance of raw materials.

The city of Thebes, located in Boeotia, Greece, was an important Late Bronze Age site from Early Helladic to Late Helladic period, developed to a powerful Mycenaean centre. Systematic excavations within the city walls have revealed evidence of the Mycenaean occupation in an extensive area, now covered by the contemporary city of Thebes.

In total 73 of Early Mycenaean pottery fragments stored in the archaeological museum of Thebes, were taken in the Laboratory of Archaeometry at the University of the Peloponnese, Kalamata, and were initially observed macroscopically and microscopically through Optical Microscopy (OM). Then a detailed examination using a Scanning Electron Microscope (SEM), coupled with an Energy Dispersive System (EDS) was applied for their microstructure and chemical characterisation. In addition through a portable X-ray Fluorescence (p-XRF) detector, provenance issues were addressed. For 20 of the samples which were macroscopically characterized as coarse-grained, a thin section petrography analysis was performed for mineralogical characterization as well as provenance and technological issues.

Through this interdisciplinary research was made clear how important is the combination of various techniques for the examination of pottery. The microscopic analysis in correlation with non-destructive analytical techniques provide significant information about pottery technology and provenance. Future research in this prehistoric material will investigate more the questions raised by this initial work.

Preface

The aim of this thesis is to discuss pottery analysis through an assemblage found in a waster pit dated in 17th-16th centuries B.C. In order to address questions about their technological characteristics and possible provenance of raw materials, multiple analytical techniques have been applied in order to gain as much information as possible for the pottery samples under study.

The present study consists of 6 chapters and is accompanied by 2 appendices.

In Chapter 1, a brief introduction of the excavations in the city of Thebes and the unearthed pottery assemblages dated from Middle Helladic to Late Helladic is given. In addition pottery analysis issues concerning the *chaîne opératoire* and the variety of information gained, are highlighted.

In Chapter 2, the pottery assemblage is presented and the methodological criteria along with the laboratory equipment and the exact laboratory conditions used for the chemical analysis of the samples are analytically displayed.

In Chapter 3, the macroscopic and microscopic analysis through Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) is attested and a variety of optical characteristics is documented and explained.

In Chapter 4, the chemical analyses used for the examination of the samples is presented. The results of the SEM/EDS and p-XRF analytical techniques are elaborated through statistical tools in order to evaluate better the chemical composition.

In Chapter 5, a thin section petrography analysis of 20 selected samples is presented and discussed. Through their optical characteristics important information concerning technological procedures and provenance hypothesis are made.

In Chapter 6, a preliminary report about firing conditions is attested, as a significant technological process taking place in pottery manufacturing. The vitrification state of the analysed samples through SEM is discussed and an estimation of firing degrees is given.

In Chapter 7, the conclusions of this research are thoroughly presented. Moreover, emphasis is given in the importance of analytical techniques for a better investigation of pottery material and the significant additional information gained.

Appendix I is a detailed catalogue of the pottery samples and their optical characteristics under Optical Microscopy. In Appendix II, the chemical data from the SEM/EDS and p-XRF analysis are presented along with a catalogue of SEM images of the samples.

1 Introduction

1.1 History of the site

The city of Thebes is situated in Boeotia, central Greece. It is mainly known as a powerful state during historic times, holding a leading role in classical period and especially in the 4^{th} c. B.C. Epic poems concerning myths around its foundation by Kadmos and the subsequent descendants, well known to ancient Greeks, reveal the significance of the area also in prehistoric times. Archaeological excavations in and around the city of Thebes have revealed extensive remains of occupation during Bronze Age period, as early as Early Helladic II and III, continuing on into Middle Helladic and through Late Helladic IIIA-B focused mainly on the top hill of Kadmeia (the acropolis of Thebes) (Aravantinos, 2014).

Architectural features of a large Mycenaean palace were unearthed recently on the top of Kadmeia, as well as architectural remains of EH, MH and Early Mycenaean phases. It is obvious that the area is the main residential nucleus, characterized by continuous occupation testified by building and burial remains (Konsola, 1985; Aravantinos and Fappas, 2012). Apart the citadel of Thebes, it is well attested that in Boeotia during Bronze Age also other centers were flourished and well organized, such as Orchomenos and Eutresis, exploiting the fertile lands of the region and taking part in communications and the trade routes with other mainland and insular areas. The transition to Mycenaean era, from the 17th century BC. marks changes in social organization and artistic production, which combines the Middle Helladic tradition and the strong influence of Minoan Crete in mainland Greece (Aravantinos, 2010). It was then that the fundaments were built for the subsequent appearance of the Mycenaean palaces and the social, economic and political organization that laid.

1.2. pottery production

The transition to Mycenaean period is also characterized by a change in pottery production as well. Middle Helladic pottery is still produced but now the prevalent wares are the Minyan of yellow burnished surface and the matt-painted ware, defined as mainland polychrome ware, that is decorated with bichrome, red and black, curvilinear and figurative motifs (Touchais, 1996: 362; Mathioudaki, 2010 :110-116). This new type of pottery with light burnished surfaces and decoration dark on light, is attested throughout mainland

Greece, Peloponnese, Boeotia and Akrotiri in Thira, although differences exists referring to the type's denomination (Mathioudaki, 2010 :110-116). As for the decorative motifs in the polychrome wares, the shoulder zone of the vessels is usually bordered by vertical and horizontal bichrome bands that form symmetrical spaces and also figurative motifs such as birds appear in the body (Mathioudaki, 2010:38-39). As for the shapes there is a variety from small fine to large coarse vessels. In the city of Thebes various assemblages of this pre-Mycenaean period pottery have been excavated representing also both the above mentioned types (Konsola, 1985).

1.3. Pottery studies

Pottery is an earthen material produced by clay and water, air and fire. As those elements are fundamental also for other aspects of human sustain, pottery and ceramics in general constitute one of the first synthetic material made by humans. The importance of ceramics and especially pottery, lie in the abundance of the material found in archaeological excavations and in their good state preservation. Through pottery a variety of hypothesis can be extracted for past societies, as it concerns an everyday life material, easy to manufacture, use and reject.

Pottery manufacturing concerns a variety of steps before the final product. This process, also described as *chaîne operatoire,* involves a variety of choices and actions made by the potter and depending on the desirable properties of the final object. From the initial raw material selection, its processing through various modification methods (crushing, cleaning, sieving or levigation) in order to prepare a suitable paste, the intentional tempering with material in order to improve final product's properties, forming methods, finishing techniques, drying, firing conditions, including also use, discharge and post-depositional alterations, this step by step structure of the life of an artifact leaves its imprint and needs to be taken under consideration in the archaeological research (Orton & Hughes, 2013).

Apart from studies concerning typological categorizations of pottery material, by classifying vessels through their shape and decoration, various analytical techniques are applied in order to investigate beyond traditional aspects of studies. Through archaeometric techniques a more in depth ceramic characterization concerning textural, petrographic, mineral and chemical analysis (Rice, 1987; Orton & Hughes, 2013) can be addressed in order to provide results concerning technological and provenance issues (Hunt, 2017). In order to gain as much information as possible a multi-analytical approach is needed as each technique provides specific results for certain features and for each of the step by step manufacturing process.

2 Samples- Methodology

The assemblage under study comprises of 73 samples, found during the excavation of the Theodorou plot at the top of Kadmeia hill, in a waster pit part of a huge amount of vessels and other buried material of the 17^{th}-16^{th} centuries B.C. The pottery assemblage was probably used for feasting activities, as all the shapes belong to tableware pottery with a few storage vessels. This pit also included bone fragments of domestic animals and cut pieces of deer antlers, evidence of workshops wastes. As the pit was centrally situated above the top hill, probably was used as a discharge area of various human activities (Aravantinos, 2012; 2014). All samples were photographed and documented in situ at the Archaeological Museum of Thebes, where they are stored. Then sampling was performed in order to continue the analysis at the Laboratory of Archaeometry of the University of the Peloponnese in Kalamata. As no archaeological research concerning the typological features of the samples has been made, this analytical research concentrates mostly in material analysis matters, clay paste characterisation, identification of fabrics and chemical composition.

For the study of the optical, chemical and mineralogical characteristics of the assemblage, a multi-technique approach was applied. The ceramic body of all samples was first examined macroscopically and then by Optical Microscopy (OM), using a Fiber Optics Microscope (FOM/i-scope, Moritex) (Palamara et al., 2016). Additionally, a Munsell Soil Colour Chart of 2000 was used to determine the colour. The aim of this preliminary analysis was to make a preliminary distinction into groups according to the macroscopic and microscopic optical characteristics of the clay paste. All observations made under Optical microscopy are presented in Appendix I (colour, inclusions, firing process).

Then SEM/EDS microscopic and chemical analysis was applied in all samples in order to examine the microstructure and texture, as well as their chemical composition. The samples were analysed with a JEOL Scanning Electron Microscope (JSM-6510LV) coupled with an Energy Dispersive Spectrometer (Oxford Systems) (Palamara, et al 2016). The analytical data were obtained by INCA software. The analyses were conducted at 20 kV accelerating voltage, under a magnification of ×300 and with a count time of 180 s using Secondary electron image (SE) for the study of microstructure and texture. At least 3 measurements were taken for each sample on different areas of fresh cuts. The detailed SEM/EDS data is presented in Appendix II.

In addition p-XRF analysis was performed in all samples to determine the minor and trace elements for the provenance investigation of the samples. A portable Bruker Tracer III SD with a beam diameter of 3 mm, was used for the analysis. Data quantification was made using the S1PXRF software and a built-in calibration curve for clay (Zacharias et al., 2018). In order to optimize the analytical range, two settings were used: (1) an unfiltered low-energy excitation mode (high voltage set at 15 kV and current of 24 μA, analyses carried out under vacuum) was used for the analysis of major and minor elements with an atomic number, Z, between 11 and 29 and (2) an Al/Ti filtered (0.012 inches Al plus 0.001 inches Ti) high-energy excitation mode (high voltage set at 40 kV and current of 12 μA) was used for the analysis of minor and trace elements with an atomic number Z>29. At least 3 measurements were taken for each sample.

The precision for the SEM/EDS and the XRF device was monitored using a soil and clay standard (Soil 7). In Table 1 the values of Soil 7, as estimated by both techniques, are presented . According to these data, the precision is overall good for both techniques. The SEM/EDS values are overestimated for Al2O3 and K2O while the percentages of SiO2 are underestimated. By p-XRF the values of Na2O, Al2O3 and CaO are overestimated and the values MgO and SiO2 are underestimated.

Table 1. Values of the clay standard soil 7

		Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3
Soil 7	**XRF**	0.83	1.43	12.44	46.68	1.82	31.44	0.68	4.69
	SEM	0.38	2.40	14.03	48.02	2.14	27.69	0.62	4.72
	Real values	0.42	2.40	11.38	49.35	1.87	29.23	0.64	4.71

Finally, thin section petrography analysis was applied for further technological and provenance issues. For the petrographic analysis 20 samples were selected, which macroscopically were observed as more coarse-grained and were considered representative of most of the wares included in the assemblage. For the thin section petrography analysis a Leica DM EP polarized microscope was used assisted by a 2.5 Megapixel HD Microscope Camera Leica MC120 HD supplied with software for managing microphotographs.

For the examination of the samples with the two analytical techniques fresh fractures of the samples were prepared. The analysed areas were not polished prior to the analysis; however an effort was made to select homogeneous and representative surfaces for each sample following the macroscopical observations and the OM recorded images. For the study under polarized microscope, thin sections were prepared[1].

3 Microscopic Observations

All samples belong to open and closed shape vessels pottery types (jugs, jars, amphorae, goblets and bowls) mostly tableware, some of them bearing painted decoration. The majority of the samples (40) belongs to yellow to reddish matt-painted ware with bichrome (red and black) or monochrome (mainly black or dark brown) decoration, nine (9) samples are of yellow burnished surface with no decorative patterns, (16) samples belong mostly to large storage vessels and cups, bear no decoration and their surface is gritty with white inclusions. Five (5) samples belong to grey wares, three of them with a burnished dark grey surface and two with a lighter grey surface. One sample is of whitish surface colour.

During sampling the hardness of the samples was tested and all samples were characterized as hard, as they were difficult to break and left clean edges after cutting (Rice, 1987:355).

As the main interest of this study focuses on the pottery fabrics under examination, no further analysis concerning surface features was performed. Initially through FOM observations a distinction was made to 6 groups based on the microscopic features of the samples. The description was performed taking into account the colour of the fabric, its texture, the distribution and shape of inclusions and the form and quantity of voids, the main paste characteristics that can define a fabric (Druc, 2015). The size of inclusions here described as small, medium and large, is made according to an estimation chart that categorises the size from 0.5-1.0mm, 0.5-2.0mm and 0.5-3.0mm respectively (Orton & Hughes, 2013:Appendix I)

The first group (Group 1) that includes 39 samples of reddish yellow to yellowish red clay paste colour, is characterized by well- sorted fine silt size grain fabric, with up to 5% small-grained rounded shape inclusions and up to 5% elongated and rounded voids (Fig.1, left). The second group (Group 2) of 24 samples that consists mostly of large vessels, share with the previous one the same clay paste colour but it differentiates in the texture that is defined as moderately sorted with up to 10% distribution of inclusions of medium and large size rounded and subangular inclusions. In this category voids are abundant of rounded, elongated and vaugh shape (Fig.1, right). The third group (Group 3) comprises four

[1] The author gratefully acknowledges Dr. E. Nodarou, INSTAP, Crete for the preparation of the thin sections.

samples of strong brown paste colour, of moderately sorted medium size grain fabric. Contains various inclusions up to 10% medium to large size, of subangular and rounded shape. Voids are mostly of elongated shape with few large size vaugh shape (Fig.2, left). Another group (Group 4) with three samples is defined of dark grey colour paste. This group is characterized by a well-sorted silt size fine grain texture, with up to 5% small size inclusions and an abundance of elongated and rounded small size voids (Fig.2, right). Group five (Group 5) consists of two samples with light grey colour paste, of well sorted silt size fine grain texture, up to 5% small size inclusions and an abundance of rounded shape voids (Fig.3, left). Finally group six (Group 6) is determined by only one sample of very pale brown colour paste, with well sorted silt size grain distribution, up to 5% small size inclusions and small size rounded voids with few large vaugh shape (Fig.3, right).

Examining the firing conditions through the optical characteristics of the cross sections, samples of the second group belonging to large vessels show an incomplete oxidation with a greyish core (Fig. 2b, 6a). also samples of group five have a lighter greyish core (Fig. 3a). Microscopic images of all samples under study are provided in APPENDIX I.

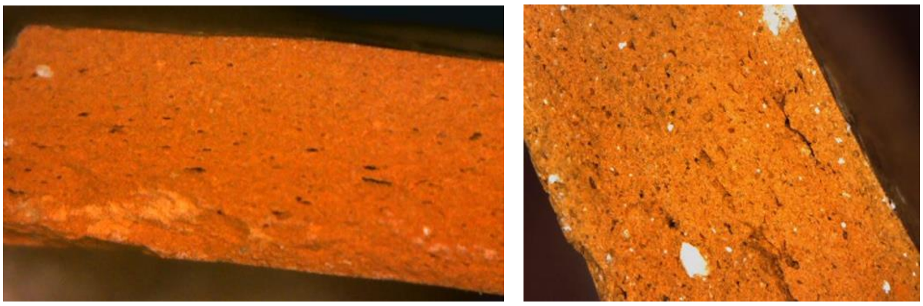


Fig. 1 FOM images (magnification x10) group fabrics. Left: Group 1;Right: Group 2

Fig. 2. FOM images (magnification x10) group fabrics. Left: Group 3;Right: Group 4

Fig. 3. FOM images (magnification x10) group fabrics. Left: Group 5;Right: Group 6

From all the above, a distinction was noted in the coarseness of the fabric between different shapes of pottery. More specifically, the smaller, thinner-wall pottery shapes showed a well-sorted, fine, silt size grain fabric, whereas the larger shapes showed a moderately sorted distribution of small and medium size inclusions (Fig. 4).

The examination of inclusions revealed a variation in the abundance of different inclusions, of white, red and black colour. In particular rounded small-grained quartz inclusions were observed, subangular calcitic small and medium grained inclusions, rounded clay pellets and black ferromagnesian silt size grains in all pottery samples. Secondary calcite also is visible in some of the samples in various forms, as needle shapes, “dogtooth” shape and grains partially filling voids (Fig. 6) (Ontiveros et al., 2002)

In addition a variety of voids are visible in all samples, mostly small size elongated and rounded shape voids are abundant in fine ware vessels showing a parallel alignment to the margins, while large vessels contain voids of rounded and vaugh shape (Fig. 5).

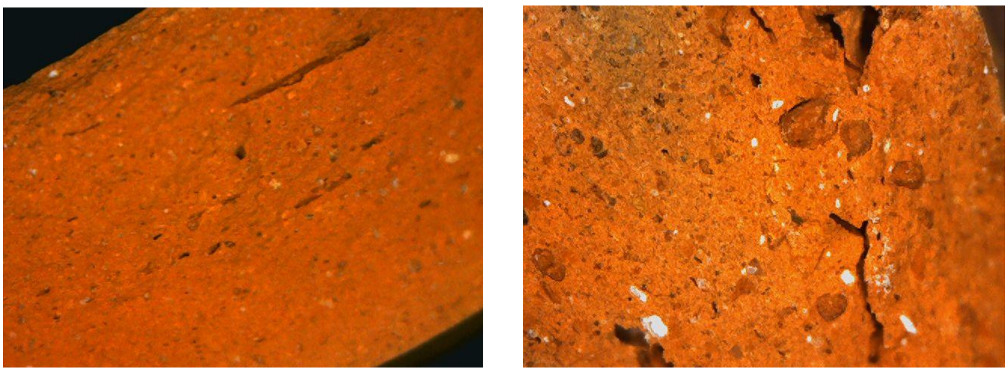


Fig. 4. FOM images (magnification x10) distribution of inclusions. Left: Group 1, well-sorted fine grain inclusions; Rigth: Group 2, moderately sorted of small and medium size inclusions

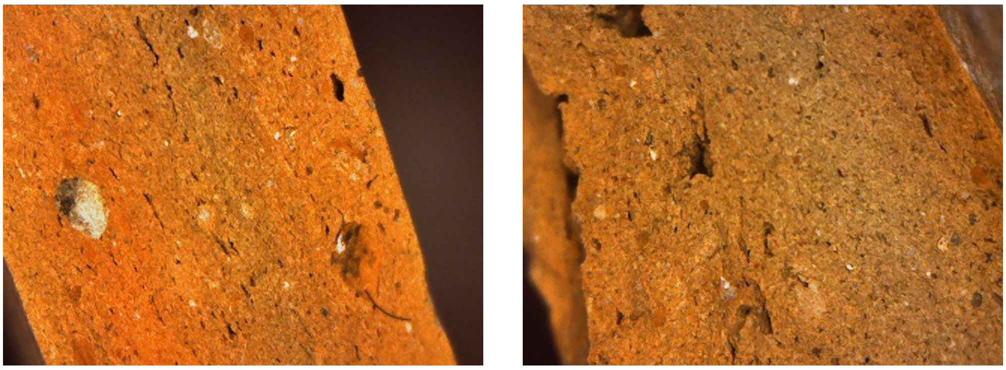


Fig. 5. FOM images (magnification x10) distribution and shape of voids. Left: parallel elongated and rounded voids; Right: rounded and vaugh shape voids

Fig. 6. FOM images (magnification x50) secondary calcite. Left: needle shape calcite, Right: “dogtooth” shape calcite

The SEM-EDS technique provides high magnification images allowing the in depth study of the micro-structure of ceramic materials , along with elemental quantification by using X-ray spectroscopy. The SEM images can also be used to estimate the firing temperature, based on the micro-structure of the fabric, as will be discussed in detail in Paragraph 6.

The microstructural characteristics of the samples were observed by using secondary electron mode in order to identify the nature of the clay paste, the range of inclusions and examine the porosity of the samples. All of the samples show similar dense microstructure and a small to moderate distribution of different inclusions, in accordance to the distinguished group fabrics observed (Fig.7). Inclusions are usually surrounded by ring voids (Fig.7 right, 8 left) and a variety of secondary calcite formations is observed. In addition an abundance of elongated, rounded and vaugh shape voids is attested showing a parallel alignement. Information of the manufacture technology can be extracted from the fact that elongated voids show a parallel orientation, which is a characteristic of wheel-throwing. In addition, the formation of secondary calcite and the vaugh shape voids is associated to the decomposition of calcium: calcium creates pores and, during cooling or through post-depositional alteration, calcitic formations are re-created in the voids (Ontiveros et al., 2002).

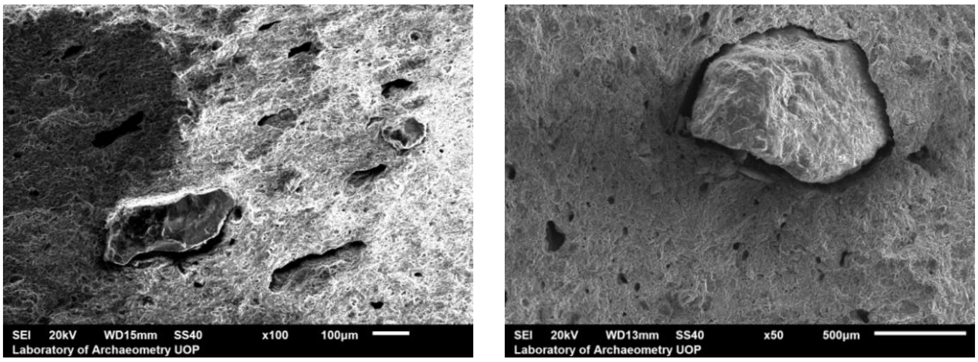


Fig. 7. Left: SEM image of quartz inclusions and parallel voids (sample AA428, magnification x100); Right: SEM image of inclusion in a ring shape void and rounded voids (sample AA435, magnification x50)

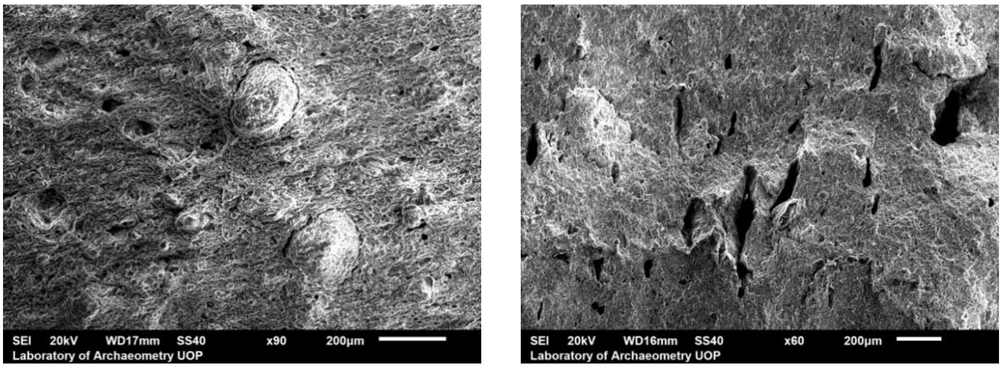


Fig. 8. Left: SEM image of inclusions in ring voids and rounded voids (sample AA498 magnification x90) ; Right: SEM image of parallel voids (sample AA756 magnification x60)

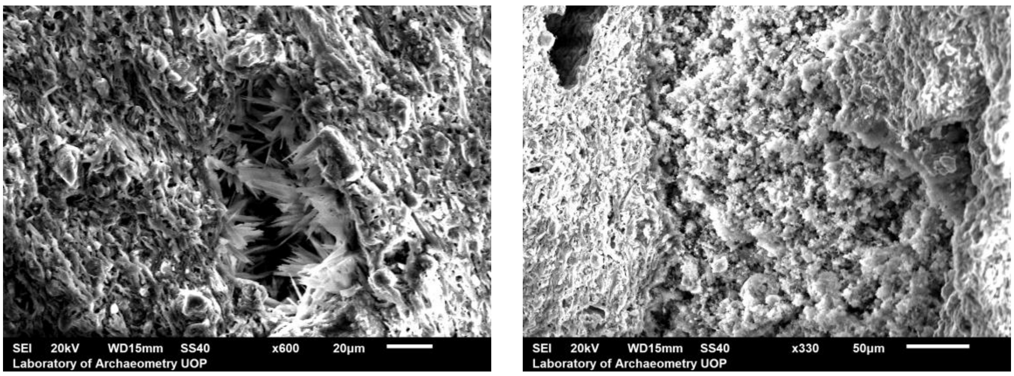


Fig. 9. Left: SEM image needle shape calcite sample (sample AA25 magnification x600) ; Right: SEM image calcite grains (sample AA29 magnification x600)

To sum up the microscopic analysis discussed above indicate six main fabrics according to their paste elements. As firing conditions tend to modify the color of clay paste and as clay preparation by the potters can also alter various optical characteristics, a chemical analysis is needed in order to better examine the differences noted between samples.

Based on the microscopic examination some significant conclusions can be drawn about the manufacture technology:

- Production using wheel-throwing is attested by the observation of parallel alignment in inclusions and voids.
- Preparation of clay mostly for fine thin-walled vessels, as they are well-sorted silt size grained, an indication of cleaning the clay from large size impurities.
- The secondary calcite observed in the samples can be associated to the manufacturing process or to post-depositional alterations.

4 Chemical Analysis

The SEM/EDS elemental analysis revealed significant variation in the amount of some of the major elements, and particularly calcium oxide (Appendix II-Table 1). An initial grouping of the samples was made based on their calcium content: (1) a low calcareous group, with CaO between 4 wt% and 10 wt%, which includes the majority of the samples, and (2) a medium calcareous group, with more than 10 wt% CaO, which comprises of only 11 samples. Within the medium calcareous group, one sample (AA603) stands out with significantly higher calcium content (16.75 wt%).

Fig.10 shows the ratio of Al_2O_3/SiO_2 versus the CaO+MgO content of the samples under study. Based on this plot, two main groups and 3 outliers can be identified. The previous microscopic distinction of the 6 fabric groups is not clear by the chemical analysis where is evident only Group 6 represented by one sample, outlier AA603and samples of Group 3 that show more than 15% CaO and are included in the second chemical Group B. As for the other groups, Group 1 and 2 are both represented in the two chemical groups as well as Group 4. From the fabric group 5 one sample AA234/54 is defined as an outlier and the other is included in chemical Group A.

- Group A consists of calcareous samples, with the exception of samples AA234/54 and AA6. This group presents relatively high chemical variation, with a CaO content between 4 and 10 wt% and an Al_2O_3/SiO_2 ratio between 0.25 and 0.32.

- Group B consists also of calcareous samples, with the exception of sample AA603. This group also presents relatively high chemical variation, with a CaO content between 10 and 14 wt% and an Al_2O_3/SiO_2 ratio varying significantly between 0.24 and 0.30. Samples belong primarily to the polychrome and the coarse wares, with only one sample belonging to the yellowish, no decoration type.
- Calcareous samples AA234/54 and AA3 are clearly differentiated from Group A due to their very high Al_2O_3/SiO_2 ratio (0.385-0.395). Sample AA234/54 belongs to fabric Group 5 with a light grey colour paste and sample AA6 belongs to Group 1 a reddish yellow fine grained paste.
- Sample AA603 is clearly differentiated from Group B, based on both the higher calcium amount and the higher Al_2O_3/SiO_2 ratio. This sample that form fabric Group 5 is unique within the assemblage.

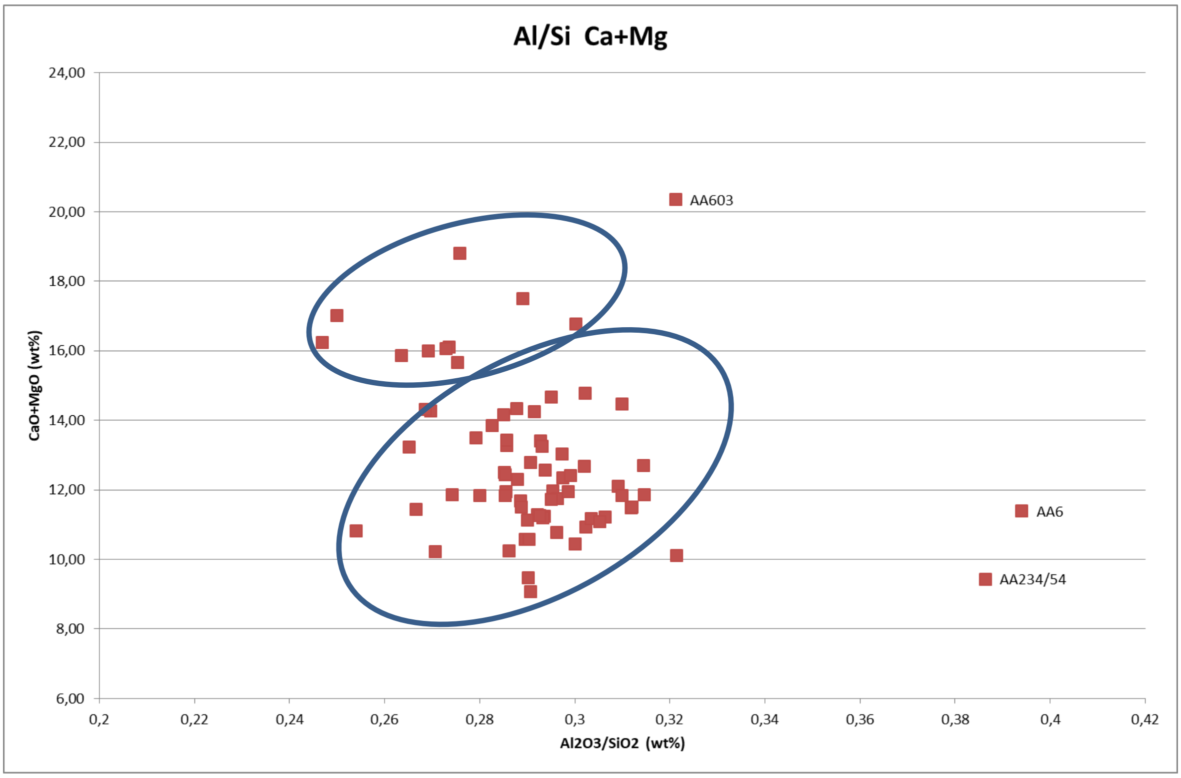


Fig. 10. Comparison of the Al_2O_3/ SiO_2 ratio versus CaO+MgO concentration of the clay bodies.

Apart from the amounts of calcium oxide that differ between samples, the amounts of MgO oxide are also showing variation. As samples from Thebes tend to show high amounts of MgO (Jones, 1986), the composition of this element could serve as an indication of provenance. A bi-plot showing the amount of CaO versus the amount of MgO was made in order to further explore this parameter (Fig. 11). From this bi-plot it can be seen that samples of both Group A and Group B present similar amounts of MgO (varying between 4 and 6 wt%). The two samples (AA234/54 and AA603) are the only ones showing lower amounts of MgO (2,6 and 3.6 wt%, respectively), further highlighting their overall chemical differentiation from the rest of the assemblage. Finally, based on the amounts of MgO, the hypothesis of a possible Theban origin is possible and should be further examined.

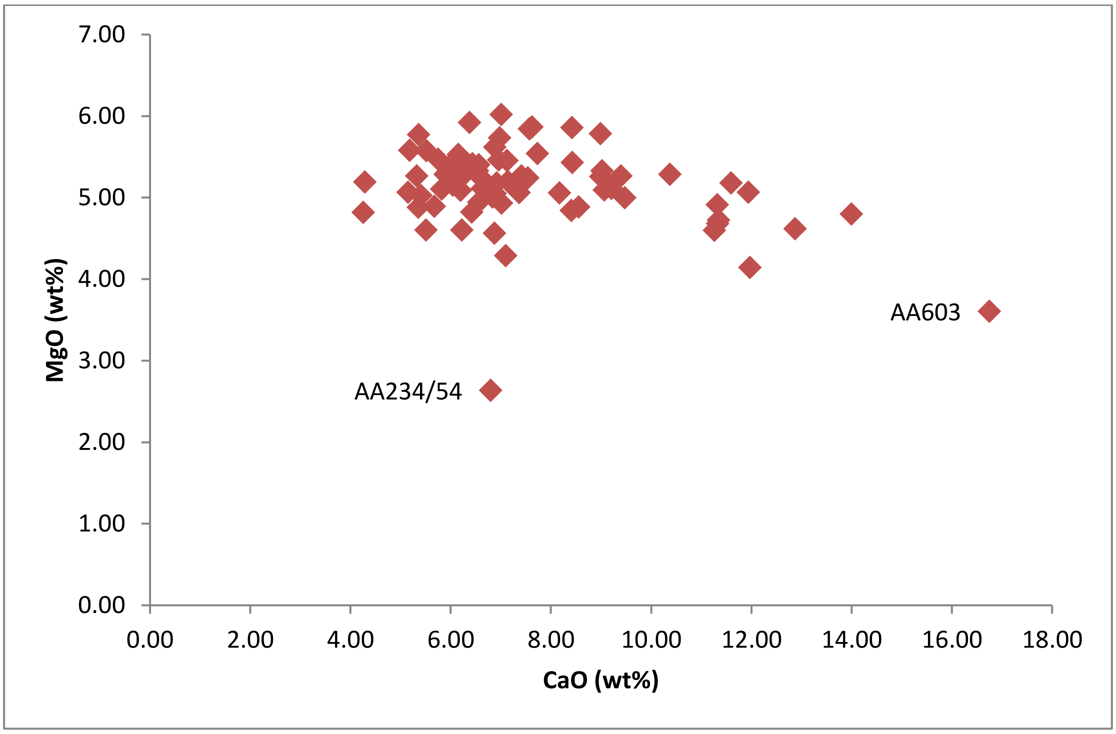


Fig. 11. Comparison of the CaO versus MgO concentration of the clay bodies.

Finally, the amount of FeO was examined, using a CaO versus FeO bi-plot (Fig. 12). Based on this plot, no clear differentiation can be seen between the samples of the assemblage, since all of the samples present a relatively high amount of FeO. The majority of the samples present a FeO content between 7 and 9 wt%, with fewer samples presenting slightly higher values (between 9 and 12 wt%). It is interesting to note that even the samples with the highest amount of CaO contain relatively high amounts of iron oxide (see for example the outlier AA603).

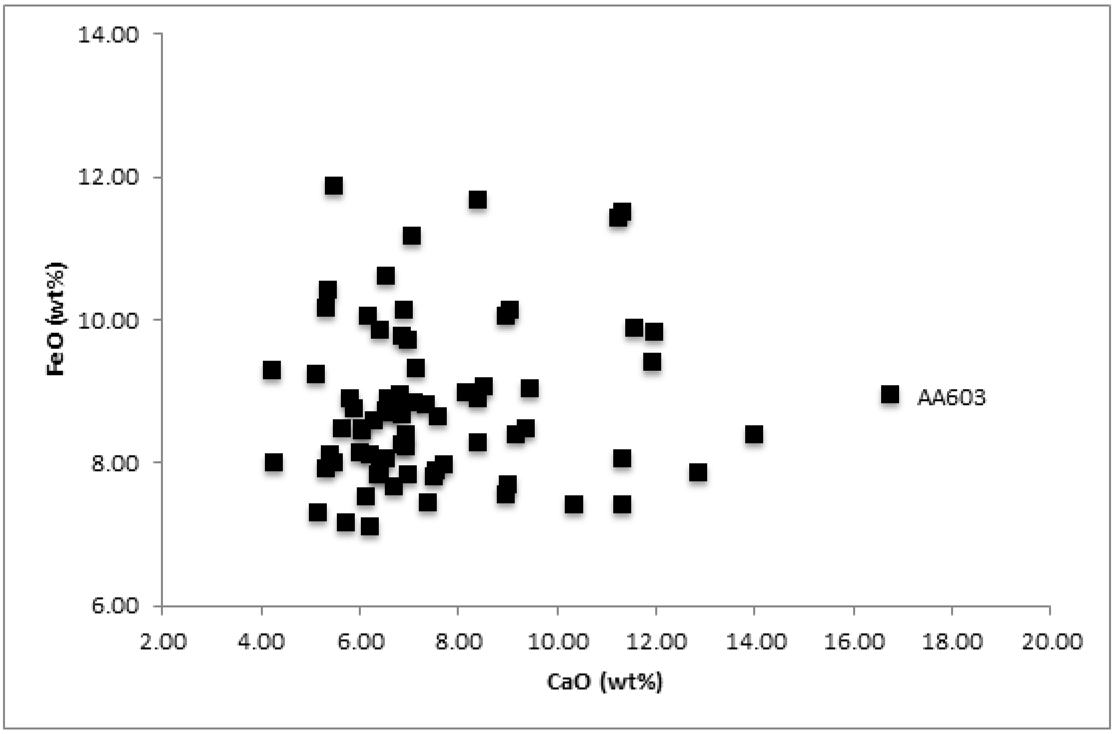


Fig. 12. Comparison of the CaO versus FeO concentration of the clay bodies.

In order to investigate further the significance of the fabric and chemical grouping of the samples and to evaluate their likely provenance issues, a more thorough examination of the minor and trace elements, estimated by p-XRF (Appendix II-Table 2), was deemed necessary. In the statistical analysis performed only minor and trace elements that showed reliable and substantial amounts were taken into consideration: Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Zr, Sb. Yttrium (Y), niobium (Nb), molybdenum (Mo), tin (Sn), thorium (Th) and uranium (U) were excluded, as they were identified in small quantities, very close to the detection limit of the device. Additionally, phosphorus (P) and sodium (S) were excluded as they are light elements with high penetration and movability in soils. Arsenic (As), lead (Pb) and barium (Ba) were excluded due to the well-documented overlapping of thein K and L bands with the bands of other common elements.

Using the commercial statistical package STATISTICA 8.0 and a combination of major elements (estimated by SEM/EDS) and the above mentioned minor and trace elements (estimated by p-XRF), Cluster Analysis was performed to investigate further the correlation between samples (Fig. 13). It should be mentioned that all data were converted to a logarithmic scale in order to avoid a skewing the analysis in favour of either the major ar the trace elements. The dendrogram does not show any clear grouping of the samples. Samples AA234/54 and AA603, the low- and medium- calcareous outlier, respectively, are shown totally separated from the rest of the group. However, sample AA6, the second low calcareous outlier, is placed well within the main group of the samples, suggesting that despite the different Al_2O_3/SiO_2 ratio, its overall chemical composition is similar to the other samples of the assemblage, and therefore likely shares the same provenance.

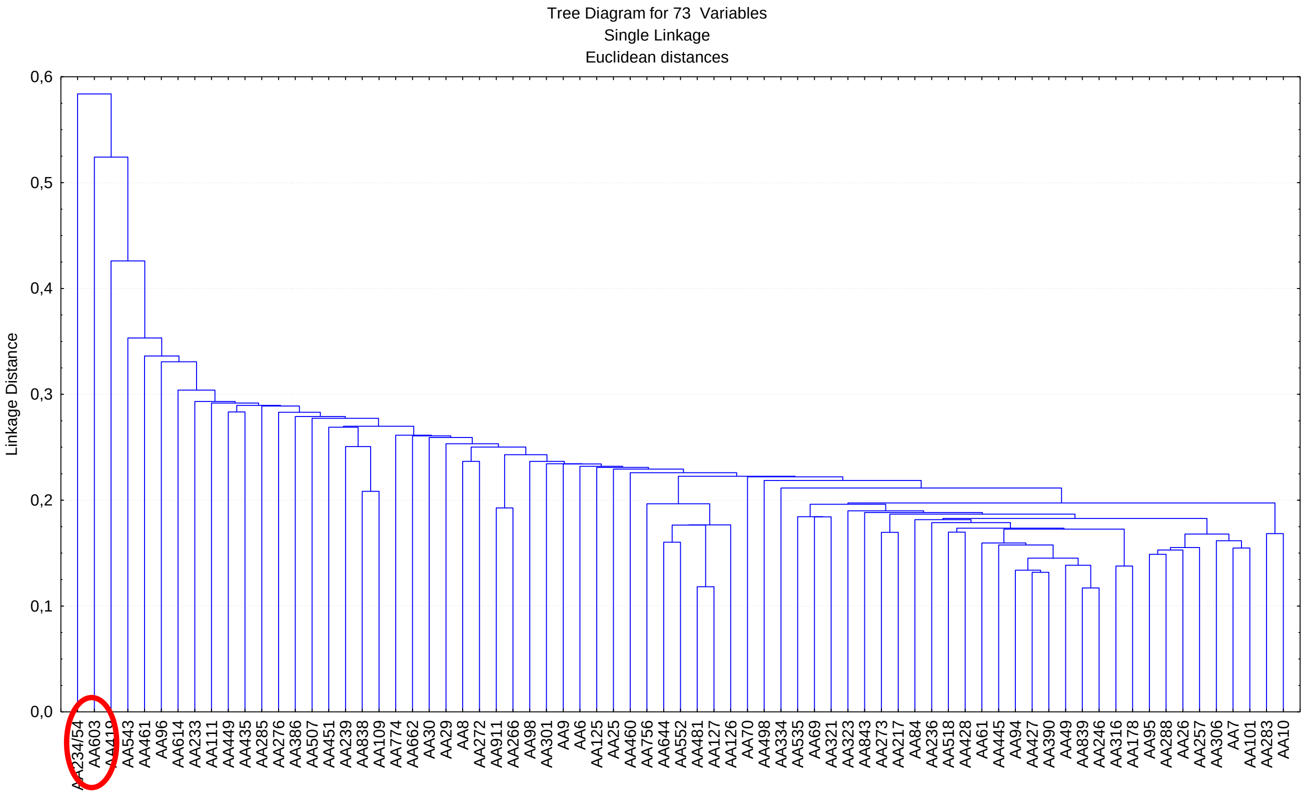


Fig. 13. Dendrogram plot based on SEM/EDS data (major and minor elements) p-XRF data (trace elements). Inset plot: PCA vectors plot.

The same major, minor and trace elements were also used to perform a Principal Components Analysis (PCA). No clear grouping can result from the PCA plot (Fig. 14). Sample AA603 seems again to be differentiated from the other samples, but the other two outliers are not clearly distinguished. Also, no difference is seen between the samples of the six initial Groups or from the chemical Group A and Group B, as defined by the composition of major elements. Based on the vectors plot of the PC analysis, it can be seen that the resulting plot relies primarily on the composition of major elements, and especially MgO and CaO. Minor and trace elements, which are more significant for the provenance analysis, seem to play a much smaller role in the plot, with the only exception of Sb.

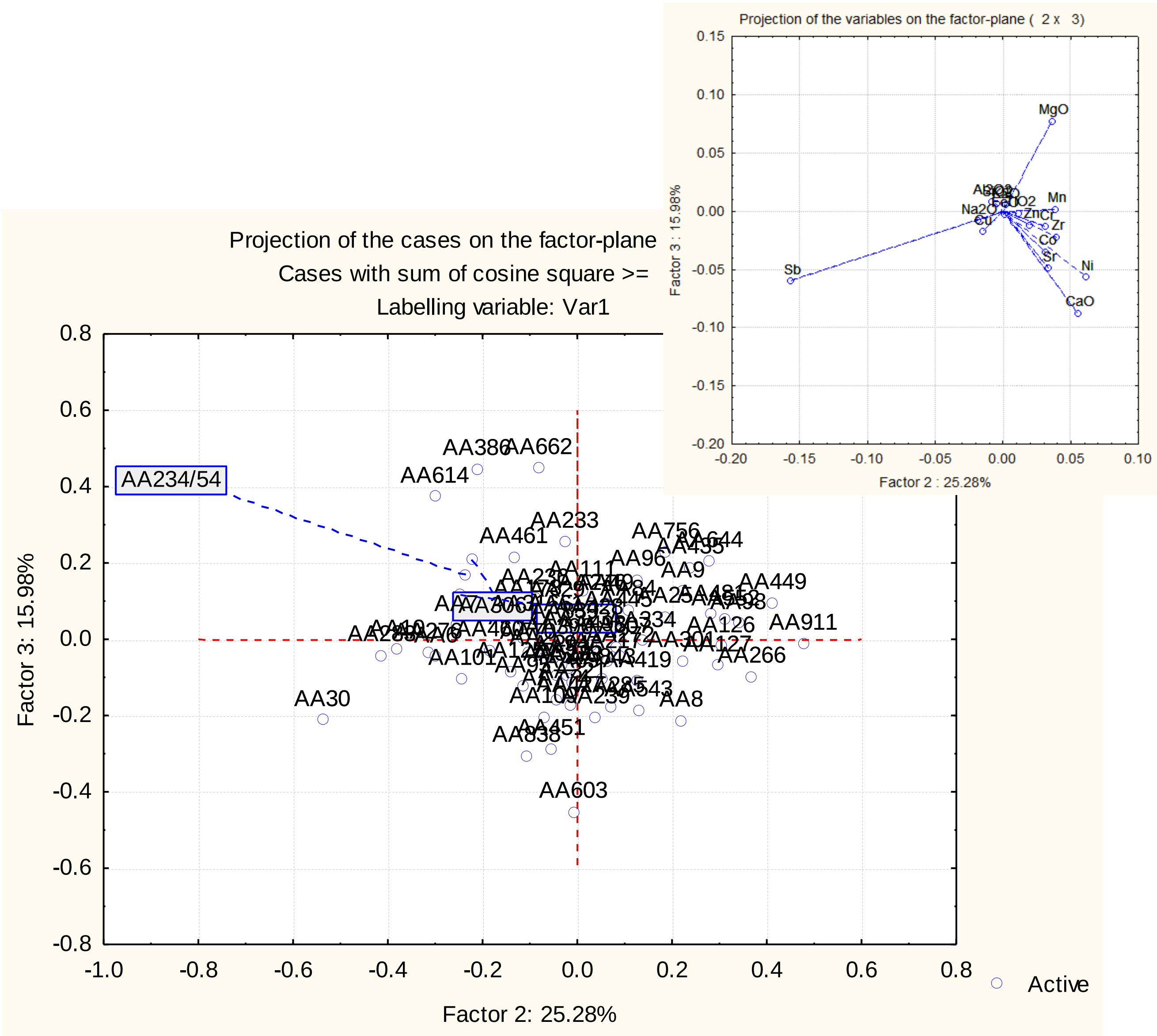


Fig. 14. PCA plot based on SEM/EDS data (major and minor elements) p-XRF data (trace elements). Inset plot: PCA vectors plot.

Finally, a separate PCA plot (Fig.15) was made using only minor and trace elements, in order to better understand the variability provided by them. These elements can be the most helpful in evaluating the likely provenance of the samples. Certain elements, such as Ni, Cr and Co, are of particular interest, since it is established that Theban clay tend to contain higher amounts (Jones, 1986).

From the resulting plot a tendency of two different groups is evident: (1) samples differentiated by their amounts of Ni, Cr, Co, and (2) another group of samples differentiated by their Cu amount. Samples AA234/54 and AA603 show a clear differentiation from the rest of the samples even without taking into account the calcium oxide amounts.

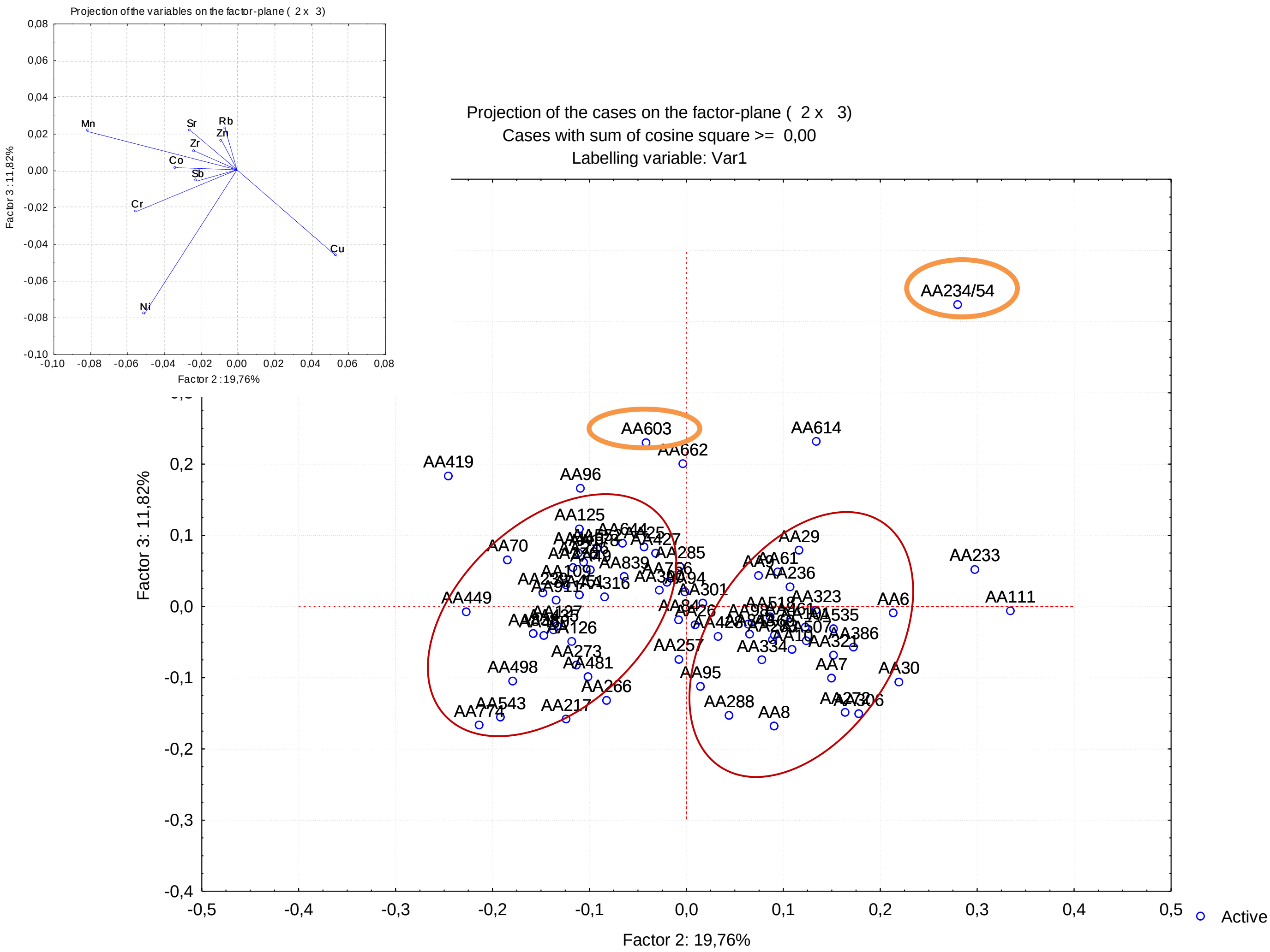


Fig. 15. PCA plot based on p-XRF data (trace elements). Inset plot: PCA vectors plot.

From the above analytical results it is evident that the two main groups are formed according to the percentages in calcium oxides. The evidence of higher percentages of MgO as well as the amounts of Ni, Cr, Co, can be related to the raw material source and must be investigated further. The two outliers (AA234/54, AA603) are totally separated both in major and minor/trace composition, indicating the probable use of a different clay source and a different production center.

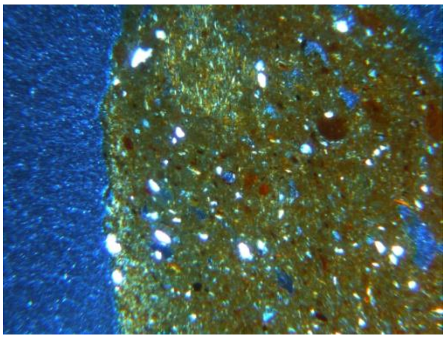
5 Thin Section Petrography Analysis

A further analysis of only 20 samples were chosen for a thin section petrography analysis, because the majority of the samples were very fine grained. The majority of the selected samples were of large storage and tableware vessels. The noted properties of all samples were very similar as all belonged to fabric Group 1 and 2 except sample AA662 of fabric Group 4 and the main results of the petrographic analysis are summarised as follows:

- *Inclusions* (Fig. 16, 18): predominant fine grain size inclusions, few medium size, bimodal distribution
  - non-plastic (Fig.16): large amount of quartz and mica (muscovite) minerals, sandstone, various type of calcite inclusions, chert, fine opaque mineral inclusions.

    Alignment of inclusions parallel to the margins of the pot.
  - plastic (Fig. 17): clay pellets of rounded shape, some surrounded by ring-shaped voids.

    Alignment of inclusions parallel to the margins of the pot.
- *Voids* (Fig. 18): planar - shaped and vughs - shaped voids, secondary calcite in voids. Alignment of planar voids parallel to the margins of the pot.
- *Matrix* (Fig. 19): buff, red, brownish colour matrix, all samples are fired in oxidizing conditions apart from sample AA662 that was in reduced conditions revealed by the dark grey colour of the matrix, no optical activity observed due to firing temperature >800-850, in all samples the exterior wall shows finer clay due to burnishing.



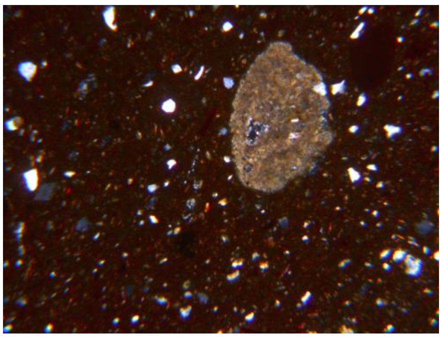


Fig. 16. Left: Sample AA427, quartz and muscovite inclusions, clay pellets, opaque mineral inclusions, sandstone Photomicrograph (x5) in XP; Right: Sample AA257, inclusion of limestone, Photomicrograph (x5) in XP.

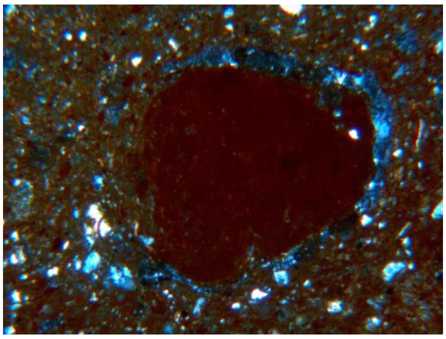


Fig. 17. Sample AA301, inclusion of clay pellet surrounded by a ring-shaped void, Photomicrograph (x10) in XP.

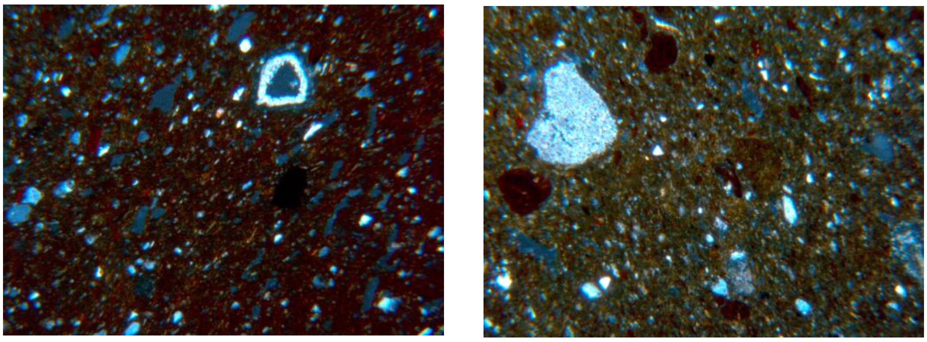


Fig. 18. Left: sample AA390, planar and vugh shaped voids, strong alignment parallel to the margins of the pot. Void filled with secondary calcite in the form of "dog-tooth" , Photomicrograph (x5) in XP; Right: Sample AA498, planar and vugh shaped voids, strong alignment parallel to the margins of the pot. Micritic calcite and clay pellets surrounded by ring-shaped voids, Photomicrograph (x10) in XP

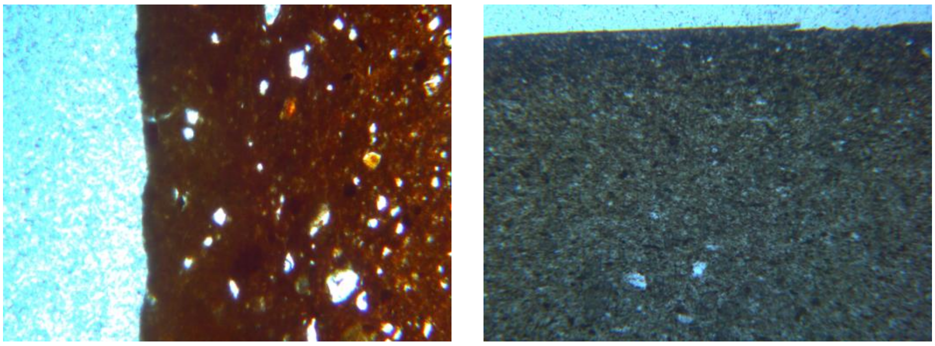


Fig. 19. Left: Sample AA8, oxidised sample, red colour in margins yellowish in core, smooth in margin due to burnishing, Photomicrograph (x5) in PPL, Right: Sample AA662, reduced sample, black margins grey core, smooth in margin due to burnishing, Photomicrograph (x5) in PPL

The fine fraction of inclusions in samples show a deliberate sieving or levitation procedure in order to remove all greater size inclusions for the production of fine more plastic clay. On the other hand, clay pellets seem to have occurred naturally in the clay matrix, based on their roundness and size.

Planar shaped voids are probably caused during drying of the pot; in fine ware pottery, rapid evaporation of water is documented to cause voids (Quinn, 2013). Vugh-shaped voids are formed probably due to thin sections preparation. The secondary calcite attested is probably caused by the decomposition of calcite within the sample filling the created voids (Ontiveros et al., 2002). Alignment observed in inclusions and voids indicates that are wheel-made. The firing conditions (oxidising-reduced) and surface treatment (burnishing) are in accordance with the pottery production in Thebes in that period (Konsola, 1985).

Firing Conditions

Previous studies have proven that it is possible to evaluate the firing procedures (fiting temperature and atmospheric conditions), based on the vitrification state of a ceramic sherd, evaluated by microscopic images, and the calcium content (Maniatis and Tite, 1981). The vitrification state of selected samples of the present study was examined via SEM, in a preliminary attempt to define firing conditions. Further analysis must be done towards this direction due to the large number of samples, and the variation in calcium content, typologies, fabric characteristics etc. The examined fresh cuts demonstrated varied degrees of vitrification, ranging from ‘Initial Vitrification” to ‘Continuous Vitrification’ (Fig. 21-23); these terms are used based on the optical descriptions provided Maniatis and Tite (1981). According to the analysis, the estimation of the firing temperature ranges from 850 to 950 ºC for all calcareous clays. Both oxidizing and reducing conditions have been noted within the assemblage, as was also indicated by the petrographic analysis.

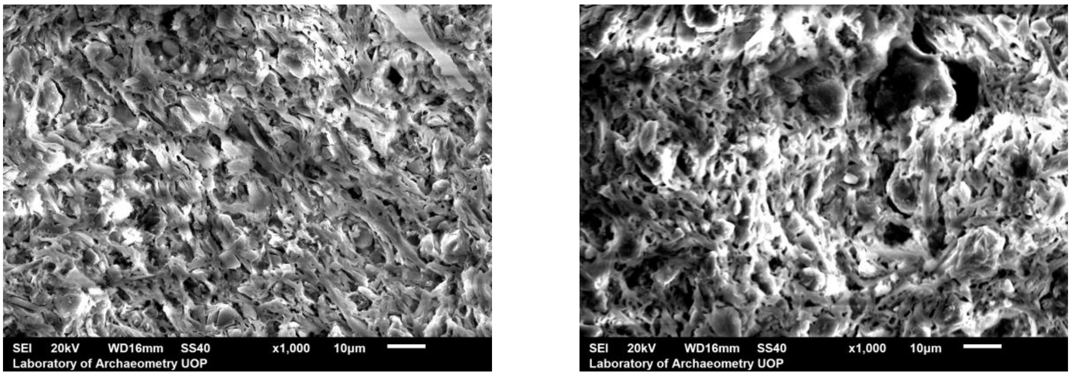


Fig. 21. Left: Sample AA236, low calcareous clay, IV, oxidizing atmosphere; Right: Sample AA445, medium calcareous clay V, oxidizing atmosphere.

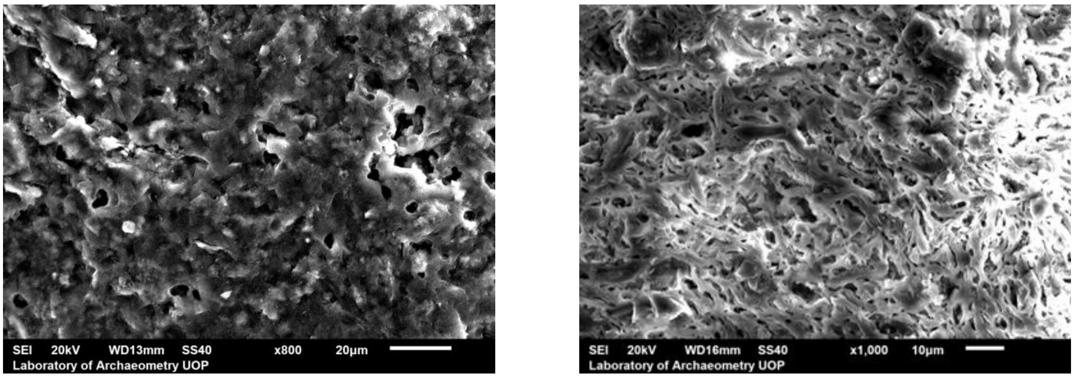


Fig. 22. Left: Sample AA435 high calcareous clay, continuous V, oxidizing atmosphere; Right: Sample AA84, high calcareous clay V, oxidizing atmosphere.

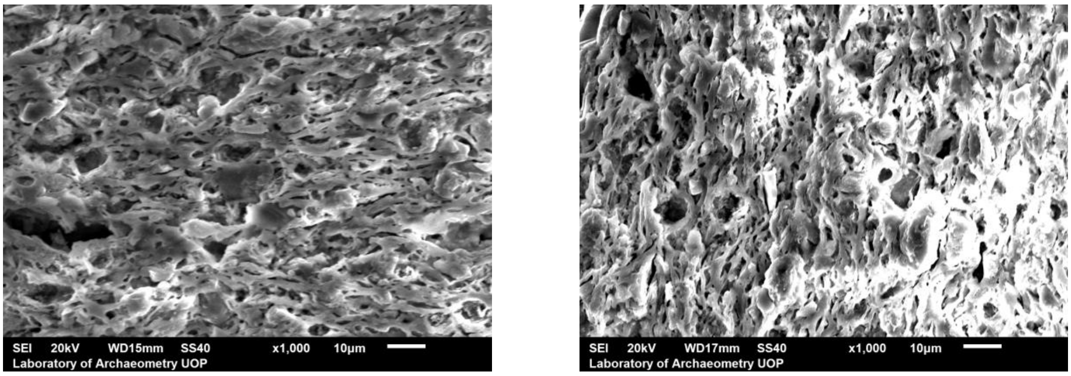


Fig. 23. Left: Sample AA644, low calcareous clay, V, reducing atmosphere; Right: Sample AA756, high calcareous clay, V, oxidizing atmosphere.

Conclusions

Through this multi-analytical approach various aspects concerning pottery production are examined. The fact that the assemblage belongs to pro-Mycenaean transitional period that is characterized by several innovations render this study necessary. Pro-Mycenaean pottery technology includes a paste prepared with refined calcareous clay and surface treatments such as burnishing and coloring. The firing techniques applied for the production of pottery was oxidation and reduction atmosphere in controlled kilns as to succeed the desirable colours and decoration patterns.

The majority of the samples are can be geologically related to the area of Thebes and only samples AA234/54 and AA603 can be connected with a different production center. The variety in raw material sources attested in studies concerning pottery samples from the area of Thebes as well as similarities in paste composition also from other sites of mainland

Greece and the island of Crete (Jones, 1986), indicate the necessity of further investigation through typological research and analytical techniques.

Through this interdisciplinary research was made clear how important is the combination of various techniques for the examination of pottery. The microscopic analysis in correlation with non-destructive analytical techniques provide significant information about pottery technology and provenance. Future research in this prehistoric material will investigate more the questions raised by this initial work.

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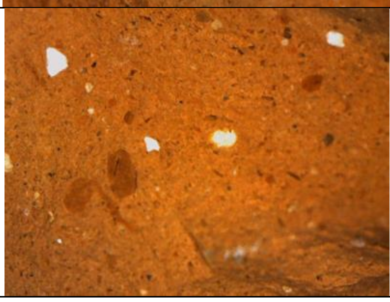
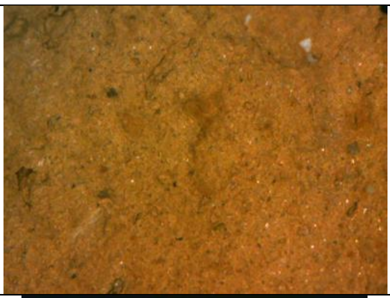
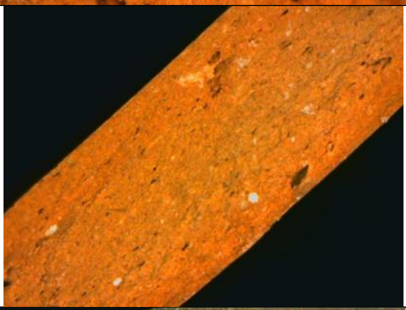
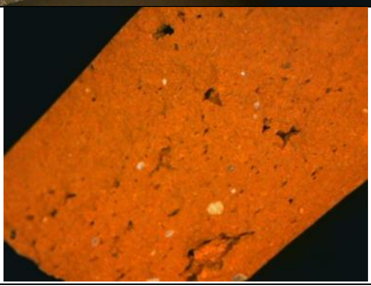
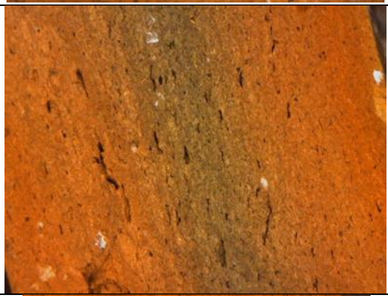
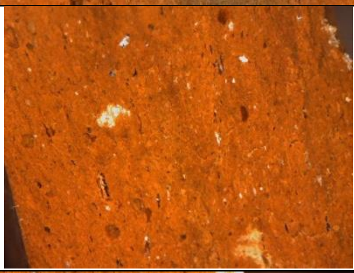
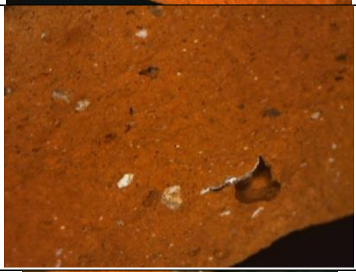
APPENDIX I

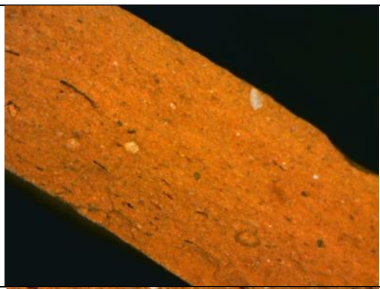
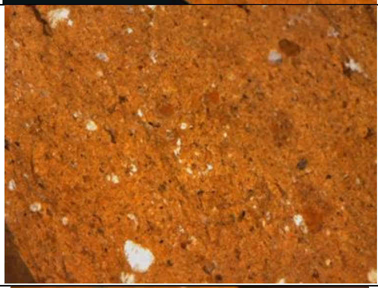
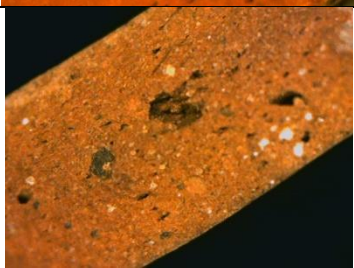
Table 1. FOM optical characteristics of the samples

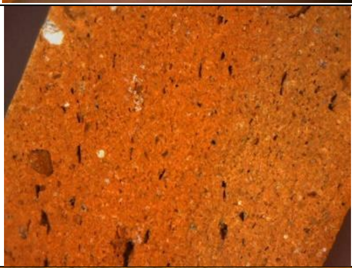
SAMPLE	PHOTO FOM	Optical characteristics
AA10		Clay paste colour: yellowish red Inclusions: small size Firing: almost complete, lighter surface margin Elongated and rounded voids
AA101		Clay paste colour: yellowish red Inclusions: small size Firing: almost complete, lighter surface margin Elongated and rounded voids
AA109		Clay paste colour: yellowish red Inclusions: small size Firing: almost complete, lighter surface margin Elongated and rounded voids
AA111		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA125		Clay paste colour: yellowish red Inclusions: small size Firing: incomplete, gray core rounded voids
AA126		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids

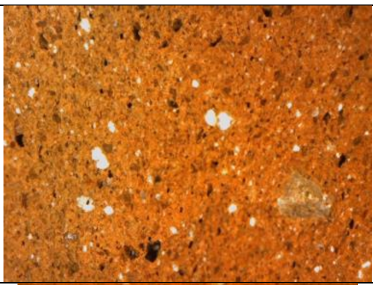
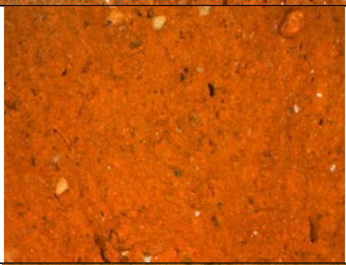
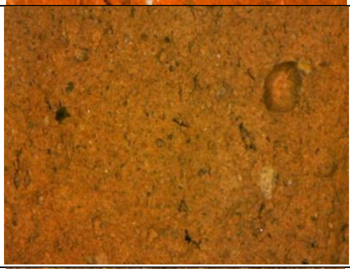
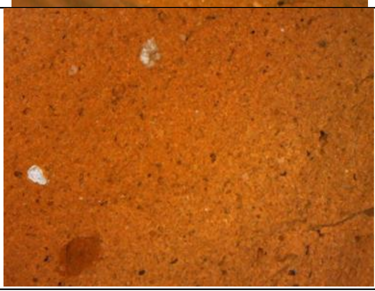
AA127		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core Elongated and rounded voids
AA178		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA217		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA233		Clay paste colour: yellowish red Inclusions: small size Firing: almost complete Elongated and rounded voids
AA234/54		Clay paste colour: light grey Inclusions: small size Firing: complete Elongated and rounded voids
AA236		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids

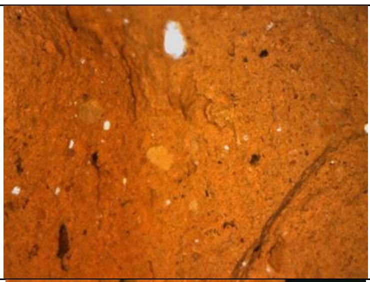
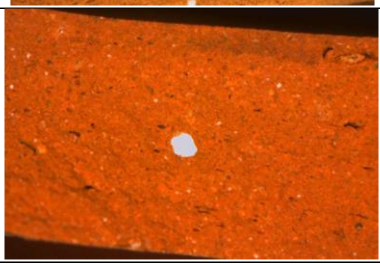
AA239		Clay paste colour: yellowish red Inclusions: small size Firing: almost complete Elongated and rounded voids
AA246		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA25		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA257		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA26		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA266		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids

AA272		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete Elongated and rounded voids
AA273		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA276		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA283		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA285		Clay paste: strong brown Inclusions: small medium size Firing: complete Elongated and rounded voids
AA288		Clay paste colour: yellowish red Inclusions: small medium size Firing: complete Elongated and rounded voids
AA29		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids

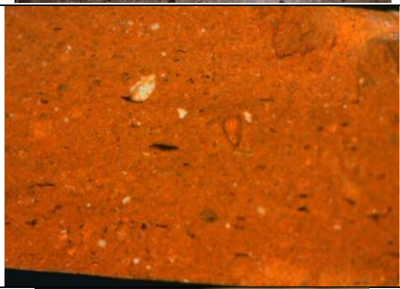
AA30		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA301		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA306		Clay paste: strong brown Inclusions: small medium size Firing: complete Elongated and rounded voids
AA316		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA321		Clay paste: strong brown Inclusions: small medium size Firing: complete Rounded and vaugh shape voids
AA323		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete Elongated and rounded voids

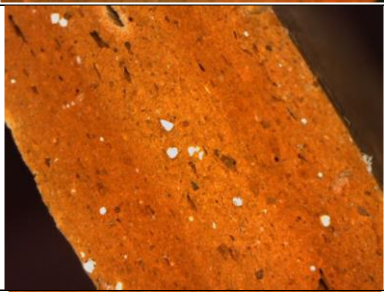
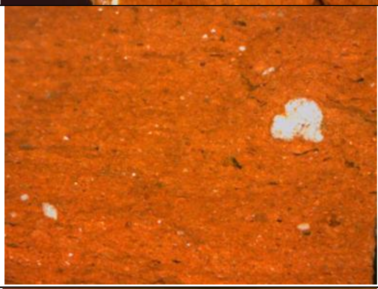
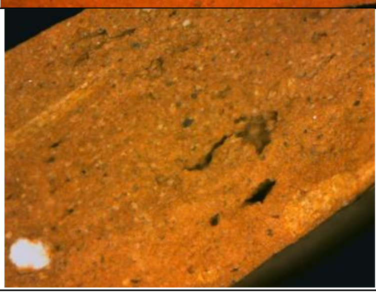
AA334		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA386		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA390		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA419		Clay paste colour: yellowish red Inclusions: small size Firing: complete Elongated and rounded voids
AA427		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA428		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids

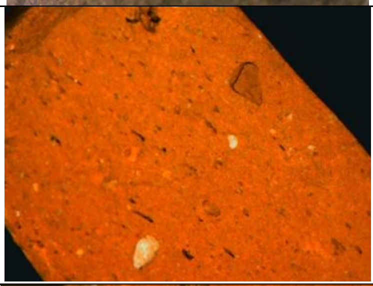
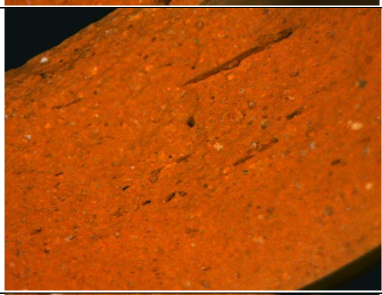
AA435		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA445		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA449		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA451		Clay paste: strong brown Inclusions: small medium size Firing: complete Elongated and rounded voids
AA460		Clay paste colour: yellowish red Inclusions: small size Firing: complete rounded voids
AA461		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids

AA481		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA49		Clay paste colour: yellowish red Inclusions: small size Firing: complete rounded voids
AA498		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA507		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA518		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA535		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids

AA543		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA552		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA6		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids
AA603		Clay paste colour: very pale brown Inclusions: small size Firing: complete Rounded and vaugh shape voids
AA61		Clay paste colour: yellowish red Inclusions: small size Firing: complete rounded voids
AA614		Clay paste colour: dark grey Inclusions: small size Firing: incomplete, lighter core rounded voids

AA644		Clay paste colour: dark grey Inclusions: small size Firing: incomplete, lighter core rounded voids
AA662		Clay paste colour: dark grey Inclusions: small size Firing: incomplete, lighter core rounded and elongated voids
AA69		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA7		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA70		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA756		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids

AA774		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded and elongated voids
AA8		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA838		Clay paste colour: yellowish red Inclusions: small and medium size Firing: incomplete, gray core rounded voids
AA839		Clay paste colour: yellowish red Inclusions: small size Firing: complete rounded voids
AA84		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids
AA843		

AA9		Clay paste colour: yellowish red Inclusions: small and medium size Firing complete rounded voids
AA911		Clay paste colour: light grey Inclusions: small and medium size Firing incomplete, light gray core rounded voids
AA94		Clay paste colour: yellowish red Inclusions: small and medium size Firing complete rounded voids
AA95		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids
AA96		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids
AA98		Clay paste colour: yellowish red Inclusions: small and medium size Firing: complete rounded voids

APPENDIX II

Table 1: Chemical composition of the ceramic bodies measured with SEM-EDS (oxide form, in wt%, normalized to 100%).

Samples		Na2O	MgO	Al2O3	SiO2	K2O	CaO	TiO2	FeO
AA10	**µ**	0.92	4.82	16.50	56.20	4.30	6.42	0.99	9.86
	s	0.10	0.11	0.58	0.63	0.11	0.63	0.06	0.48
AA101	**µ**	0.74	4.93	16.68	55.86	4.12	7.01	0.96	9.70
	s	0.12	0.43	0.18	1.31	0.21	0.49	0.19	0.60
AA109	**µ**	0.99	4.15	14.75	53.91	3.47	11.97	0.97	9.80
	s	0.08	0.20	0.26	0.46	0.10	1.51	0.18	1.02
AA111	**µ**	1.01	5.47	17.87	58.32	3.52	5.75	0.92	7.15
	s	0.12	0.36	0.55	0.24	0.06	0.29	0.11	0.42
AA125	**µ**	0.92	5.27	17.23	57.05	3.80	7.41	0.89	7.43
	s	0.03	0.22	0.59	0.41	0.13	0.45	0.11	0.31
AA126	**µ**	0.74	5.86	15.18	56.27	3.72	8.42	0.97	8.27
	s	0.09	0.26	0.24	0.27	0.15	0.16	0.08	0.17
AA127	**µ**	0.71	5.53	16.88	58.49	3.80	6.15	0.92	7.51
	s	0.07	0.07	0.32	0.71	0.15	0.14	0.07	0.39
AA178	**µ**	0.76	5.11	17.24	57.03	4.18	5.82	0.98	8.89
	s	0.09	0.25	0.55	0.68	0.16	0.06	0.07	0.58
AA217	**µ**	0.76	5.79	16.88	55.85	3.32	8.99	0.86	7.56
	s	0.21	0.33	0.29	0.42	0.10	0.36	0.10	0.08
AA233	**µ**	0.77	4.60	17.45	54.27	4.32	5.50	1.23	11.86
	s	0.07	0.09	2.36	3.05	0.22	0.45	0.12	1.32
AA234/54	**µ**	1.30	**2.64**	**20.91**	54.11	4.57	6.80	0.83	8.84
	s	0.03	0.19	0.26	1.10	0.20	0.37	0.19	0.86
AA236	**µ**	0.83	5.03	17.45	58.17	3.93	5.41	1.04	8.12
	s	0.11	0.13	0.06	0.39	0.09	0.10	0.16	0.23
AA239	**µ**	0.75	4.60	13.98	53.03	3.89	11.26	1.07	11.42
	s	0.12	0.36	0.55	1.88	0.10	1.24	0.12	0.55
AA246	**µ**	0.85	5.29	17.25	56.82	4.20	5.89	0.95	8.76
	s	0.10	0.13	0.18	0.56	0.10	0.15	0.07	0.69
AA25	**µ**	0.73	5.00	16.74	54.03	4.07	9.47	0.92	9.03
	s	0.23	0.92	1.37	2.37	0.21	4.70	0.24	0.33
AA257	**µ**	0.98	5.06	15.15	57.14	3.60	8.17	0.92	8.98
	s	0.21	0.06	0.32	1.04	0.14	0.41	0.13	0.91
AA26	**µ**	0.97	5.85	16.65	56.89	3.43	7.57	0.76	7.89
	s	0.12	0.21	0.09	0.39	0.18	0.06	0.12	0.42
AA266	**µ**	0.85	5.29	15.53	56.38	3.39	10.37	0.81	7.40
	s	0.03	0.10	0.59	3.54	0.22	5.24	0.07	0.77
AA272	**µ**	0.79	5.10	15.48	54.32	4.10	9.07	1.04	10.12
	s	0.12	0.23	0.41	0.71	0.18	0.28	0.09	0.58
AA273	**µ**	0.87	5.43	15.84	56.05	3.61	8.43	0.88	8.90
	s	0.07	0.11	0.27	0.26	0.15	0.43	0.06	0.25
AA276	**µ**	0.78	4.95	16.10	55.78	4.14	6.56	1.09	10.59
	s	0.09	0.14	0.05	0.24	0.05	0.19	0.08	0.26
AA283	**µ**	0.87	5.26	17.69	56.73	4.14	6.22	0.98	8.10
	s	0.05	0.20	0.68	0.61	0.10	0.63	0.12	0.49
AA285	**µ**	1.00	4.62	15.64	54.12	3.01	12.87	0.89	7.86
	s	0.13	0.05	0.21	0.20	0.16	0.32	0.04	0.62

AA288	**μ**	0.86	5.54	16.31	57.07	3.56	7.73	0.96	7.97
	s	0.04	0.10	0.29	0.59	0.07	0.36	0.06	0.15
AA29	**μ**	0.82	4.89	16.35	57.13	4.22	5.35	1.10	10.16
	s	0.04	0.02	0.26	0.10	0.09	0.03	0.08	0.39
AA30	**μ**	1.03	5.25	16.66	57.31	3.45	7.54	0.98	7.79
	s	0.12	0.18	0.17	0.57	0.09	0.35	0.08	0.60
AA301	**μ**	1.03	4.68	14.97	55.62	3.42	11.32	0.90	8.06
	s	0.10	0.21	0.15	1.28	0.11	1.78	0.05	0.45
AA306	**μ**	0.92	5.87	15.83	56.69	3.47	7.62	0.93	8.65
	s	0.04	0.04	0.35	0.49	0.08	0.03	0.09	0.13
AA316	**μ**	0.93	5.44	17.65	56.54	3.96	6.06	0.94	8.48
	s	0.04	0.25	0.19	0.31	0.16	0.31	0.01	0.41
AA321	**μ**	1.18	5.33	16.30	56.61	3.02	9.02	0.85	7.70
	s	0.17	0.10	0.46	0.62	0.19	0.62	0.16	0.57
AA323	**μ**	1.00	5.20	16.88	57.68	3.74	6.06	1.00	8.45
	s	0.11	0.12	0.26	0.33	0.09	0.08	0.09	0.51
AA334	**μ**	1.07	5.15	16.09	58.67	3.74	6.70	0.93	7.65
	s	0.05	0.14	0.07	0.84	0.10	0.41	0.12	0.29
AA386	**μ**	0.83	5.19	17.25	59.44	4.05	4.29	0.96	8.00
	s	0.08	0.34	0.50	0.83	0.04	0.30	0.02	0.06
AA390	**μ**	1.08	5.01	16.08	57.40	3.66	6.83	0.98	8.95
	s	0.05	0.38	0.39	0.57	0.09	0.18	0.11	0.64
AA419	**μ**	1.12	5.05	16.52	57.84	3.42	6.88	0.91	8.24
	s	0.07	0.33	0.33	0.76	0.17	0.52	0.05	0.70
AA427	**μ**	1.05	5.74	17.47	55.57	3.75	6.97	0.99	8.22
	s	0.10	0.34	0.25	0.25	0.28	0.16	0.05	0.79
AA428	**μ**	1.07	5.41	16.82	57.02	3.88	6.32	0.88	8.59
	s	0.09	0.17	0.48	0.77	0.15	0.24	0.03	0.73
AA435	**μ**	0.78	5.07	13.54	54.14	4.16	11.94	0.95	9.41
	s	0.30	0.20	0.98	2.28	0.32	2.50	0.29	0.89
AA445	**μ**	0.90	5.12	16.94	57.18	3.60	6.63	0.94	8.70
	s	0.04	0.13	1.07	0.95	0.06	0.19	0.07	0.21
AA449	**μ**	0.73	4.91	13.26	53.69	3.68	11.32	0.92	11.50
	s	0.03	0.16	0.86	0.67	0.08	2.09	0.19	0.87
AA451	μ	1.29	4.73	15.43	56.54	2.45	11.35	0.81	7.42
	s	0.08	0.40	0.58	1.29	0.17	1.00	0.09	0.18
AA460	μ	1.01	5.46	16.56	56.39	3.68	7.12	0.95	8.82
	s	0.02	0.08	0.11	0.48	0.13	0.15	0.09	0.51
AA461	μ	1.09	5.58	17.46	58.95	3.56	5.18	0.87	7.29
	s	0.03	0.05	0.11	1.40	0.11	0.55	0.10	0.76
AA481	μ	0.74	5.92	16.66	57.87	3.69	6.37	0.90	7.84
	s	0.06	0.16	0.10	0.47	0.09	0.20	0.12	0.44
AA49	μ	0.72	5.09	16.44	56.27	4.21	6.20	1.03	10.04
	s	0.05	0.10	0.30	0.43	0.08	0.29	0.08	0.14
AA498	μ	0.89	4.57	15.40	57.75	3.80	6.87	0.98	9.75
	s	0.13	0.11	0.67	2.37	0.12	0.83	0.20	1.96
AA507	μ	0.76	4.82	16.92	58.23	4.62	4.26	1.12	9.27
	s	0.02	0.08	0.39	0.95	0.25	0.22	0.05	0.88
AA518	μ	0.94	4.60	15.46	60.87	3.90	6.22	0.89	7.11
	s	0.02	0.01	0.14	0.28	0.06	0.50	0.06	0.23
AA535	μ	0.93	4.89	15.93	55.75	3.84	8.55	1.05	9.06

	s	0.10	0.24	0.47	1.01	0.13	0.22	0.02	0.54
AA543	µ	0.93	6.02	16.94	57.00	3.45	7.01	0.83	7.82
	s	0.11	0.35	0.55	0.79	0.22	0.39	0.09	0.95
AA552	µ	0.88	5.16	16.99	57.94	3.97	6.04	0.89	8.13
	s	0.13	0.18	0.54	0.52	0.10	0.39	0.13	0.83
AA6	µ	0.77	4.29	20.24	51.37	3.98	7.10	1.10	11.16
	s	0.11	0.40	3.06	3.02	0.12	0.37	0.21	1.19
AA603	µ	1.14	**3.61**	15.71	48.90	4.00	**16.75**	0.96	8.94
	s	0.01	0.22	0.31	0.98	0.24	0.61	0.05	0.84
AA61	µ	0.98	5.42	16.58	58.11	3.65	6.43	0.97	7.87
	s	0.08	0.30	0.43	0.52	0.06	0.62	0.07	0.18
AA614	µ	1.30	5.27	16.95	58.51	3.78	5.32	0.97	7.90
	s	0.06	0.05	0.09	0.15	0.03	0.11	0.11	0.11
AA644	µ	0.80	5.33	17.63	56.04	3.94	6.54	0.99	8.72
	s	0.05	0.13	0.14	0.81	0.04	0.17	0.12	0.38
AA662	µ	1.22	5.78	16.22	55.90	4.06	5.36	1.08	10.41
	s	0.10	0.16	0.25	1.69	0.25	0.34	0.16	1.41
AA69	µ	1.09	5.12	15.16	56.45	3.61	9.20	0.97	8.40
	s	0.21	0.19	0.31	0.82	0.24	0.85	0.02	0.51
AA7	µ	0.81	5.06	16.20	56.77	4.04	7.37	0.93	8.81
	s	0.04	0.18	0.43	0.77	0.14	0.63	0.07	0.44
AA70	µ	0.96	5.07	15.88	58.67	4.06	5.15	0.99	9.23
	s	0.06	0.19	0.28	0.10	0.08	0.08	0.07	0.61
AA756	µ	0.87	5.58	17.64	57.81	3.70	5.51	0.90	8.01
	s	0.15	0.65	0.86	0.40	0.31	0.77	0.04	0.11
AA774	µ	0.63	5.26	15.85	54.36	3.84	8.99	1.03	10.04
	s	0.10	0.14	0.47	0.68	0.15	0.68	0.13	1.03
AA8	µ	0.61	5.18	15.74	52.44	3.49	11.59	1.06	9.88
	s	0.09	0.28	0.04	0.44	0.11	0.23	0.13	0.67
AA838	µ	0.85	4.80	14.59	52.89	3.66	14.00	0.83	8.38
	s	0.07	0.21	0.71	1.04	0.17	0.54	0.08	0.57
AA839	µ	0.81	5.26	17.32	55.88	4.32	6.58	0.94	8.88
	s	0.11	0.20	0.36	0.63	0.13	0.31	0.09	0.64
AA84	µ	0.88	5.18	16.90	54.67	4.27	6.92	1.06	10.11
	s	0.10	0.10	0.53	1.54	0.10	0.16	0.15	1.66
AA843	µ	1.00	4.84	15.71	53.60	3.87	8.40	0.92	11.65
	s	0.13	0.39	0.71	3.34	0.52	0.88	0.13	3.19
AA9	µ	0.75	5.20	16.57	55.70	4.19	7.14	1.14	9.32
	s	0.08	0.06	0.08	0.83	0.06	0.49	0.07	0.52
AA911	µ	0.83	5.27	16.39	55.54	3.27	9.40	0.83	8.48
	s	0.02	0.11	0.21	0.43	0.09	0.46	0.07	0.25
AA94	µ	0.91	5.41	16.96	57.42	3.81	6.56	0.89	8.04
	s	0.05	0.09	0.12	0.82	0.20	0.22	0.05	0.60
AA95	µ	0.98	5.62	16.30	57.16	3.56	6.88	0.82	8.67
	s	0.03	0.44	0.18	1.02	0.31	0.57	0.13	0.70
AA96	µ	0.96	4.90	16.90	58.21	3.95	5.67	0.95	8.48
	s	0.07	0.17	0.48	0.78	0.23	0.20	0.03	0.99
AA98	µ	0.81	5.46	17.00	56.82	3.68	6.95	0.91	8.38
	s	0.07	0.18	0.52	0.28	0.09	0.35	0.04	0.23

Table 2: Minor and trace elements composition of the ceramic bodies measured with p-XRF (elemental form, in ppm).

Sample			Cr	Mn	Co	Ni	Cu	Zn	Rb	Sr	Zr	Sb
AA10		m	110.50	390.00	26.50	253.50	136.50	84.00	108.50	98.00	104.50	38.50
		s	27.58	155.56	2.12	30.41	6.36	5.66	7.78	16.97	13.44	14.85
AA101		m	109.50	357.50	26.50	264.50	122.50	88.50	120.50	102.50	112.50	26.00
		s	0.71	36.06	3.54	31.82	9.19	0.71	12.02	9.19	14.85	16.97
AA109		m	118.50	541.50	27.00	301.50	86.00	92.50	99.00	128.00	125.50	32.00
	0	s	6.36	0.71	0.00	2.12	2.83	7.78	2.83	1.41	0.71	2.83
AA111		m	84.50	256.50	24.50	257.50	130.00	89.00	117.50	112.50	115.50	10.50
	0	s	12.02	21.92	0.71	4.95	15.56	1.41	0.71	0.71	2.12	2.12
AA125		m	129.50	502.50	26.50	251.50	75.00	94.00	122.00	115.00	119.50	34.50
	0	s	6.36	9.19	0.71	16.26	7.07	1.41	4.24	8.49	9.19	17.68
AA126		m	139.50	462.00	32.50	407.00	89.00	104.00	124.50	127.00	130.50	12.50
	0	s	6.36	9.90	0.71	2.83	8.49	7.07	3.54	8.49	6.36	4.95
AA127		m	144.50	482.50	33.00	394.00	92.00	123.50	128.00	126.50	139.00	12.00
	0	s	4.95	9.19	1.41	7.07	8.49	2.12	4.24	0.71	7.07	2.83
AA178		m	122.00	480.50	30.50	277.00	92.00	113.00	135.50	124.00	128.50	31.50
		s	2.83	20.51	0.71	1.41	12.73	1.41	0.71	7.07	4.95	4.95
AA217		m	133.50	473.50	31.50	448.50	109.00	106.50	110.00	113.00	118.00	25.00
		s	6.36	7.78	0.71	19.09	5.66	3.54	5.66	11.31	16.97	22.63
AA233		m	85.50	312.50	25.50	227.00	126.00	93.00	118.00	100.00	118.00	10.50
		s	7.78	23.33	0.71	18.38	0.00	5.66	2.83	4.24	2.83	10.61
AA234/54		m	69.50	422.50	26.50	**105.00**	96.00	129.50	143.50	90.00	122.50	19.00
		s	4.95	28.99	0.71	4.24	4.24	9.19	4.95	2.83	3.54	11.31
AA236		m	105.50	365.00	30.00	261.00	113.50	92.50	133.50	108.50	125.50	18.50
		s	0.71	12.73	0.00	2.83	0.71	3.54	2.12	0.71	4.95	0.71
AA239		m	133.50	485.50	29.50	339.50	81.00	98.50	120.50	132.00	135.00	23.50
		s	4.95	19.09	0.71	31.82	5.66	16.26	3.54	4.24	7.07	2.12
AA246		m	125.50	496.00	31.50	301.50	91.00	112.50	142.00	122.00	135.00	22.00
		s	12.02	43.84	3.54	14.85	9.90	4.95	15.56	12.73	15.56	14.14
AA25		m	131.50	476.50	28.50	272.00	91.00	102.00	123.00	133.00	127.50	14.50
		s	6.36	7.78	0.71	15.56	5.66	9.90	1.41	7.07	2.12	3.54
AA257		m	130.00	426.00	26.00	316.50	120.00	100.50	106.00	116.50	125.00	27.50
		s	9.90	84.85	0.00	7.78	1.41	12.02	1.41	0.71	4.24	4.95
AA26		m	125.00	485.50	27.50	275.00	129.50	107.50	109.00	111.00	115.50	25.00
		s	1.41	71.42	0.71	14.14	14.85	6.36	11.31	7.07	14.85	11.31
AA266		m	132.50	473.50	32.00	475.00	98.00	103.00	108.00	110.50	126.50	9.00
		s	0.71	33.23	2.83	32.53	7.07	1.41	2.83	7.78	7.78	1.41
AA272		m	108.50	294.00	33.50	361.00	149.00	84.00	120.00	125.00	124.00	12.50
		s	7.78	9.90	7.78	4.24	21.21	26.87	5.66	12.73	16.97	17.68

AA273	m	127.00	424.50	32.00	395.00	97.00	103.50	118.00	127.50	128.00	28.50
	s	14.14	50.20	0.00	0.00	1.41	3.54	0.00	0.71	1.41	0.71
AA276	m	121.50	494.00	42.00	254.50	86.00	98.50	122.50	94.00	100.50	47.50
	s	0.71	0.00	21.21	30.41	63.64	12.02	19.09	8.49	6.36	13.44
AA283	m	100.50	367.50	27.00	273.00	119.00	98.50	109.00	101.00	99.00	45.50
	S	13.44	82.73	1.41	8.49	7.07	2.12	9.90	15.56	14.14	16.26
AA285	m	100.50	431.50	32.00	293.50	96.50	136.50	102.00	119.50	144.50	18.50
	s	10.61	95.46	8.49	24.75	13.44	38.89	9.90	6.36	6.36	0.71
AA288	m	117.00	410.50	27.50	355.00	132.50	103.00	100.00	99.50	99.00	27.50
	s	28.28	166.17	0.71	35.36	14.85	4.24	5.66	20.51	14.14	20.51
AA29	m	98.50	349.50	37.50	246.00	98.00	118.50	109.50	112.00	104.50	14.50
	s	9.19	62.93	16.26	4.24	36.77	27.58	24.75	7.07	24.75	3.54
AA30	m	83.50	270.50	25.00	275.50	141.00	82.00	105.50	104.50	110.50	56.00
	s	10.61	28.99	1.41	19.09	8.49	5.66	0.71	6.36	7.78	56.57
AA301	m	124.00	392.50	27.00	311.00	91.50	91.00	101.50	134.00	127.50	13.00
	s	7.07	21.92	0.00	7.07	7.78	7.07	2.12	4.24	4.95	1.41
AA306	m	93.00	290.50	26.00	339.50	133.00	91.00	98.00	106.00	107.00	29.50
	s	15.56	43.13	1.41	27.58	12.73	5.66	4.24	7.07	12.73	7.78
AA316	m	114.50	503.50	32.00	307.50	106.00	105.00	135.50	121.50	122.00	30.50
	s	12.02	12.02	1.41	41.72	1.41	4.24	9.19	0.71	0.00	0.71
AA321	m	103.00	320.50	25.50	315.50	118.50	89.00	102.50	113.50	135.50	15.00
	s	7.07	9.19	0.71	4.95	4.95	4.24	0.71	0.71	10.61	2.83
AA323	m	101.00	396.00	27.00	243.00	135.50	91.00	116.00	105.00	112.50	27.50
	s	9.90	31.11	2.83	28.28	2.12	8.49	5.66	4.24	6.36	4.95
AA334	m	122.50	366.00	28.50	333.50	115.50	88.00	110.50	114.50	128.50	12.00
	s	24.75	76.37	0.71	3.54	3.54	2.83	2.12	3.54	4.95	4.24
AA386	m	81.50	280.50	30.00	320.50	110.00	101.00	127.50	91.00	122.50	26.50
	s	3.54	23.33	5.66	44.55	32.53	11.31	17.68	11.31	24.75	9.19
AA390	m	118.00	474.00	27.50	288.50	104.00	102.00	114.00	116.50	140.00	21.50
	s	9.90	128.69	0.71	2.12	0.00	8.49	5.66	4.95	2.83	20.51
AA419	m	124.00	517.00	71.50	267.50	61.00	115.00	116.50	128.50	140.00	18.50
	s	2.83	15.56	58.69	54.45	28.28	12.73	19.09	13.44	21.21	4.95
AA427	m	114.00	453.00	29.00	277.50	91.00	110.50	125.50	122.00	124.50	21.50
	s	19.80	130.11	0.00	7.78	0.00	4.95	3.54	2.83	2.12	6.36
AA428	m	96.00	337.50	32.00	383.00	95.00	106.00	120.00	129.00	131.50	16.50
	s	16.97	75.66	1.41	14.14	0.00	2.83	2.83	4.24	4.95	3.54
AA435	m	139.50	617.50	24.50	341.50	88.00	82.50	85.50	115.50	130.00	17.00
	s	13.44	177.48	0.71	38.89	18.38	2.12	7.78	10.61	8.49	1.41
AA445	m	120.00	530.00	30.00	300.50	86.50	103.50	119.00	133.00	142.00	18.50
	s	16.97	41.01	0.00	21.92	6.36	6.36	0.00	4.24	5.66	0.71
AA449	m	127.00	786.00	30.50	400.00	88.50	93.00	103.00	124.50	145.50	11.50
	s	5.66	244.66	2.12	19.80	16.26	4.24	4.24	17.68	14.85	13.44
AA451	m	134.00	479.50	27.00	298.50	83.50	86.00	99.00	126.00	133.00	28.50
	s	0.00	12.02	1.41	2.12	7.78	2.83	2.83	11.31	19.80	24.75
AA460	m	134.50	460.50	31.00	342.50	91.00	100.50	124.50	119.00	114.00	44.50
	s	7.78	7.78	0.00	4.95	9.90	0.71	4.95	1.41	7.07	16.26
AA461	m	125.50	590.50	22.00	208.50	149.00	68.50	91.50	83.50	99.50	23.00

	s	4.95	3.54	14.14	157.68	53.74	45.96	62.93	48.79	58.69	1.41
AA481	m	151.50	445.00	33.50	414.00	100.00	116.00	123.50	106.00	133.50	13.00
	s	7.78	43.84	0.71	5.66	1.41	0.00	4.95	1.41	0.71	7.07
AA49	m	116.50	549.00	31.50	309.00	99.50	109.50	137.50	122.00	136.50	19.50
	s	6.36	50.91	0.71	2.83	16.26	7.78	9.19	8.49	14.85	14.85
AA498	m	146.00	556.50	28.50	404.50	98.00	103.00	110.00	104.00	131.50	27.00
	s	0.00	17.68	0.71	71.42	21.21	7.07	5.66	5.66	4.95	14.14
AA507	m	105.50	360.50	35.50	310.50	141.50	131.00	104.00	124.00	126.00	11.00
	s	6.36	10.61	9.19	38.89	6.36	19.80	38.18	41.01	14.14	5.66
AA518	m	102.00	320.00	28.50	331.50	102.00	116.50	126.50	119.00	133.00	16.50
	s	0.00	14.14	0.71	48.79	8.49	2.12	9.19	1.41	4.24	2.12
AA535	m	112.00	325.00	25.50	281.00	111.50	85.00	102.50	112.50	125.00	14.50
	s	1.41	11.31	0.71	5.66	3.54	2.83	3.54	3.54	5.66	0.71
AA543	m	143.00	448.50	41.50	466.50	133.00	110.00	126.00	142.00	226.50	24.00
	s	0.00	10.61	10.61	81.32	65.05	19.80	5.66	26.87	150.61	5.66
AA552	m	132.00	505.50	32.00	318.50	87.00	108.00	141.00	135.00	146.00	9.50
	s	8.49	10.61	1.41	21.92	18.38	15.56	11.31	1.41	2.83	6.36
AA6	m	89.50	309.50	24.00	253.00	134.50	122.50	108.50	111.00	113.00	27.50
	s	12.02	28.99	0.00	11.31	9.19	17.68	2.12	1.41	1.41	14.85
AA603	m	99.00	389.50	27.50	230.00	79.50	81.50	131.00	332.50	122.50	26.50
	s	2.83	33.23	0.71	1.41	2.12	6.36	1.41	27.58	0.71	7.78
AA61	m	106.00	376.50	26.00	264.00	105.50	114.00	117.00	115.00	127.00	17.50
	s	21.21	57.28	0.00	12.73	4.95	7.07	2.83	2.83	4.24	6.36
AA614	m	90.00	294.50	24.50	181.00	79.00	110.50	125.00	139.00	141.00	34.50
	s	9.90	50.20	3.54	9.90	1.41	4.95	4.24	15.56	16.97	16.26
AA644	m	119.50	483.00	31.00	316.00	89.50	134.00	144.50	128.50	141.00	11.50
	s	6.36	36.77	4.24	12.73	3.54	21.21	17.68	13.44	16.97	12.02
AA662	m	117.50	385.50	27.50	216.00	80.00	131.50	139.50	134.50	146.50	23.50
	s	13.44	26.16	0.71	16.97	2.83	10.61	2.12	3.54	2.12	4.95
AA69	m	105.50	360.50	30.00	320.00	113.50	95.50	128.00	105.50	127.00	15.50
	s	13.44	21.92	1.41	12.73	9.19	3.54	4.24	0.71	5.66	9.19
AA7	m	99.50	335.00	26.50	304.00	135.00	105.00	107.00	96.50	107.50	29.00
	s	20.51	66.47	0.71	12.73	7.07	1.41	4.24	10.61	19.09	21.21
AA70	m	137.50	536.00	29.50	304.00	70.50	94.50	121.00	109.50	138.00	28.50
	s	2.12	32.53	0.71	4.24	0.71	4.95	2.83	2.12	1.41	0.71
AA756	m	129.00	476.00	29.50	293.00	107.00	103.00	133.50	117.50	142.00	13.00
	s	12.73	76.37	0.71	8.49	21.21	5.66	2.12	0.71	0.00	8.49
AA774	m	143.00	518.50	33.50	471.50	101.50	105.50	117.50	113.50	111.00	38.00
	s	1.41	10.61	0.71	20.51	19.09	7.78	4.95	9.19	18.38	18.38
AA8	m	117.00	302.50	32.00	434.50	116.50	94.50	113.50	117.50	117.50	11.00
	s	1.41	14.85	2.83	30.41	4.95	2.12	13.44	6.36	10.61	9.90
AA838	m	127.00	481.00	29.50	365.50	88.00	99.00	113.50	132.50	123.50	36.50
	s	2.83	4.24	0.71	3.54	1.41	2.83	3.54	7.78	7.78	7.78
AA839	m	123.50	489.00	30.50	290.00	102.50	92.50	147.00	122.00	135.00	22.00
	s	10.61	21.21	0.71	8.49	3.54	2.12	5.66	4.24	9.90	5.66
AA84	m	114.50	450.50	32.00	328.00	118.50	109.00	130.00	125.00	130.50	16.00
	s	2.12	21.92	0.00	19.80	13.44	2.83	4.24	1.41	0.71	5.66

AA843	m	119.00	397.50	29.00	305.50	125.00	96.50	118.00	120.50	130.50	14.50
	s	7.07	17.68	0.00	6.36	2.83	3.54	1.41	0.71	3.54	4.95
AA9	m	111.50	408.00	27.00	289.50	97.00	98.00	119.50	117.00	123.00	10.00
	s	4.95	60.81	1.41	9.19	4.24	8.49	3.54	7.07	1.41	0.00
AA911	m	133.50	554.50	31.50	389.00	83.00	96.50	121.50	128.00	144.00	8.00
	s	0.71	61.52	2.12	7.07	8.49	9.19	0.71	5.66	2.83	1.41
AA94	m	117.00	471.00	28.50	281.50	110.50	97.50	122.50	118.00	124.50	20.00
	s	2.83	29.70	0.71	2.12	6.36	0.71	12.02	11.31	16.26	9.90
AA95	m	116.00	441.00	27.00	351.00	125.00	95.00	110.00	108.00	109.50	24.50
	s	9.90	19.80	0.00	14.14	2.83	12.73	1.41	2.83	0.71	12.02
AA96	m	80.50	888.50	28.00	276.50	98.00	99.00	126.50	126.00	140.50	14.00
	s	50.20	594.68	2.83	21.92	5.66	0.00	10.61	5.66	14.85	1.41
AA98	m	113.00	413.50	30.00	352.00	110.00	109.50	120.00	118.00	131.00	7.00
	s	2.83	26.16	0.00	14.14	2.83	0.71	5.66	0.00	2.83	1.41

Appendix III