Environmental Science and Pollution Research

Archaeometric Researches on the Provenance of Mediterranean Archaic Phoenician and Punic Pottery

--Manuscript Draft--

Manuscript Number:	ESPR-D-15-05757R1
Full Title:	Archaeometric Researches on the Provenance of Mediterranean Archaic Phoenician and Punic Pottery
Article Type:	Research Article
Corresponding Author:	Maria Letizia Amadori, M.D. university of urbino Urbino, Pesaro ITALY
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	university of urbino
Corresponding Author's Secondary Institution:	
First Author:	Maria Letizia Amadori, M.D.
First Author Secondary Information:	
Order of Authors:	Maria Letizia Amadori, M.D.
	Carla Del Vais, PhD
	Paola Fermo, PhD
	Paolo Pallante, PhD
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	The aim of this study is to set up a first chemical database that could represent the starting point for a reliable classification method to discriminate between Archaic Phoenician and Punic pottery on the base of their chemical data. This database up to now can discriminate between several different area of production and provenance and can be applied also to unknown ceramic samples of comparable age and production areas. More than one hundred ceramic fragments were involved in this research, coming from various archaeological sites having a crucial importance in the context of the Phoenician and Punic settlement in central and western Mediterranean: Carthage (Tunisia), Toscanos (South Andalusia, Spain), Sulci, Monte Sirai, Othoca, Tharros and Pithecusa (Italy). Since long time archaeologists hypothesized that Mediterranean Archaic Phoenician and Punic pottery had a local or just a regional diffusion, with the exception of some particular class like transport amphorae. To verify the pottery provenance, statistical analyses were carried out to define the existence of different ceramic compositional groups characterized by a local origin or imported from other sites. The existing literature data are now supplemented by new archaeometric investigations both on Archaic Phoenician ceramics and clay raw materials from Sardinia. Therefore diffractometric analyses, optical microscopy observations and X-ray fluorescence analyses were performed to identify mineralogical and chemical composition of Othoca ceramics and clay raw material. The obtained results were then compared with own literature data concerning Phoenician and Punic pottery in order to find features related to the different ceramic productions and their provenance. PCA and HCA were also performed on the chemical compositional data in order to discriminate ceramic groups. A very complex situation was found: imported ceramics coming from Carthage, with a large-scale distribution, were found together with a predominant local production pottery. The archaeometric results demonstrate that historical and stylistic approach

	has be supported by scientific analyses to better understand local ore Mediterranean exchanges.
Response to Reviewers:	Reviewers' comments -Authors answers Reviewer #3: « Archaeometric researches on the provenance of Mediterranean archaic Phoenician and Punic pottery » by Amadori et al. More than 100 samples of archaeological ceramics and clayey raw materials were studied from different settlements from Tunisia, southern Spain and Sardinia in Italy in order to better understand the diffusion of Archaic Phoenician and Punic pottery. Globally speaking, the study is interesting and needs to be published even if some of the data is already published. Samples from a new site are presented here to complete the previous results and enlighten us about the diffusion of these ceramics considered as a local production by archaeologists. Sometimes the text it is unclear. I suggest to rewrite some specific parts in a more clear way and make some corrections (see below) to help the readers. - We rewrite more parts and we explain with more details. First of all, in the "materials" part, the location of the outcrops or even the exact place where clayey sediments were sampled should be indicated (GPS data or a map could be useful). More information about the samples (such as age, layer…) must be included, either by adding a table or alternatively adding new columns in Table 1. -We added Table 2 and geological map (figs 2a and 2b). Check the coherence of Othoca samples, as there are only 6 in the Table but 7 are referred in the text (pg. 3). -We changed the number: the samples SGT are 6 as you can see in table 1, the samples SGSS are 7. We analysed by XRD 11 samples, by XRF 9 sample and by optical microscope 13 samples Concerning the "Methods" part, it must be specified if all methods have been applied to all samples, if the geochemical methods is ED-XRF or WD-XRF, and why only major and minor elements have been chosen (and no trace elements). - Ok we better explained in Methods part a) Please add references concerning multivariate analysis that are very useful and common in ceramics studies since 1988 (Mommsen et al, 1988….). - Ok we added references (Fermo et al. 2004, 2008; Padeletti e Fermo 2010). In the "results part", the geochemical results should be included also in the description of each site's composition. This will allow more interesting comparisons between the results of each method and can help understand the presence/absence of certain phases. For example when there is no calcite, it should be more interesting to compare with the CaO concentration and similarly with the presence of ca-silicate such as gelehnite… - Ok we added more details in the results In addition to this, a table concerning XRD results is missing. -OK we added Table 3 Mineralogical composition of ceramic samples References in relation to firing conditions are also missing to explain your proposal of temperatures. There are a lot of publications on this subject (Maggetti, 1982 and Magetti et al.,2011, Cultrone et al, 2001…). Perhaps, it would be clearer if you present your hypothesis of firing conditions in a table including also a synthesis of XRD results (presence/absence of some phases and hypothesis of firing conditions). -OK we added Table 3 Mineralogical composition of ceramic samples and some references In the discussion, you should only present comparison between new results (relative to

Othoca) and the previous ones.
- Ok we added more details in the results and in the discussion

You also explain (quickly) that you deal with literature results and the new ones, taking into account P and LOI. But is it the only difference between the 2 series of results? Are there obtained by the same analytic method and equipment?
- Ok we added the equipments used and we added more details in the results and in the discussion

Finally, the conclusions are somewhat weak and limited. An historic perspective or contextualization of your results would be advisable, insisting on, for example, the diffusion of these kinds of products and comparing it with the well-known amphorae diffusion.
- Ok we added more details in the results and in the discussion

Another remark concerns the notion of "temper". In the conclusions you mention that temper was added, but before then you never discuss how ceramics were made and in fact, you only describe (in the results) if there is a serial or bimodal distribution of the aplastic inclusions. The possibility of potters adding temper to the clay needs to be addressed at some point before the conclusions.
- Ok we added more details in the results and in the discussion

Figures
Figure 1: scale is missing
-Ok we added the scale

Figure 2a to 8b: More information on the title is needed, such as the name of the site, the chemical group, and if it is PPL or XPL photomicrograph. Please precise also if it is the local hypothesis or the imported hypothesis for each photo. Please add also on the image the sample number.
- Ok we added more details in the figures captions

There is a mistake in figure 4a and b: it is 369 and not 396.
-OK we changed the wrong number

Figure 6: why do you choose another scale? If makes it is less easy to compare with other photomicrographs.
-Yes we changed with other figures

Figure 7: I don't understand why you don't show a photomicrograph of TH2 and why you chose 2 micrographs of the same group (TH1)? Might it be an error?
-Yes we changed with another figure of a sample of TH2 group

Figure 13: Please add a legend on your dendrogram to explain the 2 groups (C1 and C2) and draw the grouping on the dendrogram to explain clusters.
-Fig. 13 now became fig. 21. The groupings have been drawn on the figures indicating the names as reported in Tables 4. We prefer not to add a legend because it could be to heavy but we reported table 4 in the figure captions.

Figure 14: what are the variables chosen to realize the PCA analysis? Do you retain LOI when you calculate? Precise these informations in the title but also please note it under the graph, on the axis or with another graph referring to variables.
-Fig. 14 now became fig. 20. As reported in the text pag 3 Methods b) PCA, HCA were applied considering as variables the elements (oxides) determined by XRF. Now it has been also specified in the figure of the legend.

Figure 15: same as Figure 13
-Fig. 15 now became fig. 22

Tables
Table 3: Table 3 is difficult to follow because information about each sample must be found within the text (which are those from Tharos? and those from Othoca?).
-Yes we changed all the tables with other tables more clear.

	Consider producing a new table (as suggested before) explaining the sampling of clayey sediments. -OK we added table 2
Additional Information:	
Question	**Response**
§Are you submitting to a Special Issue?	Yes
(If “yes”) Please select a Special Issue from the following list: as follow-up to "§Are you submitting to a Special Issue?"	SI: CMA4CH
§Are you submitting to a Special Issue?	Yes
(If “yes”) Please select a Special Issue from the following list: as follow-up to "§Are you submitting to a Special Issue? "	SI: CMA4CH

Archaeometric Researches on the Provenance of Mediterranean Archaic Phoenician and Punic Pottery

M. L. Amadori[1], C. Del Vais[2], P. Fermo[3], P. Pallante[4]

[1]University of Urbino, Department of Pure and Applied Sciences

[2]University of Cagliari, Department of History, Cultural Heritage and Territory

[3] University of Milan, Department of Chemistry

[4] Forgeo, Associated Technical Studio, Modena

Abstract

The aim of this study is to set up a first chemical database that could represent the starting point for a reliable classification method to discriminate between Archaic Phoenician and Punic pottery on the base of their chemical data. This database up to now can discriminate between several different area of production and provenance and can be applied also to unknown ceramic samples of comparable age and production areas.
More than one hundred ceramic fragments were involved in this research, coming from various archaeological sites having a crucial importance in the context of the Phoenician and Punic settlement in central and western Mediterranean: Carthage (Tunisia), Toscanos (South Andalusia, Spain), Sulci, Monte Sirai, Othoca, Tharros and Pithecusa (Italy).
Since long time archaeologists hypothesized that Mediterranean Archaic Phoenician and Punic pottery had a local or just a regional diffusion, with the exception of some particular class like transport amphorae. To verify the pottery provenance, statistical analyses were carried out to define the existence of different ceramic compositional groups characterized by a local origin or imported from other sites.
The existing literature data are now supplemented by new archaeometric investigations both on Archaic Phoenician ceramics and clay raw materials from Sardinia. Therefore diffractometric analyses, optical microscopy observations and X-ray fluorescence analyses were performed to identify mineralogical and chemical composition of Othoca ceramics and clay raw material. The obtained results were then compared with own literature data concerning Phoenician and Punic pottery in order to find features related to the different ceramic productions and their provenance.
PCA and HCA were also performed on the chemical compositional data in order to discriminate ceramic groups.
A very complex situation was found: imported ceramics coming from Carthage, with a large-scale distribution, were found together with a predominant local production pottery. The archaeometric results demonstrate that historical and stylistic approach has be supported by scientific analyses to better understand local ore Mediterranean exchanges.

Keywords

Archaic Phoenician and Punic pottery – archaeometry – optical microscope – XRF analyses –PCA – HCA

Highlights

Archaic Phoenician and Punic pottery from central and western Mediterranean settlements were studied. The statistical treatment of the data (PCA and HCA) has confirmed the reliability of this new and useful database, attesting the presence of importation ceramics (PCA) and allowing a better discrimination between Carthage and local pottery by using two different cluster analyses.

Introduction

Since at least the end of the 9th century BC the Phoenicians settled on the coast of Lebanon, and in particular in Tyre, expanded to the West establishing numerous colonies (Aubet 2009).
The primary area of irradiation is Atlantic Spain, an important metalliferous region, particularly silver-rich. First they founded Cadiz; subsequently it occurred an early colonization of the Mediterranean coast of the Iberian Peninsula, and a series of small settlements located at a short distance from each other, among which Toscanos, was created with the aim to exploit land and sea resources. The Phoenician founded other colonies also in different areas, in particular in North Africa, Western Sicily and in South-Western Sardinia. In North Africa the most important colony is certainly Carthage, direct emanation of the Phoenician city of Tyre, founded probably in the late 9th century BC on the Tunisian coast. In Sicily, between the 8th and 7th century BC, the colonies of Mothya, Panormos and Solunto were founded. In Sardinia several coastal settlements, implanted between the Gulf of Cagliari and the Gulf of Oristano, were colonized. In the region of Sulcis, rich in mineral deposits, in the 8th century BC the city of Sulci (Sant'Antioco)

was built and later secondary centers including Monte Sirai (Carbonia) were settled. The main Phoenician centers in the Gulf of Oristano are Othoca (Santa Giusta) and Tharros (Cabras); it isn't yet clear if their foundation should be related to 8th or 7th century BC. Pithecusa, the oldest Greek colony in the West, is located in the Ischia island to a short distance from the coast of Campania. It is an important area useful to reconstruct archaic trades between Greeks and Phoenicians because in the necropolis and in the acropolis many oriental imported materials were found.

The first centuries of the West Phoenician irradiation (fig. 1) are very complex: different components of eastern origin interact fairly quickly with the local components of the areas affected by colonization.

Among all the Phoenician colonies of the West, Carthage has developed very early trade activity and cultural influences; in the second half of the 6th century BC the colony had a political control of the Western Sicily and Southwest Sardinia too.

The common archaeological approach in the research concerning the Phoenician and Punic pottery which was predominant till recent times, determined the conviction that coarse and fine pottery had a local diffusion or just a regional one, whit the exception of same particular classes like transport amphorae.

To overcome this approach and to have a more comprehensive overview of the phenomena governing the Phoenicians centers of ceramic production in the West, an archaeometric research project was carried out on more than one hundred potsherds coming from several centres located in West Central Mediterranean area in order to achieve a complete characterisation of the ceramic bodies. This research started in 1987 dealt with Archaic Phoenician and Punic ceramics found in different excavation sites: Carthage (Tunisia), Toscanos (Spain), Sulci (Sant'Antioco-CI), Monte Sirai (Carbonia-CI), Tharros (Cabras-OR) and Pithecusa (Ischia-NA) (Italy) (Amadori, et al. 1996; Amadori and Fabbri 1998a; Amadori and Fabbri 1998b; Amadori and Fabbri 1998c; Peserico 1998; Peserico 1998, 2000). The research is now supplemented by analysis of coeval ceramics and clayey raw materials from Othoca (Santa Giusta-OR).

Materials

More than one hundred potsherds were selected (Table 1) between different functional and productive ceramic categories. The finds are dated from 8th to 6th/begin 5th century BC and come from different Phoenician and Punic excavation sites. Various samples were analysed, partly belonging to tableware forms such as plates, cups, bowls, skyphoi, partly belonging to other functional categories, such as lamps, funerary jugs, transport amphorae. The unusual choice to study also open forms is determined by the intention of considering specific cultural aspects of the Phoenician and Punic society and its eating habits regarding other forms that are most commonly linked to local production; the transport amphorae in fact have higher commercial and economic implications affecting the production and transportation of foodstuff along commercial circuits of medium and large scale.

In this work, we have followed the classification proposed by Peserico for open shapes (Peserico 1998, 2000, 2002) and the one proposed by J. Ramon Torres for transport amphorae (Ramon Torres 1995). We use the definition of "Phoenician pottery" for materials produced in archaic contexts most linked to the oriental motherland and we use the definition of "Punic pottery" for materials of Carthaginian production or Carthaginian morphological type.

Carthage samples (CA samples): plates (types P1, P2, P3), cups (types CCr1, CCr3, CCr4, CCr5, CCc1, CsC5), a bowl (type Bic), an imitation skyphos (type S), a lamp (type L2) and a base (type B1) were selected (32 samples). The samples come from the excavation conducted by the University of Hamburg in an Archaic residential area under the Cardo Maximus, directed by H.G. Niemeyer (Peserico 1998, 2000, 2002; Niemeyer et al. 2007) and they are dated between 750 and begin of the 5th century BC. The city, founded by the Phoenicians of Tyre in the late 9th century BC, since archaic phases assumes a leading role in the central Mediterranean that becomes dominant since the 6th century BC. The presence of Carthaginian pottery in other Mediterranean areas in 8-7th centuries BC can show the existence of commercial contacts linked to cultural influences exerted by the city since archaic periods.

Toscanos samples (TO samples): plates, cups, bases, a lamp and an imitation skyphos were investigated (20 samples) (Amadori and Fabbri 1998c; Peserico 2000, 2002). All of them are dated between the half of 8th century to 6th century BC. The samples come from the area of the warehouse, excavated by the German Institute of Archaeology in Madrid (dir. H. Schubart). This settlement is part of the colonial program conducted by the Phoenicians along the Mediterranean coasts of Andalusia aimed at the capillary use of land and sea and to establish business relationships with the indigenous hinterland. Toscanos belongs to a political and cultural context more related to the West Spain and the commercial circle created by the Phoenicians in the Strait of Gibraltar; nevertheless the presence of the west-central imported pottery indicates the existence of contacts with that area.

Sulci samples (SU samples): plates, cups and a base were investigated (15 samples) (Amadori and Fabbri 1998b; Peserico 2000, 2002). All of them are dated between the half of 8th to 6th century BC. The samples come from the residential area of the "Cronicario", excavated by the Archaeological Superintendence of Cagliari and Oristano (dir. P. Bernardini). In this area were found the oldest Phoenician residential traces in Sardinia, which document the foundation of an archaic colony, probably related to the exploitation of massive metal resources of the Sulcis region.

Monte Sirai samples (MS samples): plates (P2), cups (CCr4, CCc2) and bases (B3) were investigated (10 samples) (Peserico 1994; Amadori and Fabbri 1998b; Peserico 2000). All of them are dated between 7th century to 6th century BC. The samples come from a residential area of the "acropolis", excavated by the Institute for Phoenician and Punic civilization (CNR - Rome) and by the Archaeological Superintendence of Cagliari and Oristano (dir. P. Bartoloni). The settlement of Monte Sirai is generally considered a secondary colony of Sulci; It was founded to control the immediate hinterland; probably the cultural and economic level was not very high but closely related to the coastal city.

Othoca samples (SG/SS and SGT samples): the SG/SS samples come from cremation graves of the necropolis of Othoca (Santa Severa village), dating from the 7th century to the half of 6th century BC, excavated by the Archaeological Superintendence of Cagliari and Oristano and the University of Cagliari (Del Vais 2010); jugs (three mushroom-lipped jug; an ovoid jug with vertical, stepped neck), two transport amphorae (ind. type) and a plate (Type P2) were investigated (7 samples). The SGT samples come from an underwater deposit of the Phoenician and Punic periods identified in the Lagoon of Santa Giusta, the basin connected to the port of the ancient city, excavated by the Archaeological Superintendence of Cagliari and Oristano in collaboration with the University of Cagliari (Del Vais and Sanna 2012); four transport amphorae (T-1.2.1.2. and T-1.4.2.1.), a domestic jug and a little cup were investigated, all dating from the late 7th century to the begin of 5th century BC (6 samples). The city of Othoca was founded by the Phoenicians to control the central sector of the Gulf of Oristano, probably in relation to the exploitation of the rich resources of the agricultural and mountainous hinterland. We have chosen to analyse both open and closed forms and transport amphorae because new researches gave us the opportunity to compare a funerary context, therefore linked to the local ritual practices, with a commercial one. In particular the existence of possible cultural and economic relations with other regions was tested; and a production of transport amphorae related to the foodstuff processing was hypotized, thanks to the presence of palaeobotanic and animal remains in these transport amphorae.

Tharros samples (THT samples): red slip plates produced between half of 7th and 6th century BC were studied (12 samples) (Amadori and Fabbri 1998b; Peserico 2000). The samples come from the pyrometallurgic district of the hill of “Su Murru Mannu”, excavated by the Institute for Phoenician and Punic civilization (CNR - Rome), the Archaeological Superintendence of Cagliari and Oristano and the University of Bologna, directed by E. Acquaro. The city of Tharros, situated in the northern sector of the Gulf of Oristano, still represents one of the Sardinian colonies showing the major cultural influences from Carthage since the Archaic period.

Pithecusa samples (PI samples): two plates (type P1), a base (type B3) and a lamp (type L2) were investigated (4 samples) (Amadori and Fabbri 1998b; Peserico 2000, 2002). All of them are dated between half of 8th to half of 7th century BC. The samples come from the San Montano necropolis and from the “scarico Gosetti” of the Monte Vico acropolis (Docter 1998; Peserico 2000), excavated by the Archaeological Superintendence of Naples and Caserta (dir. G. Buchner and D. Ridgway). Pithecusa is the oldest Greek colony in West founded by the Euboean, but frequented by Levantines and open to the influence of Carthage; from this point of view, it is a privileged observatory to understanding the interrelation of cultural phenomena linked to the most ancient oriental occupation phases in Central Mediterranean.

Raw materials: in addition to the described pottery, 7 clays from Tharros area and 7 clays from the Othoca area have been considered (Table 2), in order to identify the source materials of the local pottery production.

Tharros clays were collected from different age clays formations, outcropping in the surroundings of Tharros settlement (fig. 2a): 4 samples of Miocene clays (2 of Tortonian and 2 of Messinian formations), 1 from Pliocene and 2 from Quaternary clay formations (Amadori et al. 1996).

Othoca clays (fig. 2b) were collected from Santa Giusta Lagoon (1 sample), from Othoca necropolis near Santa Severa village (1 sample) and close to Othoca site (5 samples) which are related to different Holocenic (Quaternary) clay formations located in the area of Santa Giusta, the modern village that has developed over the ancient city of Othoca.

Methods

The following analytical methodologies were applied:

a) Determination of the chemical composition (i.e. Si, Al, Ca, Ti, Mg, Fe, Mn, K, Na) by X-rays fluorescence (XRF) on pellets. Both own and literature samples have been analysed with the same analytical technique (WD-XRF), but with a different equipment (Philips PW 1480 in Modena University with Sc-Mo anode, and Philips PW 1480 with a W anode in Faenza). Major and minor elements have been analysed by WD-XRF, no traces elements were detected as they were not analysed in the previous investigations. X-ray fluorescence analyses were performed to identify the chemical composition of Othoca ceramics and clayey raw materials. The obtained results were then compared with literature data concerning Phoenician-Punic pottery (Carthage: Amadori and Fabbri 1998a; Peserico 1998, 2000, 2002; Toscanos: Amadori and Fabbri 1998c; Sulci, Monte Sirai, Tharros and Pithecusa: Amadori and Fabbri 1998b) and clayey raw materials (Amadori et al. 1996) in order to find features related to the different ceramic productions and their provenance.To compare own previous data with Othoca new results, all chemical data have been processed and recalculated by considering also the Loss on Ignition (LOI) and the P in the global composition of the samples (table 2). LOI and P were often reported in literature data, but never considered in the data treatment and in the global composition of the samples. The re-considering of these parameters and the re-calculation of the chemical composition (100 % total) was necessary for an effective comparison between all the data following the same approach.

b) XRF data were treated by means of chemometric analytical techniques, such as principal component analysis (PCA) and hierarchical cluster analysis (HCA). In particular PCA, HCA were applied considering as variables the elements (oxides) determined by XRF. All the graphs reported in the text (scatter plots in two and dendrogram) were realized by using the statistical packages Minitab Inc. 15.1 and STATISTICA 7.1. PCA was carried out on the data covariance matrix.

Both of them are well-known multivariate methods of analysis (Baxter 1994, 2000). Principal component analysis involves a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. Hierarchical cluster analysis refers to a group of techniques of multivariate analysis whose objective is to select and group together homogeneous data. All these techniques are based on the concept of distance between two elements. The algorithm used for the analysis groups together the elements on the base of their reciprocal distance and therefore one element belongs to a group depending on the distance from that group. In the literature, these two techniques have been successfully applied in archaeological applications to solve provenance problems (Fermo et al. 2004, 2008; Padeletti and Fermo 2010).
c) Polarization microscopy was carried out on the thin sections of ceramic slices (25 µm) with a BX51 Olympus instrument polarized light. Mineralogical characterization as well as surface modification was interpreted by means of the AnalySIS five pictures Software© (Olympus Corporation, USA). The minerals were identified by means of their typical birefringence, also with supplementary petrographical interpretation using the Multiple Image Alignment (MIA) technique. Dark and bright field observations were performed with fixed oculars of 10× and objectives with different magnifications (5, 10, 20, 50 and 100×) on thin polished sections.
d) Crystalline phase composition was determined by X-ray diffraction (XRD) on powder samples using a Philips PW 1830 diffractometer continuous scanning filter with nickel. The following conditions: emission radiation Cu, Ka, voltage 40 kV, intensity 40 mA, goniometer speed 0.1 2h/s.

Results

Carthage samples

The mineralogical and petrographic investigations on Carthage samples allowed to identify the presence of ceramic bodies with a limited variability in the general matrix features (isotropy, colour, porosity, etc.), in the total abundance of the skeleton (approximately 10-20%) and in lithological or mineralogical composition of the aplastic fractions. The latter are almost always represented by monocrystalline and polycrystalline quartz, carbonate rocks fragments, bioclasts, chert, feldspars, opaque minerals, hematite and rare biotite.
The only clear and discriminating variable among the paste is the different size classes distribution of aplastics. This aspect has allowed the identification of two major groups of samples (Figs. 3a-b), each subdivided into two subgroups, and some samples (isolated samples) scattered because hardly comparable to others in terms of grain size. The first group C1, has a serial grains size distribution of aplastic with an abundance of silty and very fine sandy fraction. In the second group C2, aplastics have a hiatal grain size distribution with fine and very fine sandy fraction.
The XRD analysis showed that ceramic samples are composed of quartz, calcite and K-feldspars; sometimes plagioclase and haematite are present too (Table 3). The samples are practically free of formation minerals (gehlenite and pyroxene) and as a consequence it can be deduced that the maximum temperature reached was around 750°C. Traces of gehlenite were founded only in five samples indicating a higher firing temperatures, estimated at around 800°C. In fact in accordance with Cultrone et al. (Cultrone 2001) gehlenite appears at 800 °C increasing at 900 °C (Cultrone 2001; Padeletti and Fermo 2011). Gehlenite can occur in two varieties; the first via decarbonization process and re-crystallization by means of increasing CaO amount in high temperature reaction (Emami and Trettin 2010), or by using coarse grain calcareous material via firing process (Heimann and Maggetti 1981). The grain size of the raw mix is considerable factor for exhibition of the high temperature phases (Noll 1991). According to this case gehlenite was not form in a well-grained material, and therefore gehlenite have a sharp peak above the background in the diffractograms.
The chemical composition of Carthage ceramics, obtained by XRF analyses, shows a high homogeneity for most of the elements considered (Table 4). The samples are characterized by a quite high CaO content (average value of 17.2 % and standard deviation of 3.16 %), medium to low alumina concentrations (average value of 11.3 % and standard deviation of 1.1 %) and extremely constant and not particularly high iron content (average value of 4.9 % and standard deviation of 0.33 %). Average values of other chromophor, like manganese and titanium oxides ranges to 0.03 % and 0.65 % respectively. The widest variations are evidenced for CaO, SiO_2 and L.O.I.
By considering binary correlation diagrams, the samples are related to two groups also from the chemical point of view, namely C1 and C2. These two groupings are present in several binary correlations (i.e. MgO-CaO; fig. 4) and suggest a primary differentiation, that can be due to different areal productions within Punic pottery entailing different prime matters used, or to a non coeval production. As for the five isolated samples, the chemical affinity with the C1 and C2 groups seems quite evident in the correlation diagram of figure 4.
In the correlation diagram between the CaO and L.O.I. (fig. 5) some parallel trends are present. A first one (upper line in fig. 5), which is an almost constant correlation, is mainly due to the presence of variable amounts of calcite inside the pastes. A lower trend (samples CA 221, CA 152, CA 1013, CA 1622, CA 1204, CA 217, CA 3) with a CaO-LOI constant ratio but with a lower LOI content is present. In the lowest trend (samples CA 435, CA 1685, CA 605, CA 295) this behaviour is even more evident, and once again both samples from C1 and C2 group are present. Finally, three samples belonging to C2 group (CA 888, CA 1184) and an isolated sample (CA 1590) with a quite relevant CaO content (14.4-21.4%) have the lowest LOI.
The existence of these several and almost parallel trends can be due to different CaO contents in the pastes (clays and/or fillers) but also to higher plagioclase content or to neoformation minerals presence (like gehlenite), as suggested by the XRD analyses (Table 3).

The typological study carried out on Carthage samples attests that the two local manufactures can be ascribed to different manufactures: an ancient one (production C1), active between 750 to 650 BC, has a morphologic repertory constituted by original shapes or derived from oriental prototypes (plate P1; cup CCr5; base B1). A second one (production C2), dated from 650 to the end of 6th/begin 5th century BC, is represented by occidental shapes or evolved ones from oriental tradition (plates P2, P3; bowl Bic; cups CsC5, CCr1, CCr4). Other shapes (cups CCc1, CCr3; skyphos S; lamp L2), dated from begin 7th to the half of 6th century BC, were produced by both productions (Amadori and Fabbri 1998a; Peserico 1998, 2000, 2002).

Toscanos samples

Concerning the materials from Toscanos, mineralogical and petrographic investigations allowed to identify two main pottery groups (figs. 6a-b). T1 group is composed of thirteen samples with a anisotropic matrix and a serial grains size distribution of aplastic, with an abundance of silty and very fine sandy fraction, while other fractions are typically scarce or in traces. The skeleton abundance is in almost all samples of about 10%. The aplastic fraction is made of monocrystalline quartz and more rarely polycrystalline and metamorphic rock fragments. Quartz and mica, quartz, garnet, mica, kyanite, epidote and feldspars, quartz and feldspar, sometimes altered, mica and andalusite, chlorite, kyanite and andalusite are present. Furthermore few carbonate rocks fragments, bioclasts, opaque minerals, hematite, flint and rare sedimentary rocks fragments (quartzite and siltstones) are present too. Most of the components of the skeleton is therefore due to micaschiste, greenschist and phyllitic rocks correlated with the geological area of Toscanos. The second group (T2) is made up of seven samples with anisotropic matrix. They are characterized by a hiatal grain size distribution of aplastic represented by fine sandy fractions. The aplastic abundance is around 10%. The skeleton consists of monocrystalline quartz, carbonate rocks fragments, chert, bioclasts, opaque minerals, hematite, feldspar, polycrystalline quartz.

The XRD analysis confirms the existence of two different sample groups. The T1 group sample are constituted mainly of quartz with some calcite, plagioclases, mica/illite, chlorite and kyanite. The T2 group samples are composed of quartz, calcite and K-feldspars, sometimes plagioclase and haematite are present (Table 3). The mineralogical qualitative composition (in particular the presence of carbonate rocks fragments) and the matrix anisotropy indicate in general a low firing temperature for both groups, estimated to be about 750°C.

The difference already evidenced between the two petrographic groups, reflects also in the chemical composition for almost all the oxides (XRF data, Table 4). Even if globally a wide variation in the chemical data is present, by considering singly the groups T1 and T2, a good homogeneity in between the single group can be evidenced. Samples of T1 group are characterized by a medium alumina content (average value of 15.9 % with standard deviation of 0.97 %), medium CaO concentrations (average value of 7.1 % with standard deviation of 1.15 %), and also by high MnO (0.12 % average), potassium (2.84 % average) and medium to high iron (6.5 % average). T2 group samples are characterised by a quite high CaO content (average value of 15.4 % and standard deviation of 1.14 %), medium to low alumina concentrations (average value of 10.1 % and standard deviation of 1.13 %) and medium iron content (average value of 4.59 % and standard deviation of 0.29 %). All the chemical data for this group are different from the one of T1 group, and with average values rather similar to the previous samples from Carthage.

By using simple binary correlations (Al_2O_3-K_2O; fig. 7) the presence of two clearly distinct groupings is evident. In Toscanos samples the correlation between CaO and LOI is rather constant, this suggesting more homogeneous pastes and confirming the firing temperatures indicated before; only one sample (TO727) shows relatively low LOI contents also because of a higher presence of Ca-plagioclase.

On the base of the archaeometric results on Toscanos samples and concerning the typological study carried out on the ceramics imported from Carthage (T2) (plate P2; cup CCc1; base B3; lamp L2) it possible to hypothesize that Carthaginian imports arrived in Toscanos not before the half of the 7th century BC.

Sulci samples

Thanks to archaeometric investigations on Sulci ceramic, the existence of two groups was highlighted (figs. 8a-b). The group samples differ primarily for the mineralogical composition of the aplastic and secondarily for the abundance of the skeleton, both total and relative to the individual grain size fractions. The matrix is anisotropic for all samples, except one sample where it is in part semi-isotropic.

In the first group (S1), with nine samples, the skeleton is composed of monocrystalline quartz, more rarely polycrystalline; K-feldspar and plagioclases sometimes quite altered, mica more or less abundant; opaque minerals; chert and hematite. The metamorphic rocks fragments are found in five samples, one of which with fragments of volcanic rocks of andesitic type. The sedimentary rocks fragments (sandstones and siltstones) are present in four samples. The samples of this group show generally a hiatal grain size distribution of aplastic with fine and medium sandy fraction abundance. The aplastic abundance range between 5 and 10%. The second group (S2), with five samples, shows a 15-20% skeleton abundance. The aplastic are composed of monocrystalline quartz; carbonate rock fragments, bioclasts, K-feldspar, chert, hematite and opaque minerals. The hiatal grain size distribution of aplastic is more represented from fine and very sandy fine fractions.

From XRD analyses results (Table 3) was possible distinguish the two groups identified on the basis of their mineral-petrographic characteristic; plagioclases, pyroxenes and cristobalite are exclusive of the first group, while calcite is present only in the second group. In all of the samples large amount of quartz is present together with few amount of illite/micas.

From the comparison between the mineralogical-petrographic composition of the two groups (S1 and S2) and the local geological context, it should be noted that only group S1 can be considered as local because the aplastic composition is compatible with the geological formations of the area (Carmignani 1996).

The evaluation of the firing temperature of the local production is quite difficult, because of the very low presence of calcium in the raw materials, so the formation of compounds typical of firing is very limited. The small amounts of pyroxenes and gehlenite detected, the presence of illite/mica (Cultrone 2001), and the matrix anisotropy still allow to hypothesize firing temperatures around 800°C. Theoretically, even cristobalite could be newly formed, but its formation requires temperatures around 1050-1100° C and certainly can not have been formed during the firing of these ceramic wares, so this mineral had to be present in the raw materials. In case the temperature is higher than 1000 °C, gehlenite reacts and form two other phases such as calcium pyroxene (wollastonite) and plagioclase (anorthite) (Padeletti and Fermo 2011). The firing temperature of S2 ceramic group can be estimated around 750°C, since calcite is present in abundant amounts in all samples, while pyroxene and gehlenite are absent or in traces.

The chemical analyses (XRF) carried out on Sulci samples (Table 4) confirms the existence of two groups: the first group (S1) shows high levels of SiO_2 (66.48 % average), Al_2O_3 (16.43 % average), Na_2O (1.68 % average) and K_2O 16.43 % average), while CaO is very low (1.30 % average). The second group (S2) presents a lower content of SiO_2 (51.9 % average), Al_2O_3 (11.17 % average), Na_2O (0.31 % average) and K_2O (1.18 % average) while the concentrations of CaO are higher (15.66 % average). The sample isolated from the mineralogical and petrographic point of view fits within group S1. The standard deviation in between the single group considered is restrained, attesting a possible common provenance for the samples belonging to the same group. By using simple binary correlations (Al_2O_3-K_2O; fig. 9) the presence of two clearly distinct groupings (S1 and S2) is evident.

By considering the CaO-L.O.I. ratio, most of the Sulci samples seems to have the same characteristics with the exception of one sample (S 369/170, Cup belonging to the S2), characterized by a lower LOI content related to the plagioclase presence. The chemical data confirm the firing temperature suggested (800°C), since the neoformation of gehlenite observed by XRD should be at the very beginning and didn't affect much the CaO-LOI ratio.

The archaeometric investigations carried out on Sulci samples allowed to identify two main pottery groups; the first is considered local (S1); the other (S2) was considered imported from Carthage and presents characters compatible with the group C2 (plate P1; cups CCr1, CCc1).

<u>Monte Sirai samples</u>

The mineralogical and petrographic aspects allowed to consider these samples a more or less homogeneous group. The matrix is always from anisotropic to semi-isotropic with little clayed aggregates and bonherz (fig. 10a-b). The aplastic show generally a hiatal grain size distribution with abundance of medium and fine sandy fraction. The samples are composed of monocrystalline and polycrystalline quartz, K-feldspar and plagioclases, sometimes altered and sericitized, metamorphic and sedimentary rocks fragments, rare volcanic rocks fragments and mica, opaque minerals, hematite and chert. In two samples there are few fragments of carbonatic rocks fragments, almost completely altered because of firing. The samples show variations related to the total amount of aplastic and the abundance of the particle size fraction greater than 500 microns.

X-ray diffractions analyses show an abundance of quartz, a fair amount of K-feldspar, plagioclases and illite/mica. In some samples there are traces of cristobalite, hematite and pyroxene. Calcite is nearly always absent, with the exception of two samples which contain only trace amounts. The structural and compositional characteristics allowed to hypothesize a firing temperature estimated at around 850°C.

Monte Sirai samples from the chemical point of view (Table 4) are characterized by the presence of very low quantities of CaO (1.39 % average), by high levels of SiO_2 (68.68 % average) and medium alumina concentrations (average value of 15.17 %). Monte Sirai samples show a general chemical affinity with the local group (S1) of Sulci samples, from which they differ mainly in the K_2O content (average value of 2.95 %). Since Monte Sirai samples have low CaO content and only in two samples calcite in traces has been found by XRD, only a weak correlation with the L.O.I. is present.

The typological study of Monte Sirai ceramics supposed the pottery were a local production.

<u>Othoca samples</u>

Concerning mineralogical and petrographic characteristics, the samples from Othoca were classified in four groups. Group O1 (samples SG/SS 1, SG/SS 2 and SG/SS 6; fig. 11a) is characterized by an anisotropic matrix and a hiatal grain size distribution with abundance of silty fraction associated to scarce larger fractions. The aplastic are represented by intrusive rocks fragments, mono-and polycrystalline quartz, mica, feldspar, hematite and opaque minerals. The abundance ranges between 3 and 10%.

Group O2 (samples SG/SS 8, SG/SS 9 and SGT 1; fig. 11b) can be considered a more or less homogeneous group with an anisotropic to semi-isotropic matrix. The aplastic have a hiatal grain size distribution with abundance of fine to medium sandy fraction with scarce smaller fractions. The abundance ranges between 15 and 30%. Mono and polycrystalline quartz, intrusive rock fragments, feldspars and micas generally represent the composition. In the sample SGT1 metamorphic rock fragments are present too. Sample SG/SS 8 has an isotropic matrix; a prevalent fine sandy fraction associated to scarce smaller fractions is presents. Metamorphic rock fragments, mono and polycrystalline quartz, feldspar, micas, opaque mineral, and hematite represent the aplastic fraction.

The samples of group O3 (SGT 2, SGT 19, SGT 22, SGT 12, SGT 15, SGT 19; fig. 11c) show an anisotropic matrix and a serial grain size distribution of aplastic. The abundance ranges generally between 10 and 30%. The samples SGT 12 and SGT 15 are characterized by the presence of mono and polycrystalline quartz, feldspar and metamorphic rocks fragments, micas, opaque minerals, and hematite. Sometimes intrusive rock and sedimentary rock fragments are present (SGT 19).

The samples of group O4 (sample SG/SS 3 and SG/SS 4; fig. 11d) show an isotropic matrix and a prevalent silty and very fine sandy fraction. Intrusive and effusive rock fragments were observed. The abundance ranges between 5 and 10%.

The X-ray diffraction analyses show the presence of one group characterized by the absence of calcite (SGT 1, SGT 22, SG/SS 1, SG/SS 3, SG/SS 4, SG/SS 9); quartz, feldspars and illite/mica and sometimes pyroxenes are present too. Sample SG/SS 1 is characterized by the presence of gehlenite too. In the sample SG/SS 2, calcite, quartz, feldspars and illite/mica are present.

The grouping supported by mineralogical and petrographic composition was confirmed by a strong chemical inhomogeneity and data dispersion (Table 4). The combination of the optical microscopy observations, XRD and XRF analyses results, indicates the presence of at least three main groups according to their carbonate content. Since the number of samples for each group is small no standard deviation have been considered in the following discussion.

A first group is characterized by a medium to high CaO content (from 8.96 % to 13.46 %), and correspond perfectly to the previously identified group O1 (from the necropolis). These samples have medium Al_2O_3 concentrations (from 13.18 % to 15.77 %), medium to high K_2O (from 2.25 % to 2.88 %), and medium iron content (from 5.02 % to 6.0 %). A second group is characterized by a medium to low CaO content (from 3.99 % to 4.63 %), and correspond to the previously identified group O4 (from the necropolis). These samples have medium to high Al_2O_3 concentrations (from 17.27 % to 19.05 %), quite high K_2O (from 3.37 % to 3.81 %), and medium (but higher with respect to the previous group) Fe_2O_3 content (from 6.69 % to 6.71 %). The third group (both from the necropolis and from the Lagoon) is characterized by low CaO content (from 0.95 % to 1.63 %), and correspond to the previously identified groups O2 and O3. Only one sample from the O3 group has been chemically analysed, and the results indicates that this sample (SGT 22) is chemically very similar to the ones of O2 group. These samples have medium to high Al_2O_3 concentrations (from 17.39 % to 19.42 %), quite high K_2O (from 3.38 % to 3.89 %), and medium to high Fe_2O_3 content (from 6.66 % to 8.45 %).

By using simple binary correlations the presence of these three main group is still more evident (CaO-Al_2O_3 diagram; fig. 12).

<u>Tharros samples</u>

The mineralogical and petrographic investigations allowed to identify one main pottery group, considered local (TH1-Tharros 1) and a secondary group, represented by only two samples (TH2-Tharros 2) probably local but different than the other. The first group of ten samples show an anisotropic matrix and a skeleton having a serial grains size distribution of aplastic with an abundant silty and very fine sandy fraction (fig. 13a). Two samples with a semi-isotropic matrix, show a hiatal grain size distribution of aplastic with silty fraction abundance (fig. 13b). The main variable among the first ten samples is the total abundance of the skeleton, ranging from 5% to 10-15%. The mineralogical composition of the aplastic fraction is rather homogeneous and mainly consists of a monocrystalline quartz, micritic and spathic carbonate rock fragments, plagioclases, mica, opaque minerals, hematite, k-feldspar, polycrystalline quartz, chert, bioclasts, rare sedimentary and metamorphic rock fragments. Fragment of volcanic rock (andesite) and pyroxene were identified in two samples too.

XRD analyses (Table 3) of TH1 group samples confirm the presence of quartz, calcite, feldspars, illite/micas and sometimes iron oxides. Traces of gehlenite were detected in five samples. In the samples of TH2 group few traces of calcite were detected whit large amount of quartz and feldspars; pyroxenes and gehlenite are present in all samples, together with wairakite that probably was formed during burial (Gottardi 1969).

Taking into account the firing temperatures the situation is inhomogeneous. The constant presence of calcite (Trindade 2009), the anisotropy of the matrix and the rare traces of gehlenite found in the group of ten samples, allows to hypothesize firing temperatures between 750 and 800°C, while the presence of pyroxenes, the scarcity of calcite and the semi-isotropy in the two samples (TH2) indicate firing temperatures around 850°C (Trindade 2009). These variations certainly indicate a different processing technology with respect to the other samples.

The chemical composition of the samples (table 4, XRF data) is more or less uniform but with a certain variability in the content of SiO_2 (average value of 51.42 % with standard deviation of 2.47 %), Al_2O_3 (average value of 13.9 % with standard deviation of 1.71 %), and CaO (average value of 14.82 % with standard deviation of 2.84 %).

The highest levels of Al_2O_3 and Na_2O, and the lowest content of K_2O highlight the slight difference of the two samples differentiated even from the microscopic point of view and in grain size distribution from the samples belonging to the main group (TH2-Tharros 2 samples, Al_2O_3 - K_2O diagram, fig. 14). The correlation between CaO and LOI indicates that the two TH2-Tharros 2 samples have a lower LOI content with respect to the others, due to a higher firing temperature and to the neoformation of calcium silicates (gehlenite).

<u>Pithecusa samples</u>

From the standpoint of mineralogical and petrographic considerations, almost all the samples show an anisotropic matrix, the skeleton abundance ranges around 10%, but differ in the grain size distribution of the aplastic. Three samples (PI 2, PI 10, PI 14) have, in fact, a hiatal grain size distribution with abundance of fine and very fine sandy fractions (fig. 15a), while a sample (PI 12) shows an abundance in the silty fraction (fig. 15b). The skeleton is composed mainly of monocrystalline and polycrystalline quartz, carbonatic rocks fragments, bioclasts, rare feldspars and opaque minerals.

X-ray diffraction analyses have evidenced a good compositional homogeneity, with abundantly quartz and calcite, traces of illite/mica and feldspars; the gehlenite is present in a single sample. As regards the firing temperature the four samples of Ischia were fired at temperatures around 750°C.

Pithecusa ceramics chemical data show a good homogeneity for most of the elements considered, as attested by a low standard deviation. The samples are characterized by a quite high and slightly variable CaO content (average value of 17.92 % and standard deviation of 2.12 %), medium to low alumina concentrations (average value of 9.8 % and standard deviation of 0.4 %), low K_2O (average value of 1.31 % and standard deviation of 0.09 %) and not particularly high iron content (average value of 4.38 % and standard deviation of 0.22 %). This homogeneity suggests a common origin for all the considered samples and the similarity with the samples coming from Carthage is evident.

<u>Raw clay materials</u>

Raw clay materials coming from the surroundings of Othoca (fig. 2a-b) were sampled and analysed to identify a possible clay source for the local ceramic production. In addition, also clay raw materials from Tharros area (Figs. 2a-b) were considered. As previously reported, clays come from geological formations and outcrops present in the area, and date from Tortonian to Quaternary (Table 2).

By following the same approach used for Othoca samples, the clays chemical composition (XRF analyses) indicate that at least three (or four) main groups can be distinguished according to their carbonate content (Table 5).

A first group is characterized by a quite high CaO content (from 13.18 % to 17.45 %). In this group clays from the Tharros area, dated from Tortonian (T1 and T2), to Messinian (M2 and M6) and Quaternary (Nu1) are present. Even if some chemical differences between these samples are present, in this group medium to low Al_2O_3 concentrations (from 9.93 % to 11.42 %), medium to high K_2O (from 2.21 % to 2.63 %), and medium to low iron content (from 3.31 % to 4.25 %) are present. This group shows some general similarities with the ceramic samples of group O1 from Othoca necropolis and with the ceramics of Tharros.

A second group composed of two quaternary samples (Area 3 and Area 4) is characterized by a medium to low CaO content (from 4.28 % to 5.0 %). These samples are similar each other and show a different chemical composition from the other Holocene clays present and sampled in the immediate surroundings this suggesting a different genesis. They differ mainly for a different content in MgO, P_2O_5, SiO_2, Al_2O_3 and TiO_2, oxides that can be linked to the detrital fraction, as previously hypothesized. Some samples from Othoca necropolis (group O4) have a similar CaO content, but they differ in the concentrations of nearly all the other oxides (MgO, P_2O_5, SiO_2, Al_2O_3, TiO_2 and Fe_2O_3)

The third group is characterized by clays with a low CaO content (from 1.18 % to 1.82 %). This group is composed only by Quaternary clays from the Tharros area (M12) and from Othoca area and the Lagoon. Even if some chemical differences between these samples are present, in this group medium to high Al_2O_3 concentrations (from 17.14 % to 19.88 %), K_2O (from 2.40 % to 4.13 %) and Fe_2O_3 content (from 5.97 % to 9.9 %) are present. This group shows some general similarities with the ceramic samples of groups O2-O3 from Othoca necropolis and from the Lagoon.

Finally, one Pliocene sample from the Tharros area (ZA) differ in composition from the other considered. The CaO (2.14 %) is slightly higher than the one of the previous group, and the Fe_2O_3 content (11.9 %) is definitively higher with respect to the other groups. None of the ceramic samples analysed for this area have a comparable amount of iron.

A more detailed comparison between the chemical data of the raw clay materials and the ceramic samples from the several sites considered will be made in the following chapter (discussion), by using both binary correlations, PCA and cluster analysis.

Discussion

In the evaluation of the data, binary correlations have been made to verify firstly if the differences obtained either by optical microscopy and by a preliminary examination of the chemical data, had a diagnostic significance too.

In the global binary correlation diagrams (figs. 16-18) Carthage samples are located in a different area from most of the other samples and this allowed a first immediate distinction for the Carthage ceramics. As for Toscanos, (figs. 16-18), the presence of two clearly distinct groupings is evident. The Toscanos-T2 group fits with Carthage-C2 group (figure 19. This is also confirmed by the PCA analysis (fig. 20) in which six samples of Toscanos-T2 group fit with the pottery from Carthage.

Cluster analysis was performed on two separate dataset in order to better evidence the similarity within the two sub-groups: the first one (fig. 21) formed by not local pottery (namely Carthage and importation samples from Carthage from the colonies of Pithecusa, Toscanos and Sulci) and the second one (fig. 22) represented by the ceramic samples from Sardinia (namely Othoca, Tharros, Monte Sirai and Sulci).

In the cluster dendogram of imported pottery (fig. 21), the samples from Carthage belonging to the two groups C1 and C2 (see table 3) have been highlighted; samples CA 757 and CA 605 (identified as isolated in table 3) match with samples belonging to C2 group while samples CA 297 and CA 295 (identified as isolated too) match with the samples belonging to C1 groups.

In the correlation diagrams (figs. 16-18) the presence of two clearly distinct clustering of Sulci samples is evident; the samples of S2 group fit with Carthage C2 group (fig. 19). The presence of these two groups has been confirmed by PCA (fig. 20) and cluster analysis too (fig. 21).

In the correlation diagrams (figs. 16-18) Monte Sirai samples are positioned in a different area than the Carthage grouping. Monte Sirai samples show a general chemical affinity with the local group (S1) of Sulci samples, from which they mainly differ in the K_2O content. This affinity is confirmed by PCA (fig. 20) and cluster analysis too (fig. 22).

In the binary correlation diagrams of figure 16 the ceramic samples from Othoca (necropolis and Lagoon) are widespread, but systematically they are positioned in a different area than Carthage ceramics. As previously reported, CaO content (fig. 16, table 4) varies from a minimum of 0.95-1.63 % (groups O2 and O3 from the Lagoon and the necropolis) to a maximum of 13.46 % (group O1 from the necropolis). With regard to the raw materials, the clay samples from the Lagoon and few samples from Othoca necropolis have a corresponding CaO content. None of the clays from Othoca area have a CaO content compatible with carbonatic ceramic samples. Since the use of a carbonatic filler in the aggregate or in the matrix is not evident from optical microscopy observations, different raw source than Othoca clays must be hypothesized for these samples. According to the considered elements, the most carbonatic samples from the necropolis show a better affinity with the raw materials from the Tharros area (Miocene or Quaternary clays). As far as the others chemical elements are concerned, the carbonatic samples shows lower contents in K_2O, SiO_2 Fe_2O_3 and other major elements, as a consequence of the higher CaO content.

In figures 16 and 17 (CaO-K_2O and Al_2O_3-K_2O diagrams) a different K_2O content in the carbonatic samples with respect to the other samples was detected. In figure 18 (Na_2O-MgO diagram) the three carbonatic samples fit together, as well as the non carbonatic ones. This diagram suggests a common origin for the three main group of Othoca ceramics and also a local raw materials provenance.

The weak chemical affinity sometimes shown for the mid-carbonatic Othoca samples with Toscanos samples can be excluded on the base of the mineralogical and petrographic observations because there are not similarities between Toscanos and Othoca ceramics.

The split-up of Othoca samples into several groups characterized by different chemical characteristic is confirmed both by PCA either by cluster analysis (figs. 20 and 22).

In the binary correlation diagrams, which include all the data (figs. 16-18), Tharros samples are widespread, but they are placed systematically in an area different from the one of Carthage groupings. A slight affinity with some samples from the Othoca necropolis is sometimes present even if non systematic. The two high-temperature ceramic samples of TH-2 group fall often outside the main cluster of Tharros samples, since they are characterized by the highest levels of Al_2O_3 and Na_2O, and the lowest content of K_2O. On the base of the cluster analysis (fig. 22) these samples are highly homogeneous and clearly distinct from the other Sardinia productions, this suggesting a common and local origin.

In the binary correlation diagrams (figs. 16-18), Pithecusa ceramic samples shows a good homogeneity for most of the elements considered and always fit together with the ones from Carthage, as confirmed also by PCA analysis (fig. 21). In the correlation diagram of figure 19, two Pithecusa samples fit with Carthage C1 group, the other two fit with Carthage C2 group, this suggesting a more complex situation with respect to the other Phoenician colonies considered. These situation has been confirmed also by the results of cluster analysis (fig. 21).

Considering all the complete dataset, it's evident that the correlation diagrams reported in figures 16-18 show a wide diagnostic capability in order to define the provenance areas both of the local and the importation archaic Phoenician and Punic pottery considered in this work. In these diagrams the ceramics from Carthage always fit together, in an area where no local pottery or clays are present. This allow with a good degree of reliability to determine a provenance from Carthage for unknown pottery on the base of the chemical data only. One sample from Tharros is overlapped to the Carthage pottery samples in the first correlation diagram (fig. 16). This uncertainty can be solved with the aim of the other diagrams (figs. 17 and 18), where this overlapping is not present.

In the diagram of fig. 16 (CaO-K_2O) four main groupings are present: i) Carthage ceramics and importation ceramics from Carthage; ii) a group formed by carbonatic local ceramics from Tharros and Othoca necropolis, overlapped to Miocene and Quaternary clay samples from the Tharros area; iii) slightly carbonatic ceramics from Toscanos, from Othoca necropolis and two clay samples from the Othoca area; iv) non carbonatic ceramics from Sulci, Monte Sirai, Othoca necropolis, Othoca Lagoon and clays samples from Othoca area.

If we take in account Al_2O_3-K_2O MgO-CaO diagrams (figures 17 and 18), these groupings, with major or minor overlapping are present too. The Al_2O_3-K_2O diagram (fig. 17) allows a good discrimination between the Carthaginians and other Phoenician pottery considered. The K_2O content in the Carthaginians samples is always lower than the local ones, with a remarkable homogeneity of the data. Other Phoenician ceramics are not so homogeneous and the K_2O content (with the only exception of one sample from Tharros and one from the Pliocene clays in Tharros area) spread from 2.2 to more than 4%. The Na_2O-MgO correlation diagram (fig. 16) shows as well the four groupings, with some minor overlapping.

In Sulci and Toscanos pottery two different groups of ceramics are distinguishable because of the lower calcium oxide content and significant higher aluminium oxide content; one of them has a local provenance (S1 and T1) while the other is imported (S2 and T2) as indicated before.

All the correlations considered show a good affinity between Sulci and Monte Sirai samples, where only some minor differences are present. This can suggest that, probably, the source of clay raw materials could be similar, at least from the geological point of view.
Toscanos local ceramics are chemically different from the others, and this reflects the different composition observed both by microscopic in thin section and by XRD analyses.
Tharros samples overlap to the group formed by clay raw materials (Miocene to Quaternary clays) coming from the surroundings of the settlement. Since the compositional spread of these samples is wide, it's not possible to define which kind of clay have been used without a statistical treatment of the data.
The Othoca samples show the widest spread in all the correlation diagrams considered. As far as the clay raw materials are considered, some of the ceramic samples (non carbonatic, groups O2-O3) show an affinity with the Othoca clays, whilst this does not happen for the carbonatic samples. Since both the local ceramic and the raw materials show a wide spread of the data and some overlapping too, for these sample a provenance determination on the base of a simple binary correlation it's not always possible.
A quite relevant group of samples is always completely overlapped to the cluster formed by Carthaginian pottery. All these samples (from Pithecusa and some of Sulci and Toscanos) constitute a ceramic importation from Carthage. In the samples from Othoca, Tharros and Monte Sirai no coeval importations from Carthage were observed.
In the statistical treatment of the data, by means of classification methods some homogeneous groups within the different productions have been identified. The presence of some distinct groups is evident from PCA (fig. 21). It is worth to notice that the variance explained by the first two components is very high (99.5%). From the score plot reported in figure 21, the presence of a grouping formed by Othoca–S. Giusta Lagoon, Sulci and Monte Sirai samples is evident.
Furthermore the composition of Othoca necropolis samples is compatible with the local clays from the same area. A more complex situation is observable for all the other Othoca samples.
As regards the imported ceramics (fig. 21), two groups are present: one formed by Toscanos (T2), Sulci (S2), two samples from Pithecusa and C2 pottery sample from Carthage, the other with C1 pottery sample from Carthage and two samples from Pithecusa. This differentiation into two groups (with a high linkage distance) better details the indications obtained by the MgO-CaO correlation diagram (fig. 19) and confirms the archaeological hypothesis.
Concerning the local pottery (fig. 22) it was possible highlight a first groups consisting of samples from Sulci, Monte Sirai and Othoca S. Giusta-Lagoon in accordance with PCA results; Othoca-necropolis and the clays from the same area show a high similarity (low linkage distance); Tharros samples (TH1 and TH2) form a separate group and fit with some local clays from the same area.
Within the Tharros group, most of the samples together with three Othoca ceramic samples fits with the Quaternary clay sample (Nu1), whilst only two Tharros samples together with one sample from the Othoca necropolis show an affinity with Miocene clays (Tortonian and Messinian). This different behaviour suggest that more than one clay source (Quaternary and Miocene formations) could have been used to realize the local pottery from Tharros and may be some of the Othoca necropolis one (i.e. the carbonatic samples).
The cluster indicates that most samples from Sulci and Monte Sirai fit together too, this suggesting a similar origin for these ceramics. Within Monte Sirai-Sulci cluster two raw clay samples are present too (Area 3 and Area 4), indicating that no affinity with local pottery from Othoca is present for these clays.
Most of the samples from the Othoca necropolis fit together close to some raw clay samples (Area 1, Area 2, Area 5, US 46 and the Quaternary M12 clay), indicating as a possible source for these ceramics the local Quaternary clays present in the Othoca area.
Finally, a group of four ceramics (two from Othoca necropolis and two from the S. Giusta Lagoon) falls apart together with some Sulci and Monte Sirai samples, indicating that a different source is present too whose raw materials have not yet been identified.

Conclusions

The archaeometric researches carried out on Phoenician and Punic pottery in order to find features related to the different ceramic productions and their provenance highlighted a very complex situation. In the analysed samples several ceramic groupings can be considered from the mineralogical, petrographic and chemical point of view, mainly according to their calcium carbonate content.
The use of homogeneous data has allowed the definition of a first chemical database that could represent the starting point for a reliable classification method to discriminate in between Archaic Phoenician and Punic pottery firstly on the base of their chemical composition.
The results suggest that importation pottery from Carthage are present in several Phoenician Archaic settlements and in particular in Toscanos, Sulci as well as Pithecusa. In the sample analysed from Othoca, Tharros and Monte Sirai no importations from Carthage are present. The division into two main groups for the Carthage samples and for Toscanos samples was confirmed by statistical processing of data.
PCA has confirmed the reliability of the database, attesting the presence of importation ceramics. A first cluster analysis has confirmed the existence of two main groups in the Carthage ceramics, the same for imported ceramics from Carthage in the Punic settlements, as previously suggested by chemical binary correlations. The second cluster analysis has allowed a grouping between local pottery from Sardinia, suggesting the possible affinity with the local

clay raw materials considered. This cluster allowed the division into four main subgroups. The first group indicates that more than one clay raw source (probably Quaternary and Miocene geological formations) could have been used to realize the local ceramic from Tharros and probably also the ceramic from Othoca necropolis. In the second group most of the samples from Sulci and Monte Sirai fit together, this suggesting a similar origin for these ceramics. In the third group most of the samples from Othoca necropolis fit together close to some clay raw samples, indicating as a possible source for these ceramics the local Quaternary clays present in the Othoca area. Finally, a group of four ceramics (two from Othoca necropolis and two from the Lagoon) falls apart together with some Sulci and Monte Sirai samples, indicating that a different source is also present whose clay raw materials have not been yet identified.
The obtained results will allow to use the reference database to distinguish the ceramics imported from Carthage and the local Phoenician Archaic pottery productions.
From the historical point of view, these results confirm, as expected, that the majority of the ceramics analysed was local, compared to a poor attestation of import materials, mainly of Carthaginian production (Peserico 1998, 2000). The presence of pottery produced in Carthage in Toscanos, Sulci and Pithecusa had allowed to draw historical conclusions in relation to contacts between Carthage and the other Mediterranean sites since the Archaic period. Morphological analysis had allowed to verify the uniformity of the repertoire of the forms of oriental tradition, both in Carthage and in other Western colonies, and the early appearance of Western forms with regional morphological variants, in some cases with reciprocal influences between the different colonial areas. The early presence of Carthaginian pottery in Sardinia, linked to the possible presence on site of African residents, had led to the hypothesis that the morphological evolution of the forms of Western origin could have been influenced by Carthage, while in the Iberian area this influence was felt later and with limited and discontinuous outcomes (Peserico 1998, 2000).
The analysis performed on Othoca samples has not allowed instead to identify materials imported from Carthage; this is likely due to the failure to identify, in the necropolis and in the Lagoon, materials attributable to the 8-7th centuries BC. We have verified the absolute predominance of pottery probably produced locally and the presence of some unidentified origin samples opens new possibilities of local or Mediterranean exchanges that has yet to be fully investigated. So we also have the confirmation of the economic dynamism of the city, which was probably the seat of a substantial production of transport amphorae related to specialized agricultural crops grown in the hinterland, such as the vine and fruit trees, and of a large-scale breeding mainly relate to sheep and goats (Del Vais and Sanna 2012).

References

Amadori M, Amadori ML, Fabbri B (1996) Indagini sulle materie prime locali adatte per la produzione della ceramica punica di Tharros. Rivista di Studi Fenici XIV: 147-155.

Amadori ML and Fabbri B (1998a) Indagini archeometriche su ceramica fenicia da mensa proveniente da Cartagine (VIII–VI secolo a. C.). In: Acquaro E, Fabbri B (eds) Produzione e circolazione della ceramica fenicia e punica nel Mediterraneo: il contributo delle analisi archeometriche. Atti della 2ª Giornata di Archeometria della Ceramica (Ravenna, 14 maggio 1998). University Press Bologna, Imola, 43-55.

Amadori ML and Fabbri B (1998b) Studio archeometrico di ceramica fenicia (VIII - VI secolo a.C.) proveniente da siti archeologici della Sardegna e Ischia. In: Acquaro E, Fabbri B (eds) Produzione e circolazione della ceramica fenicia e punica nel Mediterraneo: il contributo delle analisi archeometriche. Atti della 2ª Giornata di Archeometria della Ceramica (Ravenna, 14 maggio 1998). University Press Bologna, Imola, 68-84.

Amadori ML and Fabbri B (1998c) Produzione locale e importazioni di ceramiche fenicie da mensa (fine VIII-fine VII secolo a.C.) a Toscanos (Spagna meridionale). In: Acquaro E, Fabbri B (eds) Produzione e circolazione della ceramica fenicia e punica nel Mediterraneo: il contributo delle analisi archeometriche. Atti della 2ª Giornata di Archeometria della Ceramica (Ravenna, 14 maggio 1998),.University Press Bologna, Imola, 85-94.

Aubet ME (2009). Tiro y las colonias fenicias de Occidente. Tercera edición actualizada y ampliada. Crítica, Barcelona.

Baxter MJ (1994) Exploratory Multivariate Analysis in Archaeology. Edinburg University Press, Edinburg.

Baxter MJ and Buck CE (2000) Data handling and statistical analysis. In: Ciliberto E, Spot E (eds) Modern Analytical Methods in Art and Archaeology. Chemical Analysis Series, Wi- ley, New York, 155: 681-742.

Carmignani L (1996) Carta geologica della Sardegna (Foglio Sud). A cura del Servizio Geologico Nazionale e della Regione Autonoma della Sardegna.

Cultrone G, Rodriguez-Navarro C, Sebastian E, Cavalla O, De La Torre MJ (2001) Carbonate and silicate phase reactions during ceramic firing. European Journal of Mineralogy 13: 621–634.

Del Vais C (2010) L'abitato fenicio-punico e romano. In: Coroneo R (ed), La Cattedrale di Santa Giusta. Architettura e arredi dall'XI al XIX secolo. Scuola sarda Editrice, Cagliari, 35-46.

Del Vais C and Sanna I (2012) Nuove ricerche subacquee nella laguna di Santa Giusta (OR) (campagna del 2009-2010). In: Arru MG, Campus S, Cicilloni R, Ladogana R (eds), Ricerca e confronti 2010. Atti. Giornate di studio di archeologia e storia dell'arte a 20 anni dall'istituzione del Dipartimento di Scienze Archeologiche e Storico-artistiche dell'Università degli Studi di Cagliari (Cagliari, 1-5 marzo 2010. ArcheoArte. Rivista elettronica di Archeologia e Arte, suppl. 1: 201-233 [http://ojs.unica.it/index.php/archeoarte/article/view/595].

Docter R (2000) Pottery, graves and ritual I: Phoenicians of the first generation in Pithekoussai. In: Bartoloni P and Campanella L (eds), La ceramica fenicia di Sardegna. Dati problematiche e confronti. Atti del Primo Congresso Internazionale Sulcitano (Sant'Antioco, 19-21 Settembre 1997). Collezione di Studi Fenici, 40. Consiglio Nazionale delle Ricerche, Roma, 135-149.

Emami, SM, and R. Trettin (2010) Phase Generating Processes in Ancient Ceramic Matrices Through Microstructure Investigation with High Resolution Microscopy Methods, Journal of Advanced Microscopy Research, 5(3): 181-189.

Fabbri B, Amadori M, Amadori ML (1998) Local and imported Punic pottery (IV-III century B.C.) from Tharros (Western Sardinia, Italy). Revue d'Archéometrie 22: 65-76.

Fermo P, Cariati F, Ballabio D, Consonni V, Bagnasco G (2004) Classification of ancient Etruscan ceramics using statistical multivariate analysis of data. Applied Physics A 79: 299-307.

Fermo P, Delnevo E, Lasagni M, Polla S, de Vos M (2008) Application of chemical and chemometric analytical techniques to the study of ancient ceramics from Dougga (Tunisia). Microchemical Journal 88: 150–159.

Heimann R B, and Maggetti M (1981) Experiments on simulated burial of calcareous Terra Sigillata (mineralogical change). Preliminary results, in Scientific studies in ancient ceramics, British museum research laboratory, 163-177.

Gottardi G (1969) The genesis of zeolites. European Journal of Mineralogy 1: 479-487.

Noll W (1991) Alte keramiken und ihre pigmente: studien zu material und technologie, E. Schweizerbart.

Padeletti G and Fermo P (2010) A scientific approach to the attribution problem of renaissance ceramic productions based on chemical and mineralogical markers. Applied Physics A 100: 771-784.

Peserico A (1998) La ceramica fenicia da mensa: la produzione di Cartagine e delle altre regioni fenicie d'Occidente (VIII-VI sec. a.C.). In: Acquaro E, Fabbri B (eds) Produzione e circolazione della ceramica fenicia e punica nel Mediterraneo: il contributo delle analisi archeometriche. Atti della 2 ª Giornata di Archeometria della Ceramica (Ravenna, 14 maggio 1998). University Press Bologna, Imola, 27-42.

Peserico A (2000) Importazioni cartaginesi in Spagna, Sardegna e a Pithecusa. Uno studio archeologico e archeometrico. In: Bartoloni P and Campanella L (eds), La ceramica fenicia di Sardegna. Dati problematiche e confronti. Atti del Primo Congresso Internazionale Sulcitano (Sant'Antioco, 19-21 Settembre 1997). Collezione di Studi Fenici, 40. Consiglio Nazionale delle Ricerche, Roma, 269-275.

Peserico A (2002) Die offenen Formen Red Slip Ware aus Karthago. Untersuchungen zur phönizischen Keramik im westlichen Mittelmeerraum. Hamburger Werkstattreihe zur Archäologie, 5. LIT, Münster.

Ramon Torres J (1995) Las ánforas fenicio-púnicas del Mediterráneo central y occidental. Instrumenta, 2. Universitat de Barcelona, Barcelona.

Trindade MJ, Dias MI, Coroado J, Rocha F (2009) Mineralogical transformations of calcareous rich clays with firing: A comparative study between calcite and dolomite rich clays from Algarve, Portugal. Applied Clay Science 42 : 345–355.

Figure 1

Click here to download Figure Figure 1.tif

Table 1

Location	Sample	Form	Dating century BC
CARTHAGE	CA 435	Plate P1	750-650
	CA 1183	Plate P1	750-650
	CA 1216	Plate P1	750-650
	CA 1439	Plate P1	750-650
	CA 1447	Plate P1	750-650
	CA 1456	Plate P1	750-650
	CA 1622	Plate P1	750-650
	CA 295	Carinate cup CCr5	750-650
	CA 615	Carinate cup CCr5	750-650
	CA 1075	Carinate cup CCr5	750-650
	CA 297	Flat base B1	750-650
	CA 888	Lamp L2	end 8th-end 6th
	CA 605	Carinate cup CCr3	begin 7th-575
	CA 34	Carinate cup CCc1	begin 7th-550
	CA 35	Carinate cup CCc1	begin 7th-550
	CA 152	Carinate cup CCc1	begin 7th-550
	CA 217	Carinate cup CCc1	begin 7th-550
	CA 221	Carinate cup CCc1	begin 7th-550
	CA 1685	Skyphos S	begin 7th-begin 6th
	CA 1184	Plate P2	650-500/475
	CA 1576	Plate P2	650-500/475
	CA 1126	Plate P3	650-500/475
	CA 1204	Plate P3	650-500/475
	CA 64	Carinate cup CCr1	650-500/475
	CA 194	Carinate cup CCr1	650-500/475
	CA 3	Carinate cup CCr4	650-500/475
	CA 757	Not carinate cup CsC5	650-500/475
	CA 1049	Not carinate cup CsC5	650-500/475
	CA 124	Bowl Bic	650-500/475
	CA 1013	Plate	Ind.
	CA 1573	Plate	Ind.
	CA 1590	Plate	Ind.
TOSCANOS	TO 862	Plate	700-685
	TO 570	Plate	640-620
	TO 674	Plate	620-ind.
	TO 689	Plate	620-ind.
	TO 702	Plate	620-ind.
	TO 63	Base	710-700
	TO 667	Base	685-620
	TO 727	Base	620-ind.
	TO 13	Cup	710-700
	TO 86	Cup	685-660
	TO 87	Cup	685-660
	TO 108	Cup	685-660
	TO 478	Skyphos	685-660
	TO 391	Plate	685-660
	TO 584	Plate	640-620
	TO 180	Base	685-660
	TO 212	Base	685-660
	TO 508	Base	660-640
	TO 904	Cup	700-685
	TO 328	Lamp L2	685-660

Location	Sample	Form	Dating century BC
SULCI	SU 369/143/45	Plate	8th-6th
	SU 369/102	Plate	8th-6th
	SU 369/129	Plate	8th-6th
	SU 369/142	Plate	8th-6th
	SU 369/167	Plate	8th-6th
	SU 369/182	Plate	8th-6th
	SU 369B/21	Plate	8th-6th
	SU 557/29	Cup	8th-6th
	SU 369/170	Cup	8th-6th
	SU 369/46	Cup	8th-6th
	SU 369/32	Cup	8th-6th
	SU 369B/75	Cup	8th-6th
	SU 369B/56	Cup	8th-6th
	SU 369B/10	Cup	8th-6th
	SU 369B/3	Lamp	8th-6th
MONTE SIRAI	MS 26	Plate P2	half 6th
	MS 166	Plate P2	end 7th-half 6th
	MS 210	Plate P2	end 7th-half 6th
	MS 9	Cup	7th-6th
	MS 63	Cup CCr4	6th
	MS 119	Cup CCc2	end 7th
	MS 151	Cup	7th-6th
	MS 236	Cup	7th-6th
	MS 11	Base B3	end 7th
	MS 140	Base B3	half 7th-half 6th
OTHOCA	SG/SS 1	Plate P2	first half 6th
	SG/SS 2	Jug with vertical neck	6th
	SG/SS 3	Transport amphora	6th
	SG/SS 4	Transport amphora	6th
	SG/SS 6	Mushroom-lipped jug	first half 6th
	SG/SS 8	Mushroom-lipped jug	7th
	SG/SS 9	Mushroom-lipped jug	first half 6th
	SGT 1	Transport amphora	6th
	SGT 2	Transp. Amph. T-1.2.1.2.	6th
	SGT 12	Jug	6th-5th
	SGT 15	Little cup	6th
	SGT 19	Lamp	6th-5th
	SGT 22	Transp. Amph. T.1.4.2.1.	6th
THARROS	THT 94/2/8-1	Plate P2	7th-6th
	THT94/2/8-3	Plate P2	7th-6th
	THT 94/2/8-4	Plate P2	7th-6th
	THT 94/5/9-1	Plate P2	7th-6th
	THT 94/5/9-4	Plate P2	7th-6th
	THT 94/10/10-1	Plate P2	7th-6th
	THT 94/14/10-1	Plate P2	7th-6th
	THT 94/18/5-2	Plate P2	7th-6th
	THT 94/18/8-2	Plate P2	7th-6th
	THT 94/18/8-3	Plate P2	7th-6th
	THT 94/22/6-1	Plate P2	7th-6th
	THT 94/47/5-1	Plate P2	7th-6th
PITHEC USA	PI 2	PI 2	half 8yh-half 7th
	PI 12	PI 12	half 8th-half 7th
	PI 14	PI 14	half 8th-half 7th
	PI 10	PI 10	half 8th-half 7th

Table 2

Sample	Clay formation age	Location (figs 2a-b)
T1 T2	Tortonian	S. Marco Cape, Tharros
M2 M6	Messinian	S. Marco Cape – S. Giovanni tower, Tharros
Nu1	Pliocene	North of Tharros
M12	Quaternary	S. Marco Cape, Tharros
ZA		West of Nuraghe Baboe Cabitza, S. Marco Cape
SGT ARG	Holocene	S. Giusta Lagoon
US 46		Othoca necropolis
AREA 1		S. Giusta village
AREA 2		
AREA 3		
AREA 4		
AREA 5		

Figure 2a

Click here to download Figure Figure 2a.jpg

Figure 2b

Click here to download Figure Figure 2b.jpg

Figures 3a-b

Click here to download Figure Figure 3 a-b.tiff

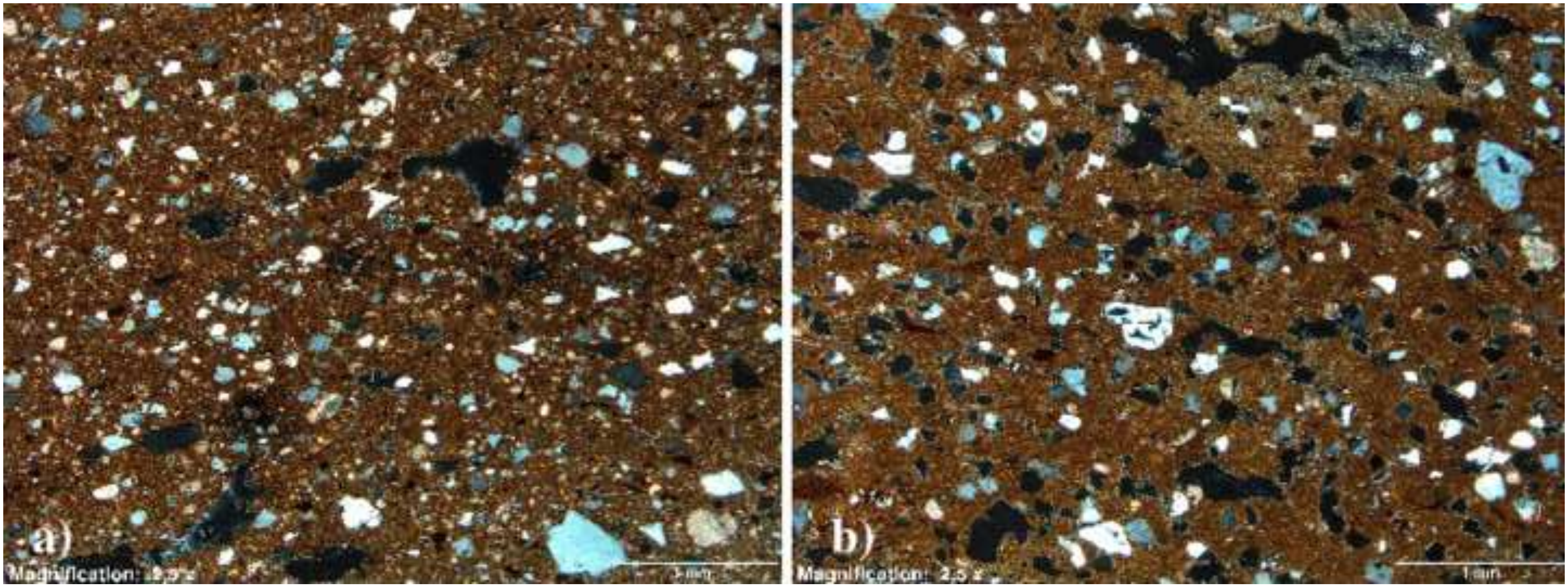


Table 3

Sample	Group	Q	C	K-F	Pl	I/M	Px	Ge	W	Fe-Ox	Cr	Cl	Ky	He
CA221		xxxx	xxx	x	tr	tr								tr
CA435		xxxx	xxx	x	x			tr						tr
CA1183		xxxx	xxx	xx		tr								tr
CA1204		xxxx	xxx	xx										
CA1439		xxxx	xxx	xx	x	tr								
CA1622		xxxx	xxx	x										
CA152	C1	xx	xx											tr
CA615		xxxx	xxx	x	tr	tr								
CA1013		xxxx	xxx	tr		tr								tr
CA1075		xxxx	xxx	tr		tr								
CA1216		xx	xxxx	tr										
CA1447		xxxx	xxx	xx	tr	tr								
CA1456		xxxx	xxxx	x		x								
CA34		xxxx	xxx	x		x								
CA35		xxxx	xxx	tr		tr								
CA64		xxxx	xxx	tr		tr								
CA888		xxxx	x	x	x			tr						
CA1049		xxxx	xxx	x		tr								
CA1126		xxxx	xxxx	tr		x								
CA1184		xxxx	x	x										
CA1573		xxxx	xxx	tr	tr	tr								
CA1576	C2	xxxx	xxx	tr										
CA1685		xxxx	xx	x	tr									
CA3		xxxx	xxx	tr	tr									
CA124		xxxx	xx											
CA184		xxxx	xxx	tr		tr								
CA217		xxxx	xx	tr	tr									
CA295		xxxx	xxx	tr				tr						
CA297		xxxx	xxx	tr	tr	x								
CA605	Isolated	xxxx	xxx			tr		tr						
CA757		xxxx	xx	xx										
CA1590		xxxx	xx	x	tr			tr						
TO 13		xxxx	xx		tr	x						x	t	
TO 63		xxxx			tr	x						tr	x	
TO 86		xxxx	tr	tr	tr	x						x	x	
TO 87		xxxx	xx		xx	x						tr	x	
TO 108		xxxx	x		x	x						x		
TO 478		xxxx	tr	tr	tr	x							tr	
TO 570	T1	xxxx	tr		x	x						x		
TO 667		xxxx	x		tr	x						x		
TO 674		xxxx	tr		x	x						tr	tr	
TO 689		xxxx	x	tr	tr	x						tr		
TO 702		xxxx	xx	tr	tr	xx							x	
TO 727		xxxx	x	tr	x	x						tr	tr	
TO 862		xxxx	x		tr	x						tr	tr	
TO 180		xxxx	xxx	tr		tr								
TO 212		xxxx	xxx	x		tr								
TO 328		xxxx	xxx	tr		tr								
TO 391	T2	xxxx	xxx	tr	tr	tr								tr
TO 508		xxxx	xxx	tr	tr	tr								
TO 584		xxxx	xxxx	tr		tr								
TO 904		xxxx	xxxx	x		tr								
SU 369B/10		xxxx		xx	xx	x	tr				xx			tr
SU 369B/56		xxxx		xx	xx	x	tr				x			
SU 369B75		xxxx		xxx	xx	x	tr				x			
SU 369/142	S1	xxxx		xx	xx	x	tr				tr			
SU 369/182		xxxx		xxx	xxx	x	x	tr			xx			
SU 369/46		xxxx		xxx	xxx	x	x	tr			xx			
SU 369/167		xxxx		xx	xxx	x	x				x			
SU 369B/21		xxxx		xx	xx	x					tr			
SU 369/143/45		xxxx		xx	xx	x					xx			
SU 369/32		xxxx		xxx	xxx	x	tr	tr						

SU 369/102	S2	xxxx	xxx	tr		tr	x	tr				tr
SU 369/129		xxxx	xxx	x		tr		tr				
SU 369/170		xxxx	xx	x								tr
SU 369B/3		xxxx	xx	x								
SU 369/29		xxxx	xxx	tr		tr		tr				
MS63	MS	xxxx		xxx	xx	x					tr	tr
MS140		xxxx		xx	x	x	tr					tr
MS166		xxxx		x	x	x	tr				tr	tr
MS119		xxxx		xxx	xx	x						tr
MS210		xxxx		xxx	x	x	tr				tr	tr
MS26		xxxx	tr	xxx	xx	x	tr					tr
MS236		xxxx		xxx	xx	x	tr				tr	tr
MS9		xxxx		xxx	xx	x						tr
MS11		xxxx	tr	xx	xx	x	tr				tr	tr
MS151		xxxx		xx	xx	x	tr				tr	tr
SG/SS 1	SG	xxxx		±	xx	tr	±					
SG/SS 2		xxxx	tr	x	xx	x	x					
SG/SS 3		xxxx		tr	±	xx	tr					
SG/SS 4		xxxx		x	x	xx	±					
SG/SS 9		xxxx		x	x	±	tr					tr
SGT 1		xxxx		x	x	xx						
SGT2		xxxx		x	x	±	x					
SGT 12		xxxx		x	xx	xx						tr
SGT 15		xxxx		x	xx	xx						
SGT 19		xxxx		x	x	x						tr
SGT 22		xxxx		x	xx	xx						
THT94/22/6-1	TH1	xxxx	xxx	x	xx	xx		tr				
THT 94/18/8-3		xxxx	xx	x	xx	x						
THT 94/47/5-1		xxxx	xxx	x	x	xx				tr		
THT 94/10/10-1		xxxx	xx	xx	xx	tr		tr				
THT 94/18/8-2		xxxx	xx	xx	xx	tr				tr		
THT 94/5/9-4		xxxx	xx	xx	xxx	x						
THT 94/2/8-3		xxxx	xx	x	x	x						
THT 94/5/9-1		xxxx	x	x	xx	x		tr		tr		
THT 94/18/5-2		xxxx	xxxx	xx	xxx	xx		tr		tr		
THT 94/2/8-4		xxxx	xxxx	x	x	xx		x				
THT 94/2/8-1	TH2	xxxx	tr	xx	xx		xx	tr	tr			
THT 94/14/10-1		xxxx	tr	xx	xx		xx	xx	x			
PI2	C2	xxxx	xxx	tr		tr						
PI10		xxxx	xxxx			tr						
PI12	C1	xxxx	xxxx	tr	tr	tr		tr				
PI14		xxxx	xxxx	tr	tr	tr						

xxxxx=very abundant, xxx=abundant, xx=slightly abundant, x=low, tr=traces

Q=quartz, C=calcite, K-F=K-feldspar, Pl=plagioclase, I/M=illite/montmorillonite, Px=pyroxenes, Ge=gehlenite, W=wairakite, Fe-Ox= iron oxides, Cr=cristobalite, He=hematite, Cl=chlorite, Ky=kyanite

Table 4

Sample	Group	LOI	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
CA 435	C1	10.98	0.42	1.64	11.74	48.10	0.37	1.60	19.20	0.72	0.03	5.21
CA 1183		17.61	0.54	1.04	9.93	42.77	0.49	1.65	19.95	0.60	0.02	5.39
CA 1439		16.09	0.48	1.10	10.64	46.78	0.55	1.64	17.54	0.62	0.03	4.54
CA 1622		14.95	0.57	1.12	9.79	45.40	0.54	1.70	20.43	0.63	0.03	4.86
CA 221		16.80	0.63	1.20	10.25	41.59	0.31	1.74	21.97	0.59	0.04	4.87
CA1204		14.65	0.57	1.17	10.48	43.61	0.53	1.77	21.48	0.63	0.03	5.07
CA 1216		18.37	0.46	1.54	10.88	41.95	0.34	1.71	19.81	0.61	0.02	4.31
CA 1447		16.95	0.37	1.18	10.07	45.65	0.44	1.57	18.64	0.62	0.02	4.49
CA 1456		19.29	0.19	1.52	9.47	41.41	0.23	1.50	20.93	0.57	0.03	4.84
CA 615		18.11	0.40	1.21	9.77	43.82	0.20	1.58	19.82	0.60	0.02	4.46
CA 1075		18.37	0.48	1.26	9.16	43.29	0.23	1.70	20.83	0.55	0.03	4.10
CA 152		15.49	0.56	1.29	11.67	44.14	0.34	1.57	19.15	0.65	0.04	5.10
CA 1013		13.83	0.47	1.30	12.21	45.44	0.18	1.73	19.04	0.69	0.05	5.06
CA 888	C2	4.46	0.50	1.51	12.02	58.83	0.66	1.42	14.40	0.72	0.03	5.44
CA 34		11.91	0.45	1.36	12.78	53.19	0.21	1.74	12.72	0.69	0.03	4.92
CA 35		13.67	0.30	1.16	11.93	51.25	0.23	1.66	14.14	0.68	0.03	4.95
CA 1685		6.64	0.60	1.55	12.19	56.98	0.40	1.72	13.71	0.73	0.04	5.45
CA 1184		6.30	0.38	1.56	12.20	56.32	0.24	1.42	15.96	0.66	0.03	4.93
CA 1576		14.94	0.39	1.41	11.69	47.39	0.31	1.61	16.75	0.66	0.03	4.83
CA 1126		14.38	0.28	1.43	12.56	50.08	0.23	1.55	13.71	0.67	0.02	5.09
CA 64		14.09	0.52	1.33	11.01	50.36	0.40	1.50	15.37	0.59	0.03	4.80
CA 1049		12.99	0.45	1.41	12.32	51.51	0.18	1.57	13.44	0.69	0.03	5.40
CA 1573		12.27	0.40	1.45	11.52	52.86	0.18	1.66	14.01	0.65	0.03	4.98
CA 217		9.82	0.51	1.40	12.51	53.84	0.25	1.74	14.15	0.72	0.04	5.02
CA 184		13.74	0.55	1.34	11.50	50.29	0.30	1.68	15.22	0.63	0.02	4.74
CA 3		11.91	0.48	1.54	11.41	50.73	0.21	1.66	16.53	0.64	0.03	4.86
CA 124		12.70	0.55	1.43	11.11	52.80	0.25	1.55	14.46	0.65	0.03	4.47
CA 295	isolated	12.21	0.70	1.39	10.35	45.92	0.68	1.59	21.56	0.64	0.03	4.94
CA 297		16.74	0.49	1.91	12.48	44.32	0.41	1.56	16.37	0.70	0.02	5.00
CA 605		9.75	0.48	1.50	11.13	52.50	0.25	1.46	17.34	0.63	0.03	4.93
CA 757		9.25	0.43	1.67	13.41	56.91	0.24	1.77	10.22	0.76	0.04	5.31
CA 1590		7.31	0.51	1.64	12.11	49.66	0.30	1.42	21.04	0.68	0.05	5.28
TO 862	T1	4.97	0.77	2.71	15.44	58.52	0.32	2.79	6.87	0.85	0.11	6.65
TO 570		3.69	0.82	3.07	16.33	57.91	0.41	2.90	7.16	0.89	0.12	6.69
TO 674		2.67	0.78	2.94	17.05	58.11	0.46	2.87	7.40	0.90	0.11	6.71
TO 689		5.26	0.73	2.79	16.36	57.23	0.38	2.89	7.00	0.85	0.11	6.40
TO 702		8.69	0.49	2.49	14.56	55.95	0.18	2.55	7.93	0.83	0.10	6.23
TO 63		4.23	0.74	2.93	16.03	60.10	0.24	3.05	5.09	0.91	0.09	6.61
TO 667		5.01	0.63	2.90	16.45	56.09	0.23	2.81	9.02	0.85	0.09	5.92
TO 727		7.05	0.62	3.37	14.83	58.49	0.27	2.83	5.12	0.87	0.11	6.43
TO 13		5.47	0.36	2.27	14.56	58.79	0.34	2.30	8.68	0.89	0.13	6.21
TO 86		3.93	0.99	2.83	16.82	57.71	0.36	3.19	6.44	0.91	0.11	6.69
TO 87		7.52	0.38	2.43	14.59	56.73	0.75	2.78	7.55	0.88	0.15	6.25
TO 108		4.19	0.58	2.89	16.96	56.43	0.57	3.09	6.97	0.88	0.18	7.25
TO 478		3.45	0.76	3.04	16.68	57.81	0.53	2.88	7.44	0.86	0.11	6.46
TO 391	T2	15.37	0.15	1.42	9.74	51.65	0.30	1.25	14.83	0.60	0.04	4.65
TO 584		16.73	0.21	1.24	8.44	51.60	0.29	1.07	15.65	0.61	0.04	4.12
TO 180		13.02	0.21	1.24	11.62	51.64	0.72	1.72	14.13	0.68	0.04	4.98
TO 212		16.38	0.25	1.53	10.88	46.25	0.78	1.43	17.09	0.64	0.04	4.74
TO 508		15.75	0.38	1.33	9.19	50.38	0.63	1.46	15.84	0.59	0.03	4.41
TO 904		14.78	0.28	1.28	9.78	53.11	0.42	1.36	13.99	0.57	0.03	4.41
TO 328		15.10	0.40	1.62	11.08	47.16	0.92	1.88	16.26	0.71	0.04	4.81
SU 369/142	S1	3.84	1.35	1.50	17.09	65.00	0.05	3.08	1.30	0.69	0.05	6.06
SU 369/143/45		3.94	1.61	1.08	16.34	66.71	0.06	3.55	1.13	0.61	0.08	4.89
SU 369/167		3.63	1.69	0.96	15.97	67.37	0.06	3.83	1.16	0.58	0.09	4.66
SU 369/182		2.11	2.32	0.65	16.88	68.37	0.06	3.81	1.25	0.51	0.04	4.01
SU 369B/75		4.42	1.43	1.19	15.76	66.61	0.04	3.31	1.27	0.63	0.09	5.24
SU 369/32		3.03	2.10	0.87	15.55	68.71	0.07	3.70	0.97	0.51	0.04	4.44
SU 369/46		4.22	2.18	0.75	17.44	65.63	0.06	3.51	1.46	0.49	0.06	4.20
SU 369B/10		4.52	1.42	1.38	16.68	64.96	0.07	3.39	1.39	0.66	0.09	5.44

Sample	Group	LOI	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
SU 369B/21		4.07	1.27	1.58	17.36	64.67	0.05	3.03	1.28	0.68	0.05	5.96
SU 369B/56		4.61	1.44	1.23	15.25	66.75	0.06	3.39	1.77	0.59	0.09	4.81
SU 369/102	S2	14.14	0.39	1.11	11.00	50.52	0.18	1.30	16.17	0.63	0.04	4.52
SU 369/129	S2	15.82	0.36	1.29	10.49	48.85	0.15	1.26	16.71	0.59	0.03	4.45
SU 369/170	S2	6.52	0.29	1.36	11.53	58.06	0.51	1.12	14.96	0.64	0.03	4.98
SU 369B/3	S2	13.83	0.25	1.33	11.38	52.28	0.14	1.13	14.53	0.62	0.04	4.47
SU 557/29	S2	14.60	0.27	1.30	11.47	49.79	0.19	1.08	15.95	0.64	0.03	4.68
MS 26	MS	1.92	1.40	1.21	14.83	69.63	0.10	3.03	1.71	0.61	0.13	5.43
MS 166	MS	2.11	1.15	1.51	16.62	67.27	0.17	2.89	0.84	0.65	0.08	6.69
MS 210	MS	2.37	1.21	1.60	18.27	64.57	0.37	2.90	1.02	0.68	0.18	6.83
MS 9	MS	3.25	0.81	0.87	12.61	73.05	0.22	2.82	0.63	0.61	0.02	5.12
MS 63	MS	4.10	1.25	0.98	13.53	68.27	1.21	3.04	2.33	0.51	0.09	4.70
MS 119	MS	1.46	1.57	1.06	15.89	69.14	0.06	2.80	1.76	0.58	0.08	5.61
MS 151	MS	3.59	1.07	1.21	14.46	69.36	0.22	3.03	1.04	0.62	0.06	5.35
MS 236	MS	2.31	1.27	0.79	12.85	74.05	0.24	2.89	0.73	0.50	0.05	4.32
MS 11	MS	2.42	1.33	1.44	15.98	66.14	0.15	3.00	2.56	0.66	0.16	6.17
MS 140	MS	4.00	1.33	1.29	16.71	64.67	0.75	3.07	1.28	0.64	0.14	6.12
SG/SS 1	SG	10.15	1.53	2.86	13.18	50.83	0.34	2.25	13.17	0.62	0.04	5.02
SG/SS 2	SG	6.60	0.84	2.94	15.77	55.05	0.34	2.70	8.96	0.76	0.04	6.00
SG/SS 3	SG	3.25	0.83	2.33	17.27	60.55	0.38	3.81	3.99	0.87	0.04	6.69
SG/SS 4	SG	3.67	0.92	3.00	19.05	57.49	0.21	3.37	4.63	0.92	0.04	6.71
SG/SS 6	SG	10.39	0.77	2.75	14.33	49.53	0.16	2.88	13.46	0.67	0.03	5.04
SG/SS 8	SG	1.92	1.60	2.85	19.42	58.67	0.65	3.38	1.63	1.37	0.06	8.45
SG/SS 9	SG	1.44	1.50	2.59	18.68	61.88	0.14	3.87	0.95	1.04	0.09	7.83
SGT 1	SG	1.28	1.48	2.73	17.73	64.22	0.06	3.89	1.01	0.82	0.08	6.71
SGT 22	SG	1.38	1.62	2.53	17.39	64.46	0.10	3.86	1.15	0.79	0.08	6.66
THT94/2/8-3	TH1	8.02	1.11	2.21	14.76	50.25	0.21	2.60	15.35	0.62	0.03	4.84
THT 94/5/9-1	TH1	5.57	1.33	2.42	15.48	52.43	0.18	2.94	13.74	0.68	0.03	5.20
THT 94/5/9-4	TH1	7.42	1.39	2.20	13.23	56.00	0.30	2.86	11.85	0.62	0.03	4.11
THT 94/2/8-4	TH1	3.50	1.20	2.14	13.62	51.82	0.17	2.97	19.51	0.63	0.03	4.41
THT 94/10/10-1	TH1	9.62	1.23	2.10	12.56	51.20	0.25	2.60	15.64	0.59	0.04	4.15
THT 94/18/5-2	TH1	15.58	1.21	1.61	10.76	47.37	0.16	2.59	16.58	0.52	0.03	3.60
THT 94/18/8-2	TH1	8.31	1.26	2.22	13.29	53.64	0.19	2.86	13.51	0.60	0.03	4.07
THT 94/18/8-3	TH1	7.69	1.45	2.20	13.69	51.04	0.45	2.87	15.73	0.62	0.03	4.23
THT 94/22/6-1	TH1	13.84	1.12	2.09	12.75	48.33	0.17	2.67	14.23	0.58	0.03	4.20
THT 94/47/5-1	TH1	11.92	1.34	2.15	13.49	49.38	0.17	3.17	13.37	0.61	0.03	4.39
THT 94/2/8-1	TH2	2.34	1.91	2.72	17.10	54.30	0.20	2.49	12.75	0.71	0.05	5.42
THT 94/14/10-1	TH2	4.33	2.33	2.36	16.08	51.33	0.38	1.72	15.56	0.67	0.04	5.18
PI 2	C2	15.24	0.48	1.38	9.21	51.77	0.14	1.30	15.69	0.56	0.03	4.20
PI 10	C2	17.34	0.48	1.29	9.95	43.63	0.16	1.20	20.62	0.63	0.02	4.69
PI 12	C1	16.95	0.34	1.29	10.08	46.51	0.16	1.35	18.43	0.61	0.02	4.25
PI 14	C1	15.43	0.44	1.54	9.96	49.07	0.19	1.40	16.93	0.63	0.03	4.39

Figure 4

Click here to download Figure Figure 4.tif

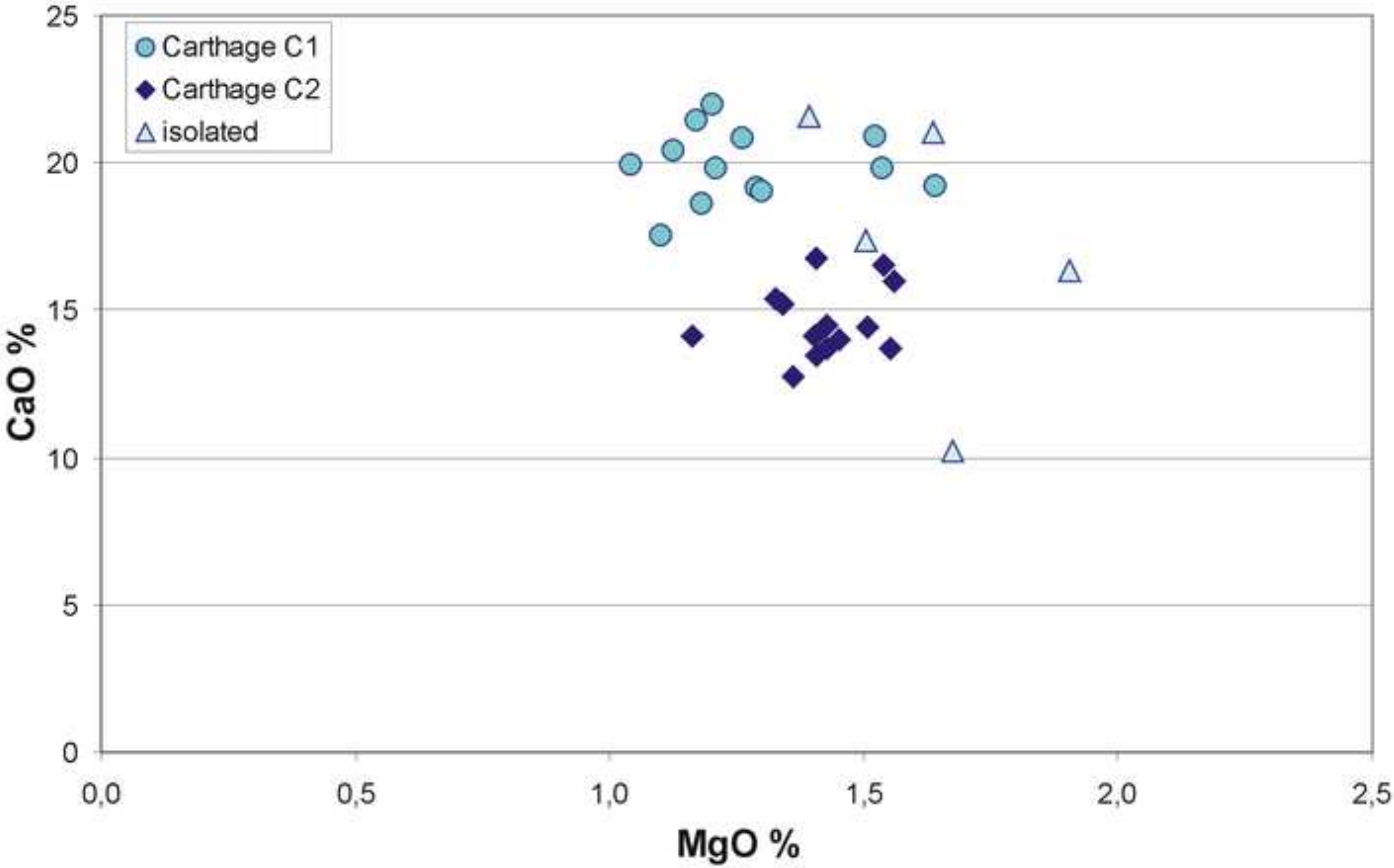
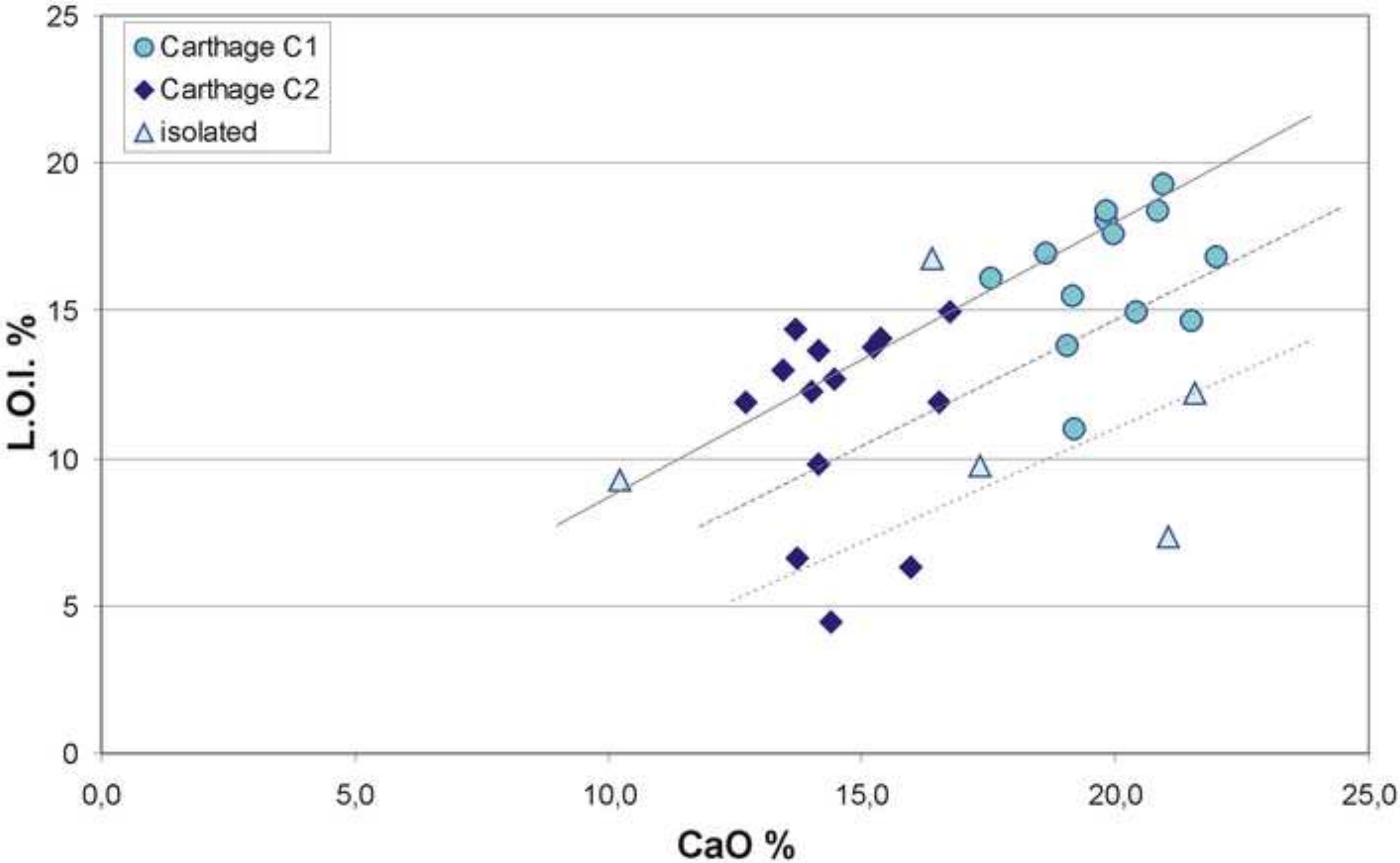


Figure 5


Carthage C1
Carthage C2
isolated
L.O.I. %
CaO %
0
5
10
15
20
25
0,0
5,0
10,0
15,0
20,0
25,0

Figures 6a-b

Click here to download Figure Figure 6 a-b.tiff

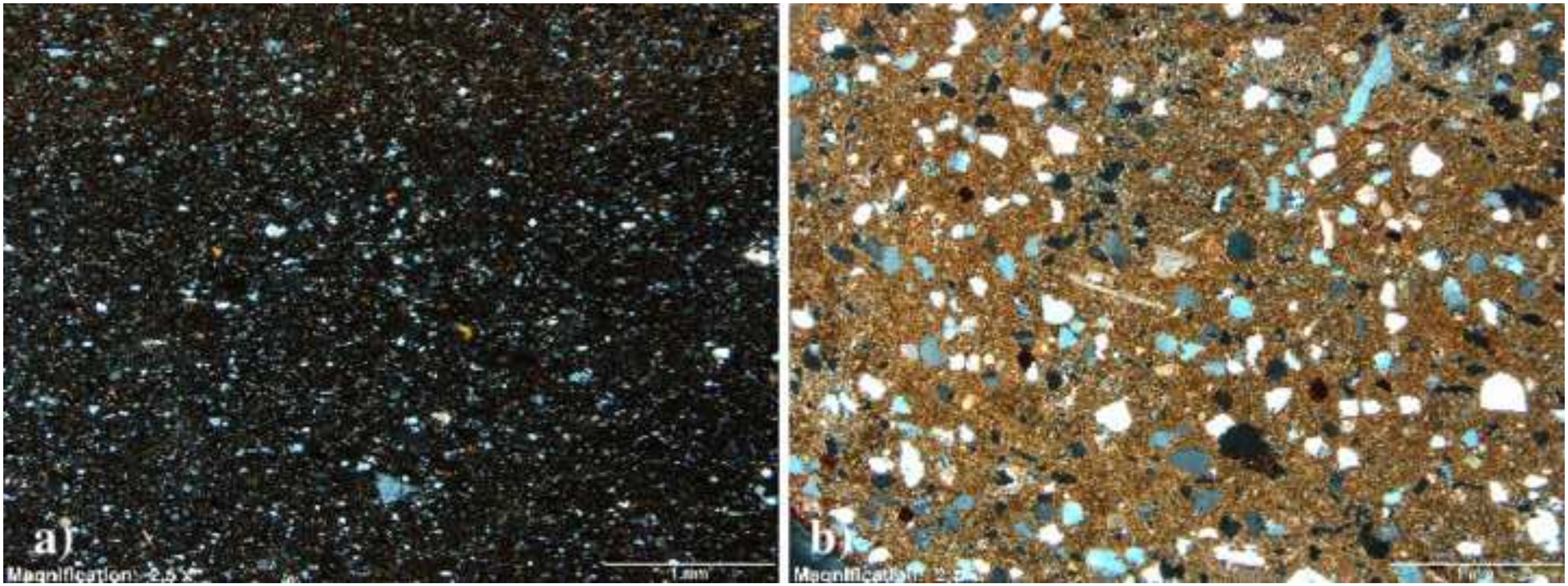
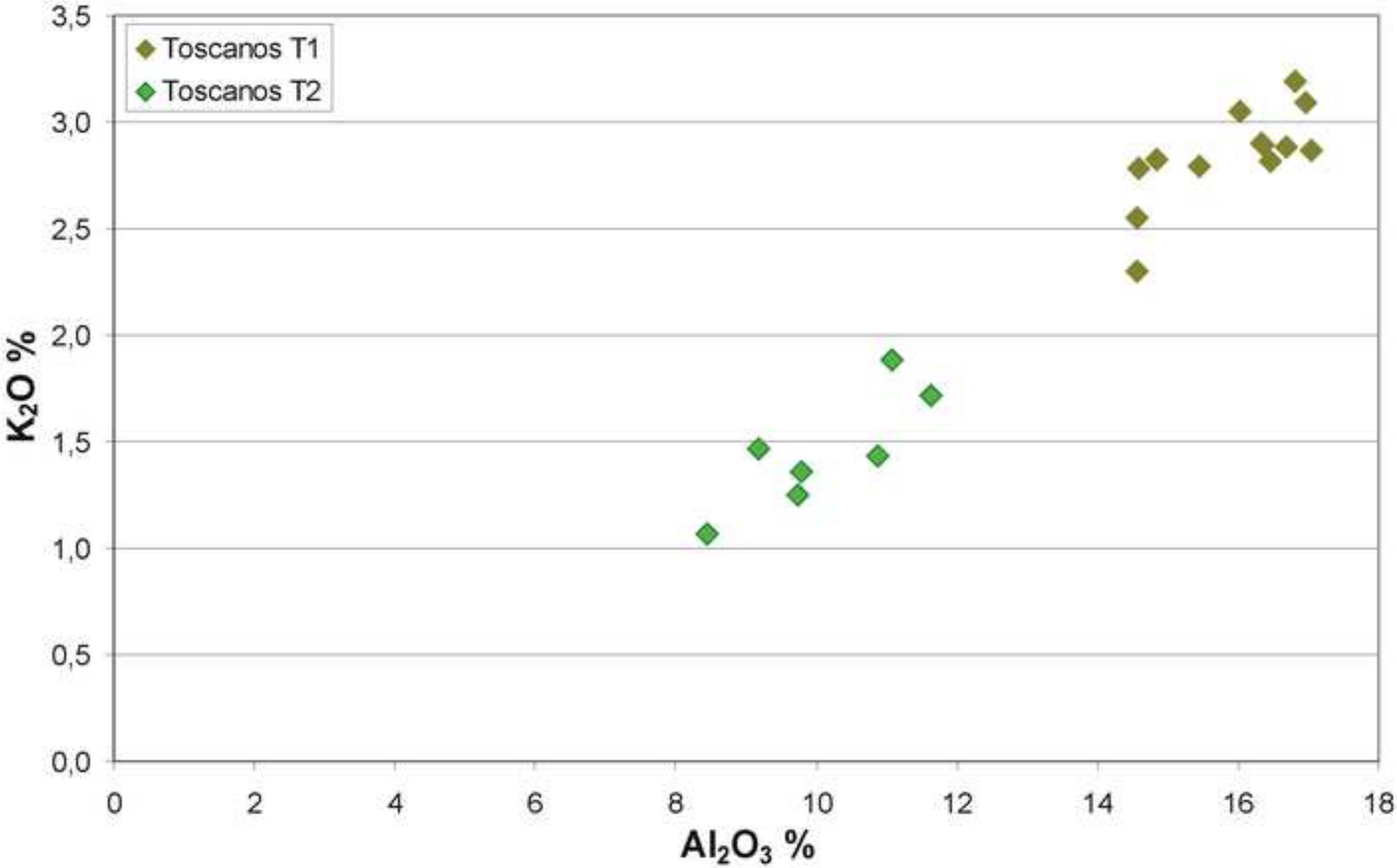


Figure 7

Click here to download Figure Figure 7.tif



Figures 8a-b

Click here to download Figure Figure 8 a-b.tiff

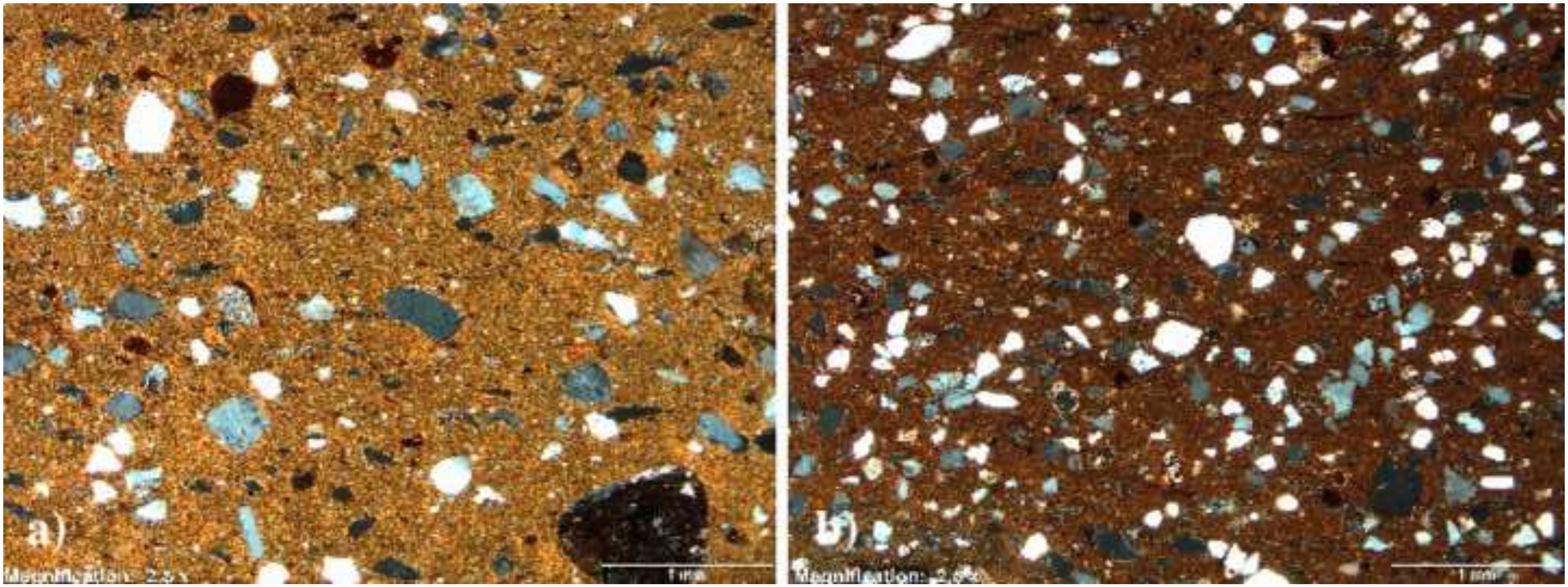
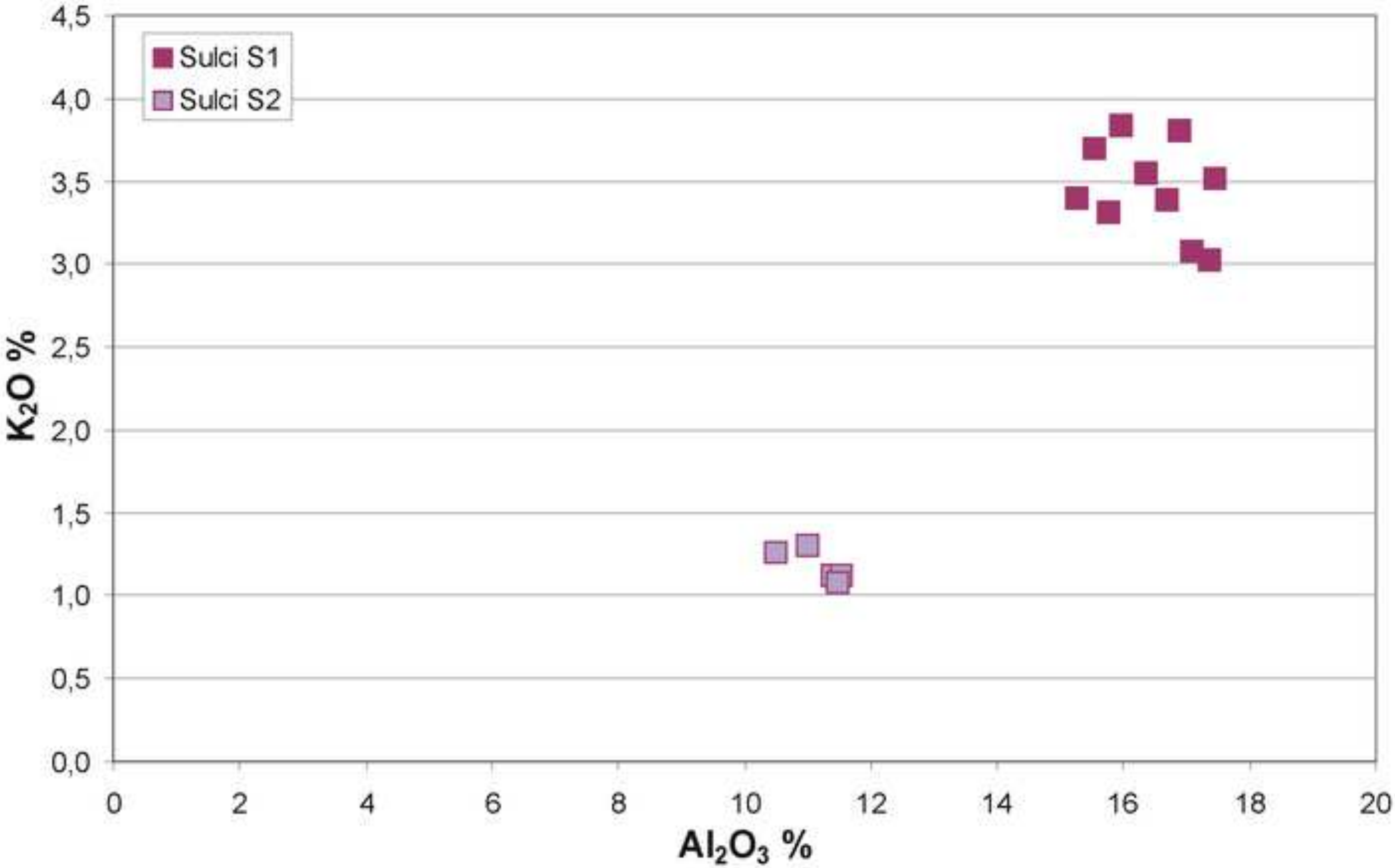


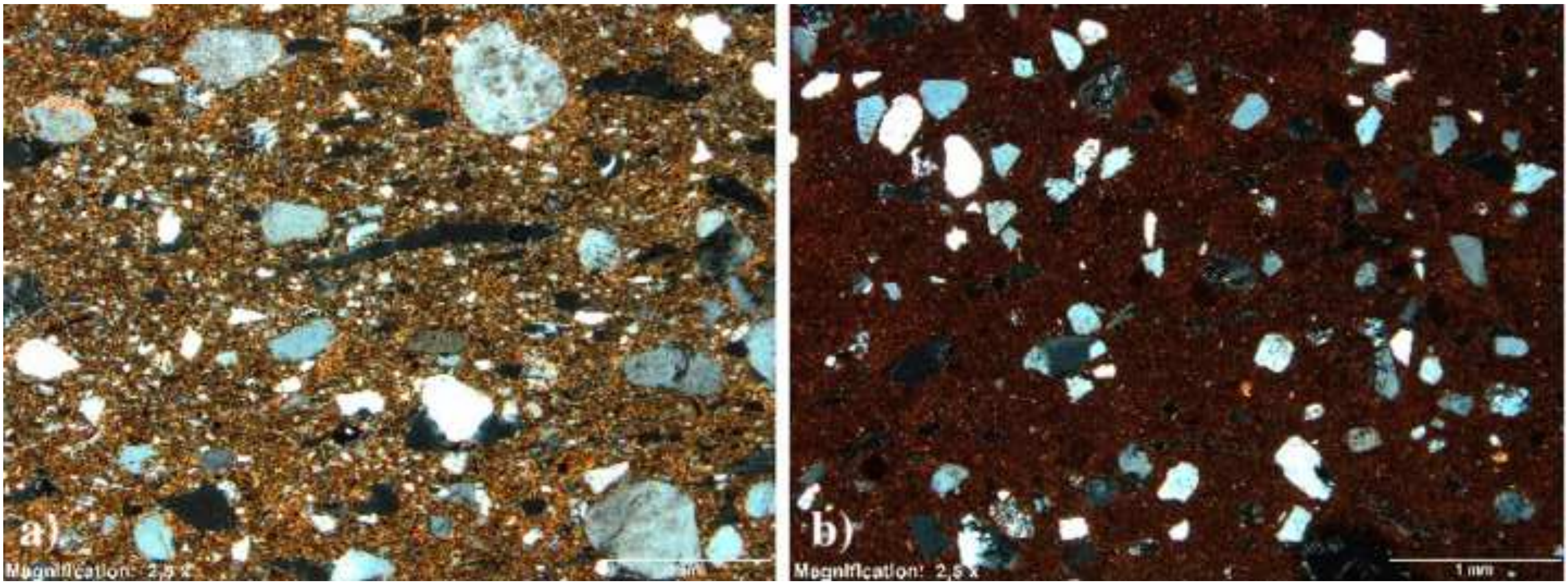
Figure 9

Click here to download Figure Figure 9.tif



Figures 10a-b

Click here to download Figure Figure 10 a-b.tiff



Figures 11a-b-c-d

Click here to download Figure Figure 11 a-b-c-d .jpg

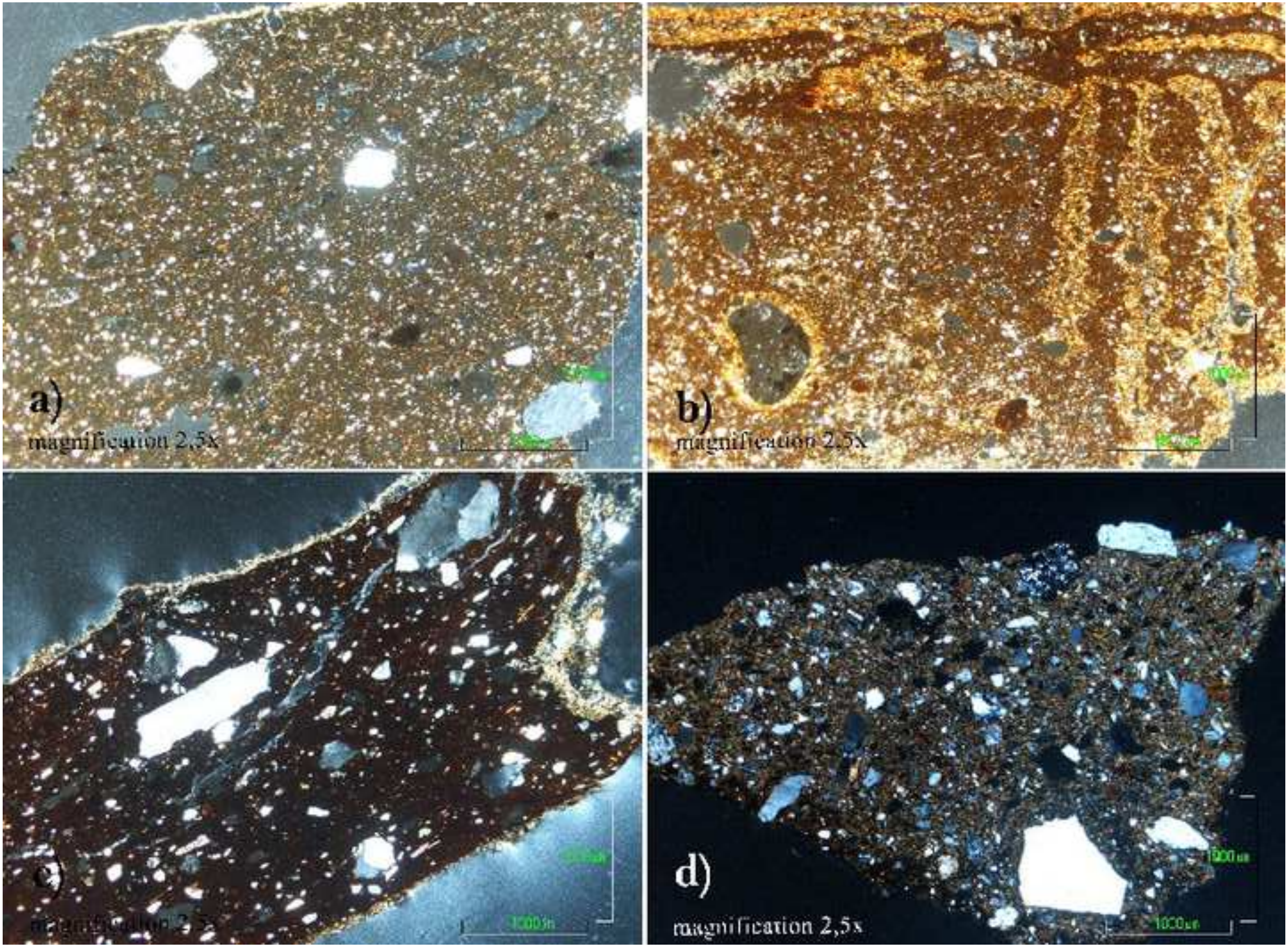
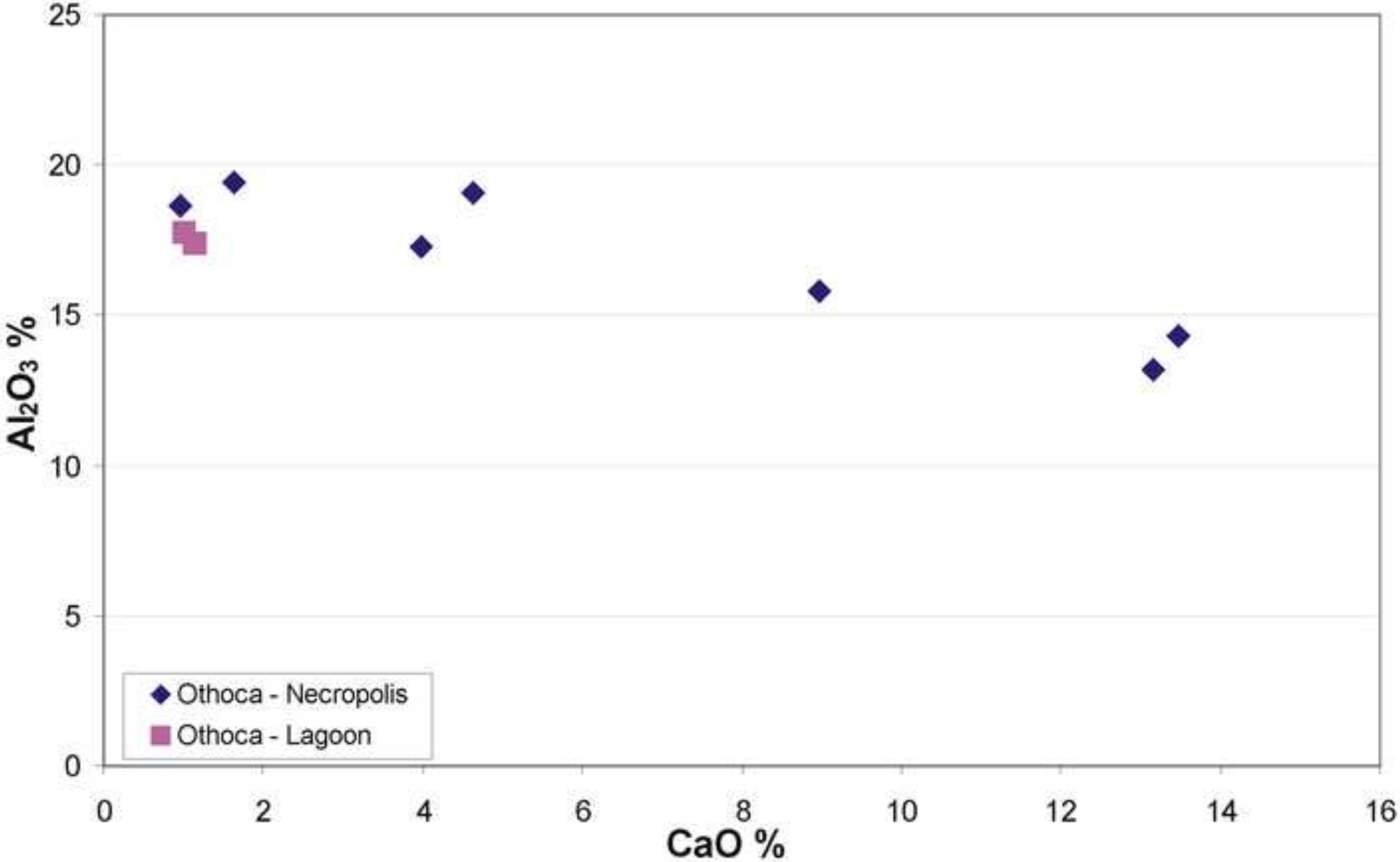


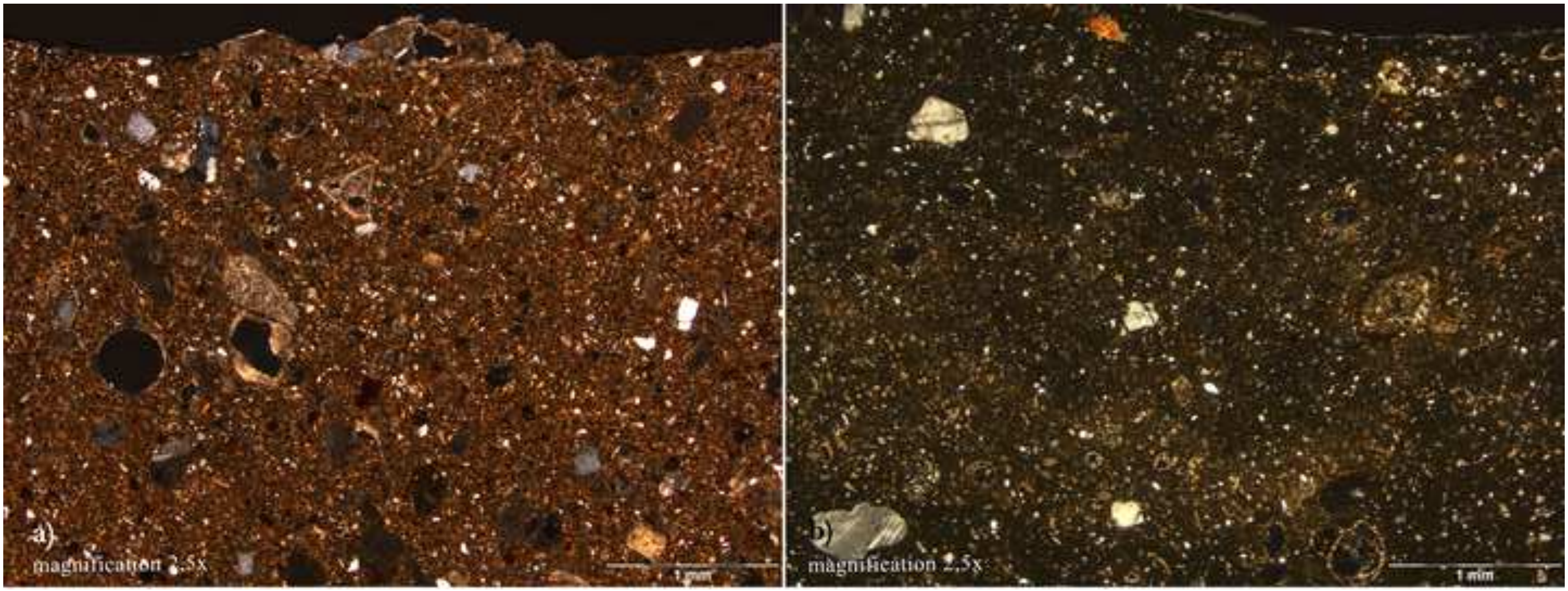
Figure 12

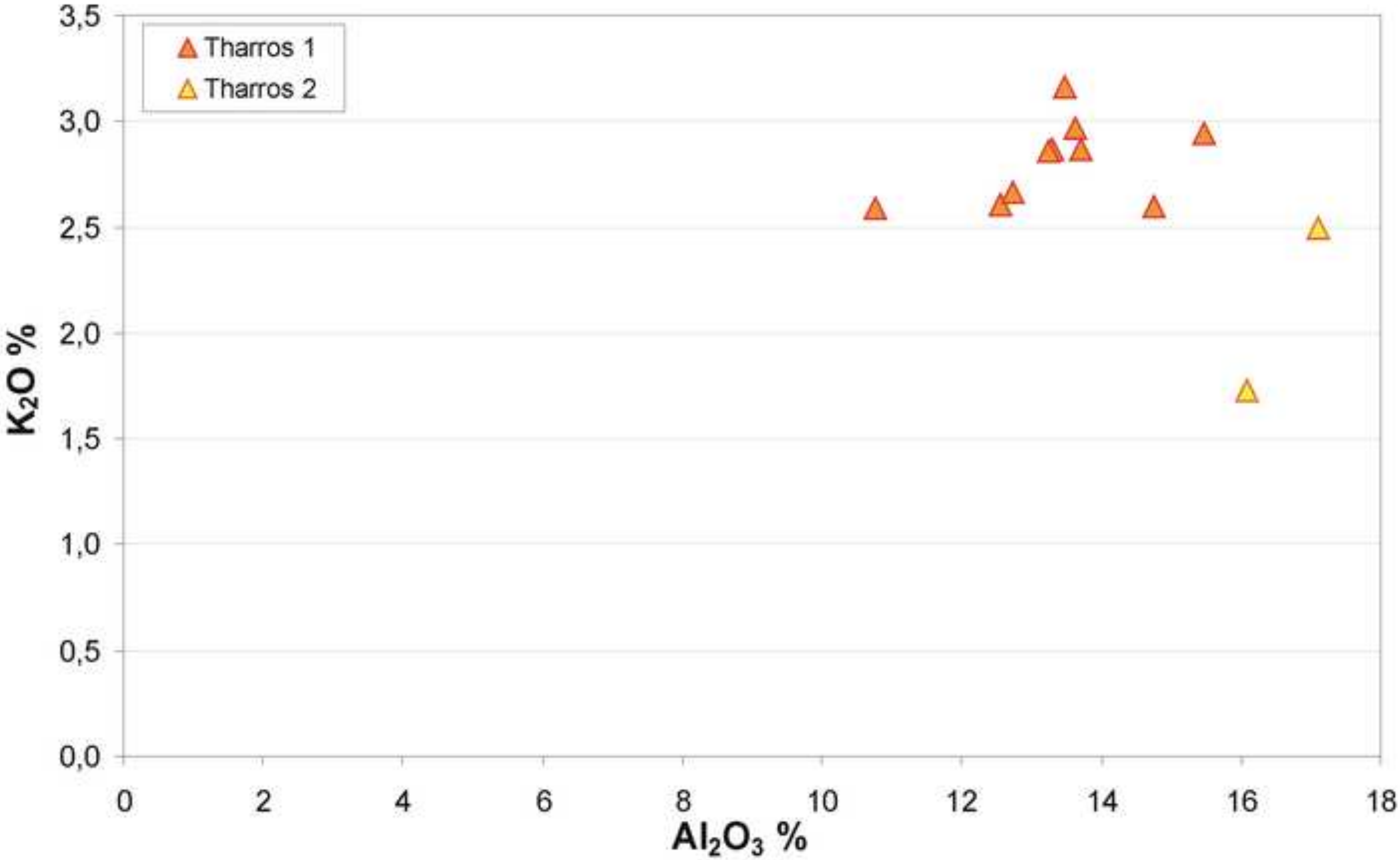


25
20
15
10
5
0
Al2O3 %
0
2
4
6
8
10
12
14
16
CaO %
Othoca - Necropolis
Othoca - Lagoon

Figures 13a-b

Click here to download Figure Figure 13a-b.jpg





Tharros 1
Tharros 2
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
K2O %
0
2
4
6
8
10
12
14
16
18
Al2O3 %

Figures 15a-b

Click here to download Figure Figure 15 a-b.tiff

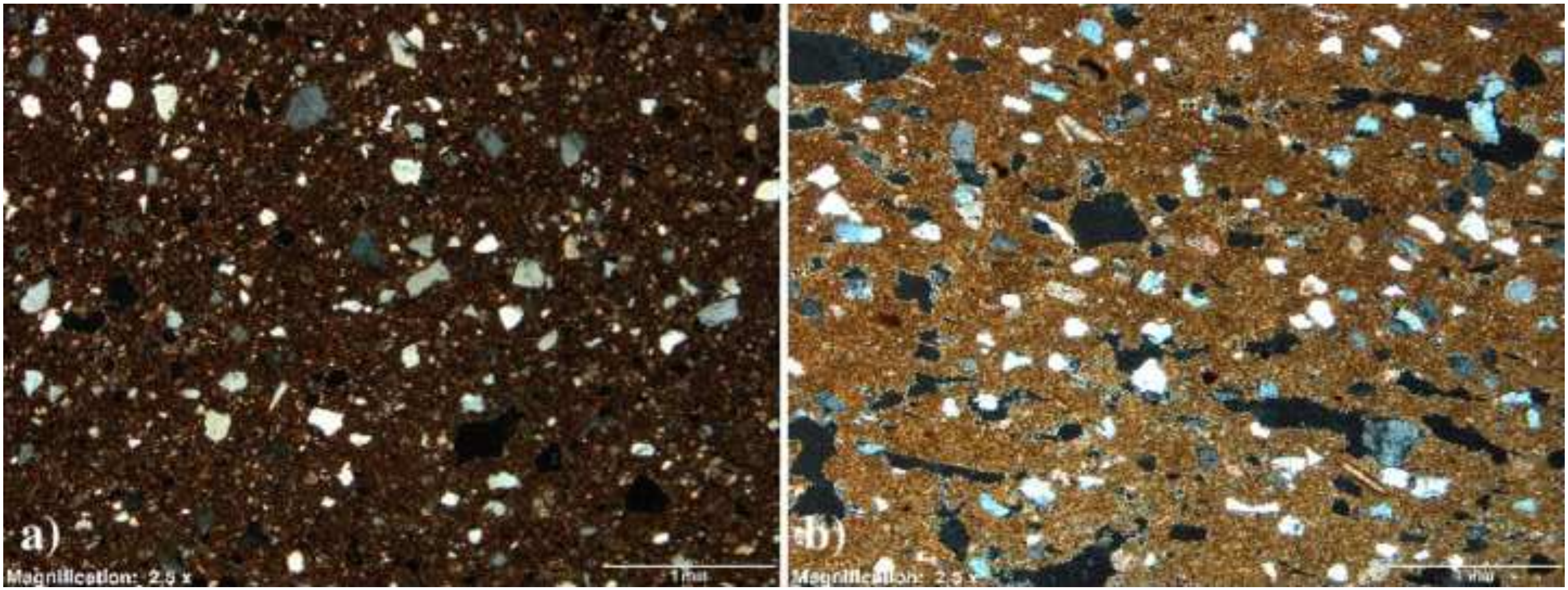


Table 5

Sample	Location	LOI	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
T1	Tharros	16.18	2.82	2.02	10.48	45.38	0.12	2.42	16.74	0.56	0.02	3.26
T2	Tharros	16.80	1.97	1.89	9.93	47.72	0.12	2.21	15.51	0.52	0.03	3.29
M2	Tharros	15.52	1.42	2.13	12.03	46.65	0.12	2.60	14.61	0.63	0.03	4.25
M6	Tharros	17.78	2.37	1.95	10.78	43.10	0.12	2.36	17.45	0.56	0.03	3.50
Nu1	Tharros	14.49	1.35	1.72	11.42	51.32	0.12	2.63	13.18	0.61	0.02	3.13
M12	Tharros	8.11	0.91	2.40	17.14	58.96	0.34	2.41	1.65	0.71	0.05	7.31
ZA	Tharros	9.42	1.81	2.31	17.18	51.69	0.85	1.81	2.14	0.59	0.23	11.96
SGT ARG	S. Giusta Lagoon	3.17	1.38	3.98	17.48	58.49	0.14	3.12	1.18	1.10	0.06	9.90
US 46	Necropolis	5.01	0.91	3.39	19.88	57.03	0.12	4.13	1.49	0.98	0.06	6.99
AREA 1	Othoca	8.57	1.21	2.75	17.66	58.04	0.16	3.55	1.31	0.81	0.05	5.88
AREA 2	Othoca	10.05	1.17	2.38	18.06	56.90	0.08	3.47	1.06	0.78	0.07	5.97
AREA 3	Othoca	4.89	1.57	1.60	12.87	66.11	0.89	3.35	5.00	0.49	0.06	3.16
AREA 4	Othoca	7.46	1.66	1.72	12.99	63.87	0.98	3.16	4.28	0.49	0.05	3.36
AREA 5	Othoca	9.51	1.18	2.26	17.51	56.65	0.35	3.85	1.82	0.73	0.07	6.08

Figure 16

Click here to download Figure Figure 16.tif

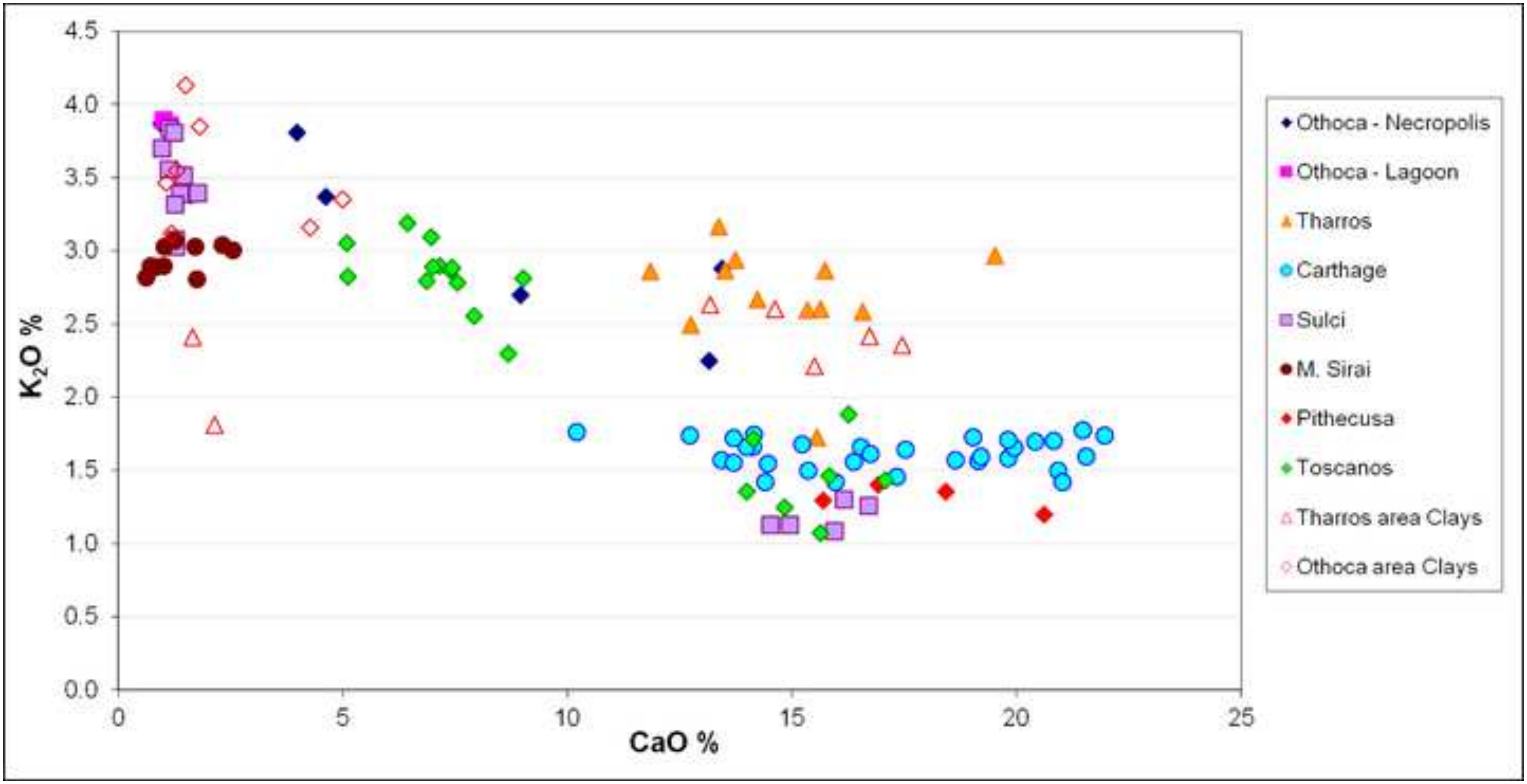
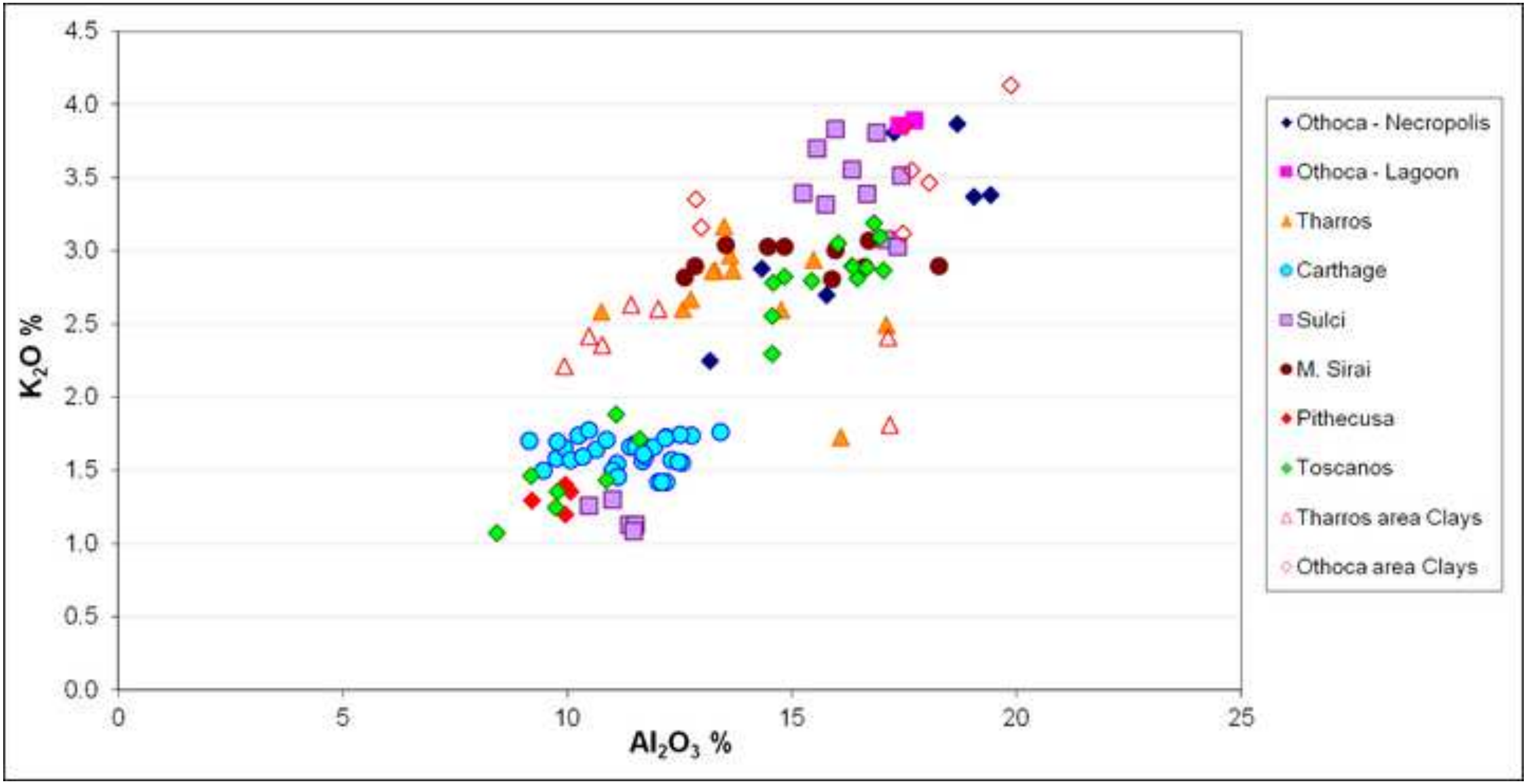


Figure 17



K2O %
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Al2O3 %
Othoca - Necropolis
Othoca - Lagoon
Tharros
Carthage
Sulci
M. Sirai
Pithecusa
Toscanos
Tharros area Clays
Othoca area Clays

Figure 18

Click here to download Figure Figure 18.tif

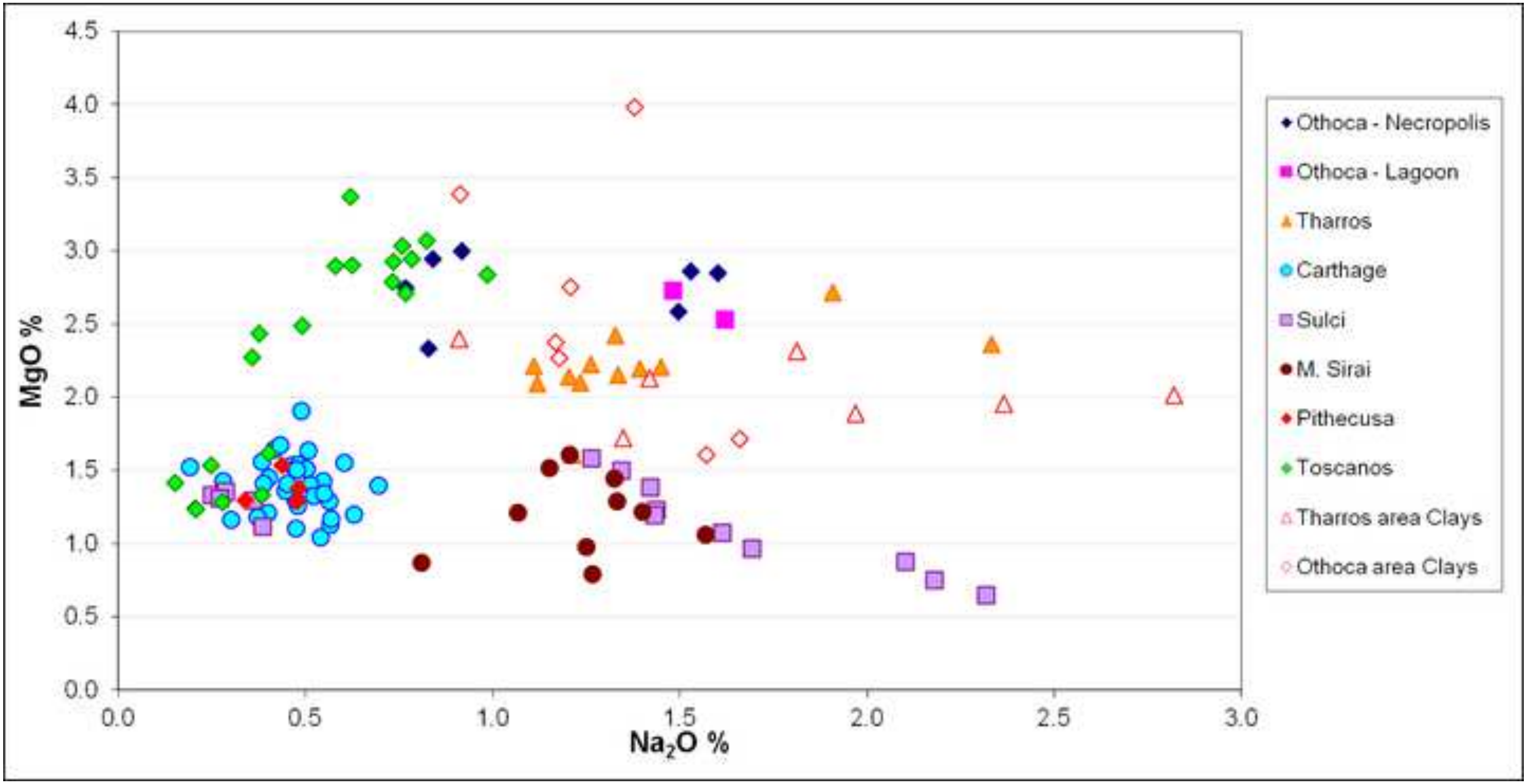


Figure 19

Click here to download Figure Figure 19.tif

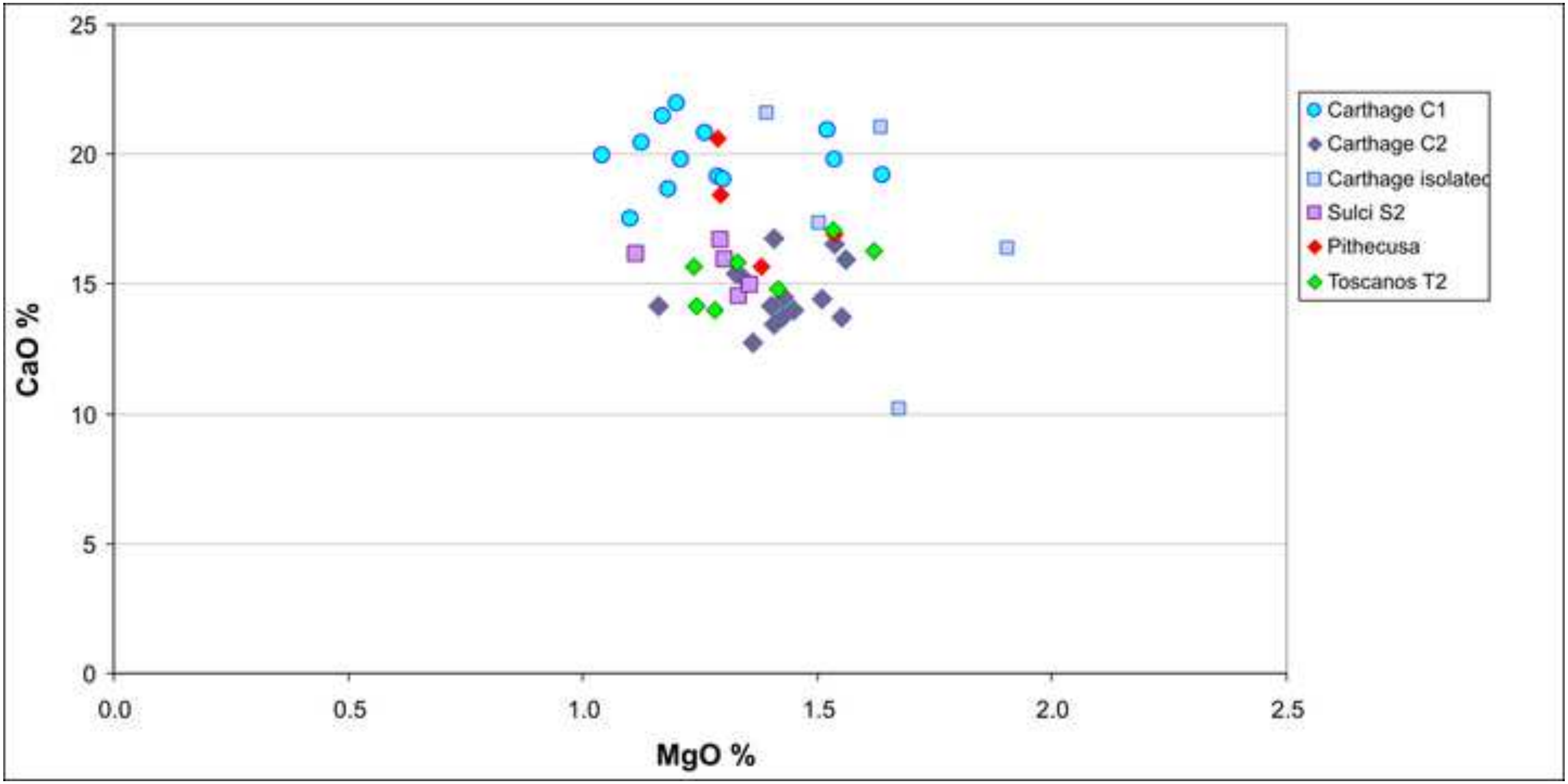
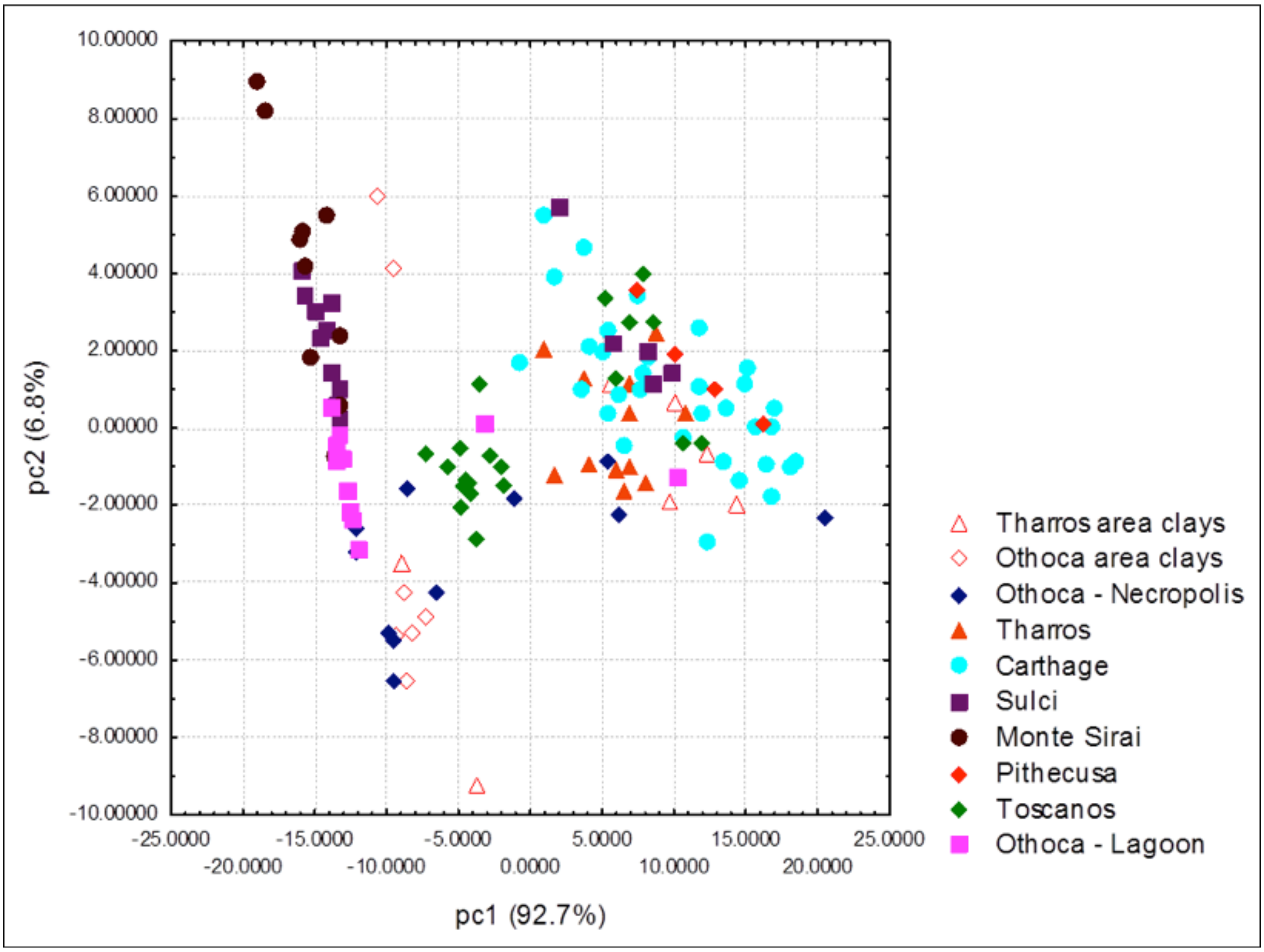
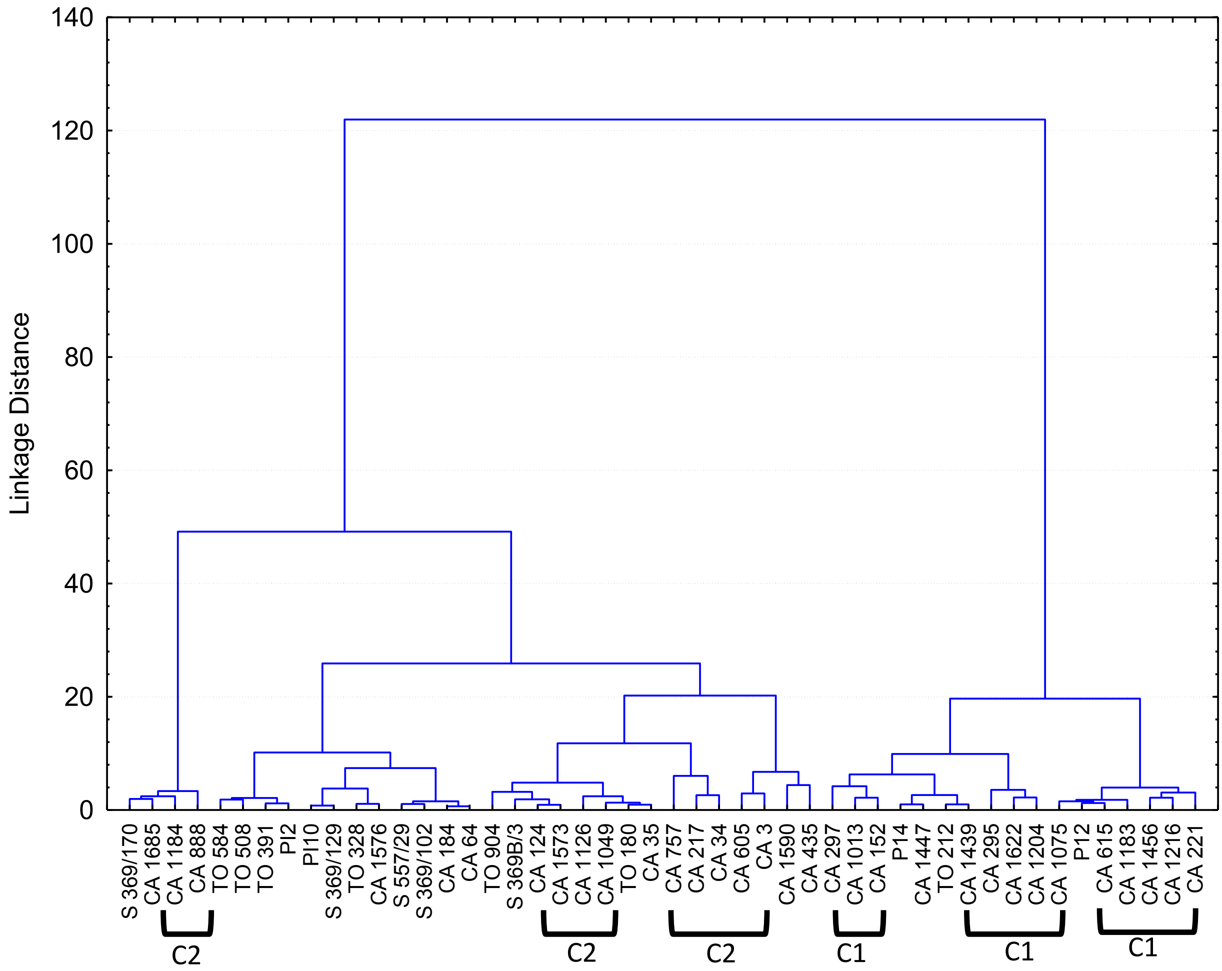


Figure 20



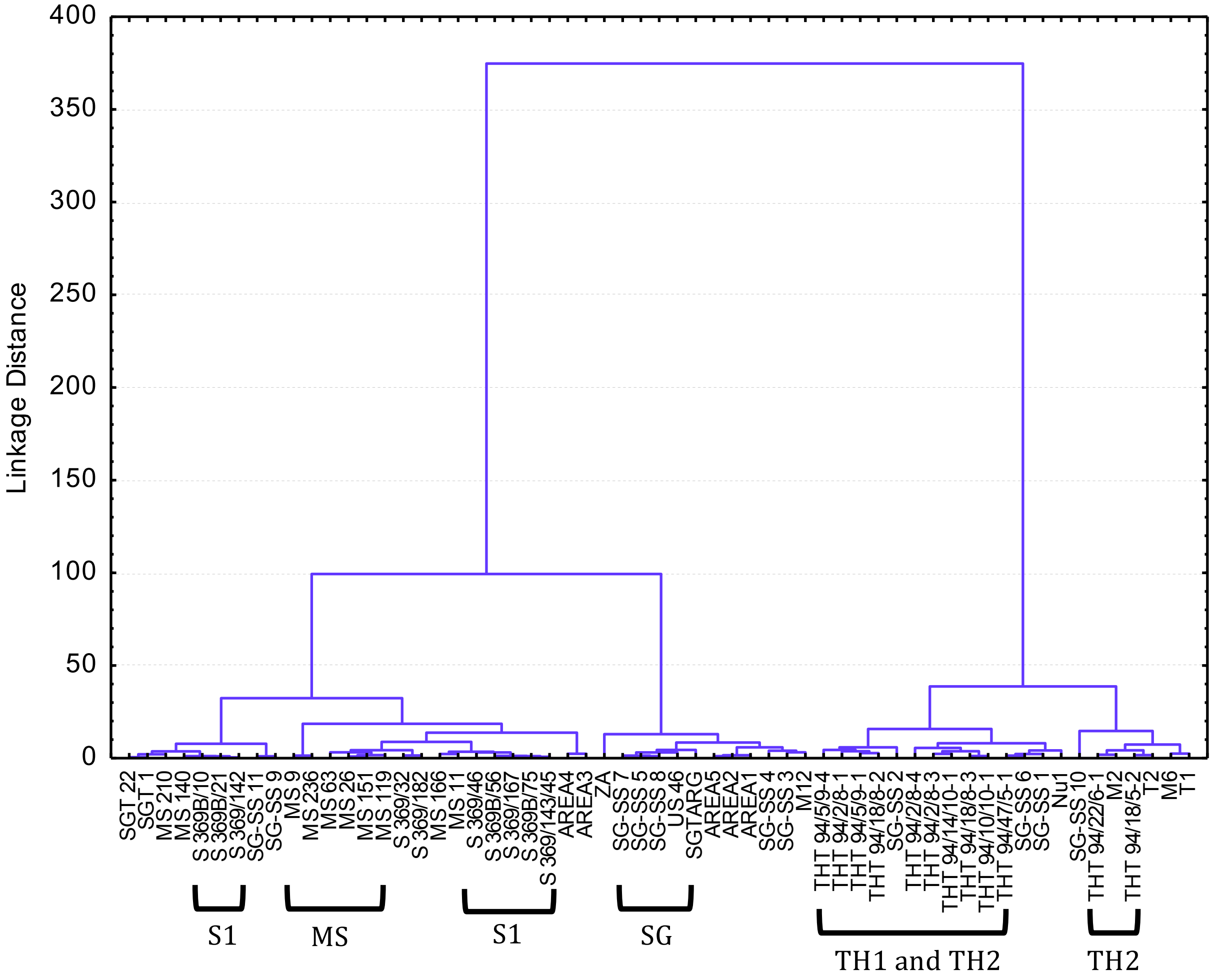
10.00000
8.00000
6.00000
4.00000
2.00000
0.00000
-2.00000
-4.00000
-6.00000
-8.00000
-10.00000
pc2 (6.8%)
-25.0000
-15.0000
-5.0000
5.0000
15.0000
25.0000
-20.0000
-10.0000
0.0000
10.0000
20.0000
pc1 (92.7%)
Tharros area clays
Othoca area clays
Othoca - Necropolis
Tharros
Carthage
Sulci
Monte Sirai
Pithecusa
Toscanos
Othoca - Lagoon

Figure 21



Linkage Distance
140
120
100
80
60
40
20
0
S 369/170
CA 1685
CA 1184
CA 888
TO 584
TO 508
TO 391
PI2
PI10
S 369/129
TO 328
CA 1576
S 557/29
S 369/102
CA 184
CA 64
TO 904
S 369B/3
CA 124
CA 1573
CA 1126
CA 1049
TO 180
CA 35
CA 757
CA 217
CA 34
CA 605
CA 3
CA 1590
CA 435
CA 297
CA 1013
CA 152
P14
CA 1447
TO 212
CA 1439
CA 295
CA 1622
CA 1204
CA 1075
P12
CA 615
CA 1183
CA 1456
CA 1216
CA 221
C2
C2
C2
C1
C1
C1

Figure 22



Linkage Distance
0
50
100
150
200
250
300
350
400
SGT 22
SGT 1
MS 210
MS 140
S 369B/10
S 369B/21
S 369/142
SG-SS 11
SG-SS 9
MS 9
MS 236
MS 63
MS 26
MS 151
MS 119
S 369/32
S 369/182
MS 166
MS 11
S 369/46
S 369B/56
S 369/167
S 369B/75
S 369/143/45
AREA4
AREA3
ZA
SG-SS 7
SG-SS 5
SG-SS 8
US 46
SGTARG
AREA5
AREA2
AREA1
SG-SS 4
SG-SS 3
M12
THT 94/5/9-4
THT 94/2/8-1
THT 94/5/9-1
THT 94/18/8-2
SG-SS 2
THT 94/2/8-4
THT 94/2/8-3
THT 94/14/10-1
THT 94/18/8-3
THT 94/10/10-1
THT 94/47/5-1
SG-SS 6
SG-SS 1
Nu1
SG-SS 10
THT 94/22/6-1
M2
THT 94/18/5-2
T2
M6
T1
S1
MS
S1
SG
TH1 and TH2
TH2

Figures captions

Figure 1 Map of Archaic Phoenician and Punic settlements

Figure 2a Clay samples provenance

Figure 2b Clay samples provenance

Figure 3 a) Sample CA 35, transmitted light micrograph, XPL, C1 group. Carinate cup, Carthage (local); b) Sample CA 1456, transmitted light micrograph, XPL, C2 group. Carinate cup, Carthage (local)

Figure 4 MgO-CaO binary correlation diagram, Carthage samples

Figure 5 CaO-LOI binary correlation diagram, Carthage samples

Figure 6 a) Sample TO 391, transmitted light micrograph, XPL, T2 group. Plate, Toscanos (imported); b) Sample TO 674, transmitted light micrograph, XPL, T1 group. Plate, Toscanos (local)

Figure 7 Al_2O_3-K_2O binary correlation diagram, Toscanos samples

Figure 8 a) Sample SU 369/102, transmitted light micrograph, XPL, S2. Plate, Sulci (imported); b) Sample SU 369/142, transmitted light micrograph, XPL, S1. Plate, Sulci (local)

Figure 9 Al_2O_3-K_2O binary correlation diagram, Sulci samples

Figure 10 a) Sample MS 151, transmitted light micrograph, XPL. Cup, Monte Sirai (local); b) Sample MS 210, transmitted light micrograph, XPL. Plate P2, Monte Sirai (local)

Figure 11 a) Sample SGSS 2, transmitted light micrograph, XPL, O1 group. Jug with vertical neck, Othoca (local); b) Sample SGSS 9, transmitted light micrograph, XPL, O2 group. Mushroom-lipped jug, Othoca (local); c) Sample SGT 22, transmitted light micrograph, XPL, O3 group. Transport amphora T.1.4.2.1 (local); d) Sample SGSS 3, transmitted light micrograph, XPL, O4 group. Transport amphora, Othoca (local)

Figure 12 CaO-Al_2O_3 binary correlation diagram, Othoca samples

Figure 13 a) Sample THT 94/18/5-2, transmitted light micrograph, XPL, TH1 group. Plate, Tharros (local); b) Sample THT 94/10/10-1, transmitted light micrograph, XPL, TH2 group. Plate, Tharros (local)

Figure 14 Al_2O_3-K_2O binary correlation diagram, Tharros samples

Figure 15a Sample PI 2, transmitted light micrograph, XPL. Pithecusa (imported); b) Sample PI 12, transmitted light micrograph, XPL. Pitecusa (imported)

Figure 16 CaO-K_2O binary correlation diagram for all ceramic and clay samples

Figure 17 Al_2O_3-K_2O binary correlation diagram for all ceramic and clay samples

Figure 18 Na_2O-MgO binary correlation diagram for all ceramic and clay samples

Figure 19 MgO-CaO binary correlation diagram. Carthage, Sulci, Pithecusa and Toscanos-T2 samples

Figure 20 Principal component analysis among local and imported pottery and clay samples carried out on the element determined by XRF analysis

Figure 21 Cluster dendogram of imported pottery; the samples from Chartage and belonging to the two groups C1 and C2 have been highlighted; samples CA757 and CA605 (identified as isolated) group together with samples belonging to C2 group (third cluster from the left) while sample CA297 and CA295 (also identified as isolated) group together with samples belonging to C1 groups (fourth and fifth clusters from the left) (see table 4 for the grouping)

Figure 22 Cluster dendogram of local pottery; the groups reported in table 3 have been highlighted (only in the case of clusters forms by more than 2 samples belonging to the same group) (see table 4 for the grouping)

Tables captions

Table 1 List and description of ceramic samples
Table 2 List and description of clay samples
Table 3 Mineralogical compositions of ceramic samples (XRD)
Table 4 Chemical composition of ceramic samples (%)
Table 5 Chemical composition of raw clay materials (%)

 Click here to download Manuscript cover letter_.doc

Click here to view linked References

COVER LETTER:

Dear Editor,

Please find attached the manuscript titled “Archaeometric Researches on the Provenance of Mediterranean Archaic Phoenician and Punic Pottery”.

In the name of our colleagues, we kindly ask you to evaluate our paper for its scientific approach and its interdisciplinarity to study Archaic Phoenician and Punic Pottery.

The archeological question concerning the provenance of different Archaic Phoenician and Punic Pottery was deeply investigated using statistical analyses to define the existence of different ceramic compositional groups characterized by a local origin or imported from other sites.

We had the opportunity to examine more than one hundred potsherds between different functional and productive ceramic categories. The finds are dated from 8th to 6th/begin 5th century BC and come from different Mediterranean Phoenician and Punic excavation sites.

The existing literature data were supplemented by new archeometric investigations both on Archaic Phoenician ceramics and raw clayey materials from Othoca (Sardinia).

The statistical treatment of the literature and new data has confirmed the reliability of the database, attesting the presence of importation ceramics and allowing a better discrimination between Carthage and local pottery by using two different cluster analyses.

This reference database is useful to detect the importation ceramics from Carthage and to distinguish the productions between local Phoenician Archaic pottery and can be applied also to unknown ceramic samples of comparable age and production areas.

References are selected from a large bibliography as the most relevant, besides if some of them are written in Italian language.

The corresponding author is: Prof. Maria Letizia Amadori
<maria.amadori@uniurb.it>

Best regards,

Maria Letizia Amadori

Reviewers' comments
-Authors answers

Reviewer #3: « Archaeometric researches on the provenance of Mediterranean archaic Phoenician and Punic pottery » by Amadori et al.

More than 100 samples of archaeological ceramics and clayey raw materials were studied from different settlements from Tunisia, southern Spain and Sardinia in Italy in order to better understand the diffusion of Archaic Phoenician and Punic pottery. Globally speaking, the study is interesting and needs to be published even if some of the data is already published. Samples from a new site are presented here to complete the previous results and enlighten us about the diffusion of these ceramics considered as a local production by archaeologists.

Sometimes the text it is unclear. I suggest to rewrite some specific parts in a more clear way and make some corrections (see below) to help the readers.
- We rewrite clearly more parts and we explain with more details.

First of all, in the "materials" part, the location of the outcrops or even the exact place where clayey sediments were sampled should be indicated (GPS data or a map could be useful). More information about the samples (such as age, layer…) must be included, either by adding a table or alternatively adding new columns in Table 1.

-We added Table 2 and geological map (figs 2a and 2b).

Check the coherence of Othoca samples, as there are only 6 in the Table but 7 are referred in the text (pg. 3).

-We changed the number: the samples SGT are 6 as you can see in table 1, the samples SGSS are 7. We analysed by XRD 11 samples, by XRF 9 sample and by optical microscope 13 samples

Concerning the "Methods" part, it must be specified if all methods have been applied to all samples, if the geochemical methods is ED-XRF or WD-XRF, and why only major and minor elements have been chosen (and no trace elements).

- Ok we better explained in Methods part a)

Please add references concerning multivariate analysis that are very useful and common in ceramics studies since 1988 (Mommsen et al, 1988….).
- Ok we added references (Fermo et al. 2004, 2008; Padeletti e Fermo 2010).

In the "results part", the geochemical results should be included also in the description of each site's composition. This will allow more interesting comparisons between the

results of each method and can help understand the presence/absence of certain phases. For example when there is no calcite, it should be more interesting to compare with the CaO concentration and similarly with the presence of ca-silicate such as gelehnite…
- Ok we added more details in the results

In addition to this, a table concerning XRD results is missing.
-OK we added Table 3 Mineralogical composition of ceramic samples

References in relation to firing conditions are also missing to explain your proposal of temperatures. There are a lot of publications on this subject (Maggetti, 1982 and Magetti et al.,2011, Cultrone et al, 2001…). Perhaps, it would be clearer if you present your hypothesis of firing conditions in a table including also a synthesis of XRD results (presence/absence of some phases and hypothesis of firing conditions).
-OK we added Table 3 Mineralogical composition of ceramic samples and some references

In the discussion, you should only present comparison between new results (relative to Othoca) and the previous ones.
- Ok we added more details in the results and in the discussion

You also explain (quickly) that you deal with literature results and the new ones, taking into account P and LOI. But is it the only difference between the 2 series of results? Are there obtained by the same analytic method and equipment?
- Ok we added the equipments used and we added more details in the results and in the discussion

Finally, the conclusions are somewhat weak and limited. An historic perspective or contextualization of your results would be advisable, insisting on, for example, the diffusion of these kinds of products and comparing it with the well-known amphorae diffusion.
- Ok we added more details in the results and in the discussion

Another remark concerns the notion of "temper". In the conclusions you mention that temper was added, but before then you never discuss how ceramics were made and in fact, you only describe (in the results) if there is a serial or bimodal distribution of the aplastic inclusions. The possibility of potters adding temper to the clay needs to be addressed at some point before the conclusions.
- Ok we added more details in the results and in the discussion

Figures
Figure 1: scale is missing
-Ok we added the scale

Figure 2a to 8b: More information on the title is needed, such as the name of the site, the chemical group, and if it is PPL or XPL photomicrograph. Please precise also if it is the local hypothesis or the imported hypothesis for each photo. Please add also on the image the sample number.
- Ok we added more details in the figures captions

There is a mistake in figure 4a and b: it is 369 and not 396.
-OK we changed the wrong number

Figure 6: why do you choose another scale? If makes it is less easy to compare with other photomicrographs.
-Yes we changed with other figures

Figure 7: I don't understand why you don't show a photomicrograph of TH2 and why you chose 2 micrographs of the same group (TH1)? Might it be an error?
-Yes we changed with another figure of a sample of TH2 group

Figure 13: Please add a legend on your dendrogram to explain the 2 groups (C1 and C2) and draw the grouping on the dendrogram to explain clusters.
-*Fig. 13 now became fig. 21. The groupings have been drawn on the figures indicating the names as reported in Tables 4. We prefer not to add a legend because it could be to heavy but we reported table 4 in the figure captions.*

Figure 14: what are the variables chosen to realize the PCA analysis? Do you retain LOI when you calculate? Precise these informations in the title but also please note it under the graph, on the axis or with another graph referring to variables.
-Fig. 14 now became fig. 20. As reported in the text pag 3 Methods b) PCA, HCA were applied considering as variables the elements (oxides) determined by XRF. Now it has been also specified in the figure of the legend.

Figure 15: same as Figure 13
-Fig. 15 now became fig. 22

Tables
Table 3: Table 3 is difficult to follow because information about each sample must be found within the text (which are those from Tharos? and those from Othoca?).
-Yes we changed all the tables with other tables more clear.

Consider producing a new table (as suggested before) explaining the sampling of clayey sediments.
-OK we added table 2