Mediterranean Archaeology and Archaeometry, Vol. 16, No 1,(2016), pp. 237-248

DOI: 10.5281/zenodo.44774

ROMAN CERAMIC PIECES FROM CENTRAL SPAIN: VISUAL, TEXTURAL, CHEMICAL, MINERALOGICAL AND STATISTICAL ANALYSIS

Isabel S. de Soto*[12], Rosario García Giménez[2] and M. Reyes de Soto[3]

[1]*Departamento de Ciencias del Medio Natural. Escuela Superior de Ingenieros Agrónomos. Universidad Pública de Navarra, 31006 Pamplona, Spain.*

[2] *Departamento de Geología y Geoquímica. Facultad de Ciencias. Campus de Excelencia Internacional de la Universidad Autónoma de Madrid. 28049 Madrid. Spain.*

[3.] *Departamento de Prehistoria, Historia Antigua y Arqueología. Facultad de Geografía e Historia. Universidad de Salamanca. 37008 Salamanca. Spain.*

Received: 31/07/2015
Accepted: 14/01/2016
Corresponding author: isabelsonsoles.desoto@unavarra.es

ABSTRACT

A complete visual, mineralogical, textural, chemical and statistical study is presented of thirty ceramic specimens recovered from various Roman archaeological sites in central Spain (Ávila). Therefore, the novelty of this work is that we report the first complete study of pottery fragments in the Ávila region (Castile and Leon, Spain) dating back to the Roman Empire. Potential/local raw materials were characterised, in order to classify ancient pottery samples by origin. The presence of firing minerals in the ancient ceramic samples was studied, to investigate the technology used in their manufacture. Another innovation of this article is that the statistical study has established links between ceramic samples, shedding further light on knowledge of manufacturing techniques in this region during the Roman Empire.

Similar materials were identified in most of the ceramic pieces from the archaeological sites, all present in the local geological environment, which underlines their autochthonous origin. The raw materials were initially chosen on the basis of the final use of the sample (typology of the samples: *Terra sigillata hispanica*, common pottery and *tegulae*).

The samples were manufactured within three different temperature ranges (temperature > 900Cº, between 900 – 800ºC and between 800– 600ºC) and under three different redox environments (oxidizing, reduction and irregular conditions). Non-plastic inclusions were added, intentionally or otherwise, to the initial clay, depending on the final typology of the sample.

KEYWORDS: Roman ceramics, Archaeometry, Chemical analysis, Mineralogical analysis, Centre of Spain.

1. INTRODUCTION

Archaeometry, a sub-discipline of archaeology, studies the origins of ceramic pieces, their manufacture processes and associated technologies, the location of production centres, etc. (Butzer, 1989; García Heras and Olaetxea, 1992; Pérez Arantegui *et al.,* 1996; Vigil de la Villa and García Giménez, 2005; Williams, 2005; Segvic *et al.,* 2012). Fragments of ancient pottery pieces are the most common artefacts found during the excavation of archaeological sites, which are of immense interest to archaeologists (Ravisankar *et al*., 2011). Pottery analysis reveals information on the daily life and the cultural aspects of ancient society. Mineralogical composition can reveal technological aspects of pottery production (Gallart and Mata, 1995; Palanivel and Kumar, 2011) and a comparison of the mineralogical compositions of both the raw materials and the pottery samples can often reveal the origin of the pottery (Vigil de la Villa *et al*., 1998, Barrios *et al*., 2009; Barone *et al*., 2014; Waksman *et al*., 2014). The minerals in ancient pottery are classified as primary minerals (minerals present in the raw materials that have not undergone reactions at a wide range of temperatures), and firing minerals (minerals formed during the firing process). The presence and absence of firing minerals in ancient pottery play a vital role in the estimation of firing temperature (Ramos *et al.,* 1990; Iordanidis *et al.* ,2009; Palanivel and Kumar, 2011; Ravisankar *et al.,* 2011). Chemical analysis is increasingly used as a tool in archaeological studies (Carmona *et al.,* 2014), as it can reveal the origin of the samples, when the chemical analyses of each sample and of a selection of raw materials are compared (Barone *et al.,* 2012; Finlay, *et al.*, 2012; Barone *et al.,* 2014). The regional geochemical background is crucial to identify the source of the raw materials used in the manufacture of the ceramics (Dias and Prudencio, 2008).

This paper shows archaeometric data from thirty ceramic specimens found in three Roman archaeological deposits in the region of Ávila (Spain); "Huerta de la Dehesa", "Las Torrecillas I" and "Las Vegas" (Figure 1). Despite the historical importance of ceramic samples from Roman archaeological deposits in the region of Ávila (Spain), there are very few studies of the mineralogical and the chemical composition of the ceramics from this region. In general, the identification of local products has always been founded on traditional methods, namely observation with the naked eye (Barone *et al.,* 2012; Segvic *et al.,* 2012) only in a few cases chemical and mineralogical studied has been done. For this reason, for a complete study of the samples found in Ávila, this work includes a visual, mineralogical, textural and statistical study of the ancient pottery samples and their potential local/regional raw materials, in order to classify each piece by its origin. The technology used in their manufacture is also investigated, through information gleaned from the fired minerals in the pottery samples.

The province of Ávila (Spain) had a Roman settlement at least since the first century. Roman rural settlements dating back to the Flavian period on the northern plateau of Spain have been confirmed in an archaeological survey (Ariño, 2006; Blanco, 2009). However, little information exists on Roman sites in the province of Ávila, because no detailed studies have been made. We know of the existence of Roman settlements in different towns of the province such as Piedrahita, Magazos, Niharra or Mancera de Arriba (Rodriguez, 2003), but previous data are old and not very specific. Moreover the epigraphy that has been found in the province is significantly low and is often concentrated in the city of Ávila and in the sanctuary of Postoloboso (Candeleda) (Hernando, 2005). In short, we find few studies on Roman rural settlements. So as to complete this information, a systematic survey was conducted and ceramic fragments were collected from three archaeological sites, to perform a complete characterization of the samples.

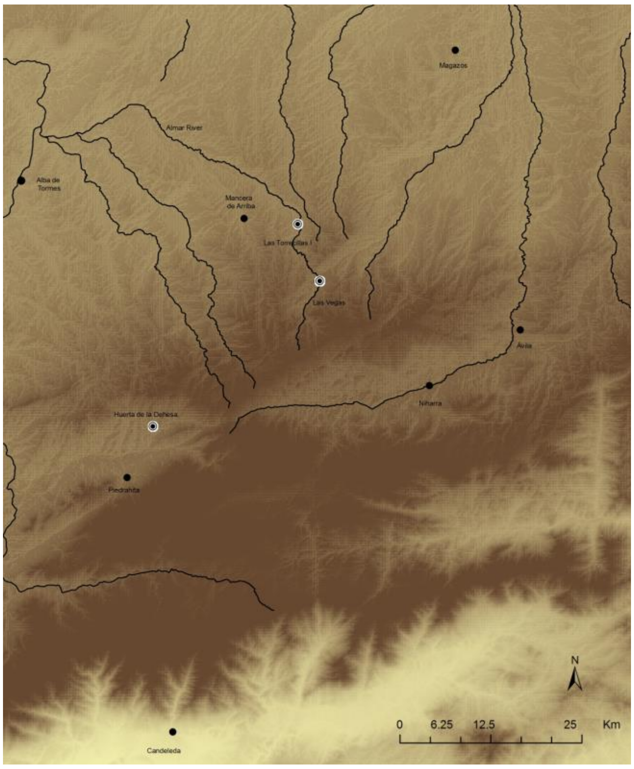

Figure 1. Location of Archaeological Sites

Las Vegas site is located at Solana del Rio Almar, in a spacious valley. Many and varied archaeological materials, some of which are constructive artefacts, have been found at this site, prominent among which are the granite blocks located near the Almar River. Las Torrecillas I is located at Blascomillán. This site preserves a structure of *opus caementicium*, which the Archaeological Inventory has associated with a large reservoir structure the ends of which are polygonal shapes. The existing wall has a width of 60 cm. and at some points rises to one meter in height. Finally, Huerta de la Dehesa is located in Bonilla de la Sierra. This archaeological site is defined by a large variety of materials on which we have very little information (Figure 1).

No complete systematic excavations appear to have been done at these Roman archaeological sites and evidence that illegal excavations have taken place on several occasions is limited to the "Las Vegas" site.

The area is geologically situated within the Central Iberian Zone, the innermost part of the Hercynian Cordil-lera System (Sociedad Geológica de España e Instituto Geológico y Minero de España, 2004). The archaeological settlements are sited on a thick sequence of Tertiary to Quater-nary sediments where siliceous sedimentary rocks are presented. The materials are levels of clays, mudstones, arkoses, sand-stones, conglomerates and limestones, with intercalations of palaeochannels of sands and gravels.

2. MATERIALS AND METHOD

A selection of 30 ancient ceramic fragments was taken from archaeological digs in the Almar Valley, near Ávila (Spain) (de Soto, 2010). Samples were selected according to their morphology, typology (*terra sigillata hispanica*, common pottery and *tegulae*) and chronology (Roman Empire). The samples were found at three archaeological sites (Huerta de la Dehesa (HD), Las Torrecillas I (LT) and Las Vegas (LV)) (Figure 1) and were as representative as possible. These samples were characterised according to their colour, texture, mineralogy and chemistry. In all cases, a minimal part of sample was taken to minimize damage to archaeological objects.

Three raw reference materials were collected in the archaeological sites and then they were analysed with the purpose of identifying the ancient clay sources. For this purpose, we had chosen the places next to the ancient craftsmen's quarters (Barone *et al.*, 2012).

The pottery samples were labelled "HD", "LT" or "LV", to indicate the location of the archaeological site, followed by an identification number. The raw material patterns were labelled with an "S" signifying soil, followed by "HD", "LT" or "LV" to indicate the location of the archaeological site.

2.1. *Visual Examination*

The colour of the samples was studied, in order to determine the redox conditions of the manufacturing process. The colour sample was observed with the Munsell Soil Color Chart (Munsell, 1975).

2.2. *Mineralogical Analysis*

XRD is a powerful tool in characterizing archaeological ceramics (Eiland and Williams, 2001). For this reason, the mineralogical compositions of the ancient ceramics and soil samples were determined by X-Ray diffraction (XDR) using a SIEMENS D-5000 with a Cu anode, operating at 30 mA and 40 kV, using divergence and reception slits of 2 mm and 0.6 mm, respectively. Peaks were identified following the criteria propose by Schultz (1964) and Brindley and Brown (1984). The estimated peaks for the semiquantitative analysis are (Islam and Lotse, 1986): smectite 14.4Å; illite 9.9Å; kaolinite 7.14Å; phyllosilicates 4.49Å; quartz 4.26Å; feldspar-K 3.30 – 3.24Å; plagioclase 3.22 – 3.18Å; calcite 3.30Å; pyroxene 2.29Å and dolomite 2.88Å. Since the powder method was used, clay minerals were not quantified.

Mineralogical and textural analysis of the samples was also studied by the observation of thin transverse sections (20–25 μm) in a Petrographic Polarisation Orto Plan Pol Leitz Microscope, using both white and crossed polarised light with 64 augmentations.

2.3. *Chemical Analysis*

Dissolution of samples was performed as follows (García Giménez *et al.*, 2005): a minimum amount of sample was treated with hydrofluoric acid in an open vessel, heating it on a hot plate until dryness. This treatment was followed by the addition of aqua regia, heating again until dryness. The residue was dissolved with 1ml of concentrated hydrochloric acid and diluted with water to the mark in Teflon volumetric flasks. Care was taken to keep contamination to a minimum. Ultrapure water was used throughout and all reagents used were of analytical grade. Chemical analyses of both major and minor elements were performed by inductively coupled plasma-mass spectrometry (ICP-MS) in a Sciex Elan 6000 Perkin Elmer spectrometer equipped with an AS91 autosampler. Inductively-coupled plasma spectrometry is one of the most important chemical techniques for the characterization of solid materials in recent studies and is becoming more popular in archaeological studies, as it provides information on a huge number of elements (William, 2005). Chemical analysis is an ideal technique, to obtain a concentration fingerprint of the pottery sample (Marengo *et al.*, 2005; William, 2005).

A total of 55 elements were determined: Al_2O_3, CaO, K_2O, Fe_2O_3, Na_2O, MgO, MnO_2, and TiO_2 as major elements; B, Ba, Be, Bi, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Ga, Ge, Gd, Hf, Hg, Ho, La, Li, Lu, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Re,Sb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Th, Tl, Tm, U, V,W, Y, Yb, Zn and Zr as minor and trace elements. Moreover, SiO_2 content was estimated. Data for As, Rh and Ru were in all the cases below the detection limits and will not be given further consideration. Blank samples, standard samples and duplicated samples were simultaneously performed as quality control.

2.4. *Statistical Analysis*

Statistical analysis is commonly used in archaeometric applications to identify or display structures in the chemical composition of archaeological artefacts (Baxter, 1995). In this study, several analyses were done using the following programs: SPSS 18 Programme and Origin 75E version. The first step was to classify the samples as a function of their major elements using a ternary diagram (Al_2O_3 - Fe_2O_3+MgO - K_2O+Na_2O+CaO), (Pérez-Arantegui *et al.,* 1996) and to compare the major constituents in different selected groups by box and whisker graphics. This representation helps interpret the distribution of data. In this plot, each box encloses the middle 50%, where the median is represented as a horizontal line inside the box. Vertical lines extending from each end of the box (called whiskers) enclose data within 1.5 interquartile ranges. Values falling beyond the whiskers, but within three interquartile ranges, are plotted as individual points (suspect outliers). Far outside points (outliers) are distinguished. Finally, in a second step, supervised pattern recognition was applied to this study. Linear discriminant analysis was used for hard classification purposes, trying to establish possible connections between groups of samples and variables and possible connections among ceramic samples and soil samples. This procedure is useful for classifying the dataset into groups. It generates a small number of functions of quantitative measurements, which are linear combinations of the standardized pattern variables with weight coefficients. The procedure assumes that the variables are drawn from a population with multivariate normal distributions and that variables have equal variances.

3. RESULTS AND DISCUSSION

3.1 *Visual Examination*

Table I and Figure 2 summarize the following characteristics: use of the piece, colour, redox condition of the melting process and the textural group. There are differences between pottery samples and the sections of the same pottery sample. The colour variations are attributed to temperature gradients, time of the process and redox conditions during the melting process (Pérez Arantegui *et al.,* 1996, Orton *et al.,* 1997; Feliu *et al.,* 2004). Red samples corresponded to the samples fired under oxidizing conditions, due to the oxidation of iron oxides. Grey pottery samples are samples fired under reduction conditions. Finally, samples with red and grey colours correspond to samples in an irregular firing process (Feliu *et al.,* 2004). The three different redox environments were produced in the firing process at these archaeological sites. The most common redox condition was the oxidizing condition (16 samples) followed by the reduction condition (7 samples) and the irregular condition (7 samples) (Table I).

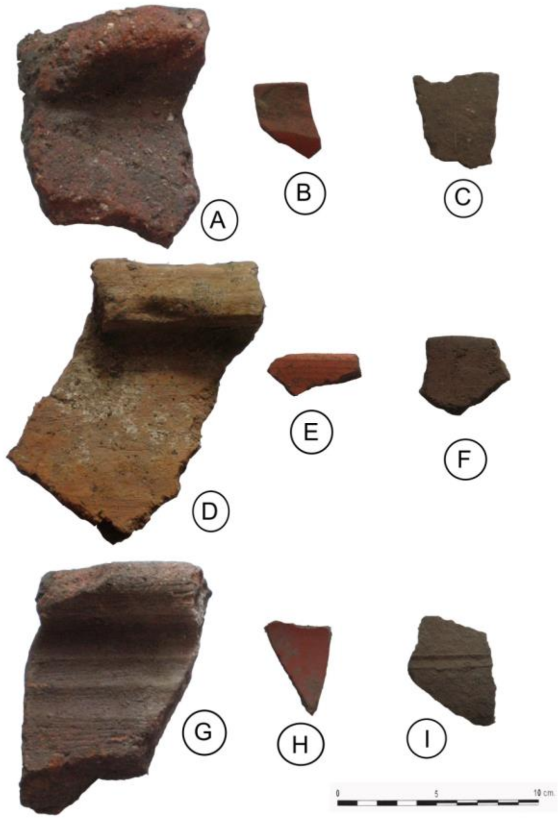

Figure 2. Photographs of ancient ceramic samples. A: HD_10, B: HD_1, C: HD_4, D: LT_9, E: LT_1, F: LT_6, G: LV_10, H: LV_2, I: LV_8

In the *terra sigillata hispanica* samples, the redox condition was always an oxidizing condition. In the *tegulae* samples, the redox condition was an irregular or an oxidizing condition. Finally, the "common pottery" samples showed all three redox conditions. The choice of one particular firing process with its oxidizing conditions would have determined the use to which the clay vessels were put (typology).

Table I. Colour, textural group and typology of the samples

Sample	Colour			Textural group	Typology	Redox condition of the melting process
	Inner surface	Outer surface	Cental part			
HD_1	2.5YR 4/6	2.5YR 4/6	2.5YR 4/6	Fine	Hispanic *terra sigillata*	Oxidizing
HD_2	2.5YR 5/8	2.5YR 5/8	2.5YR 5/8	Fine	Hispanic *terra sigillata*	Oxidizing
HD_3	2.5YR 6/8	2.5YR 6/8	2.5YR 6/8	Fine	Common pottery	Oxidizing
HD_4	10YR 6/1	10YR 6/1	10YR 4/1	Coarse	Common pottery	Reducing
HD_5	10YR 5/3	10YR 5/3	10YR 5/3	Coarse	Common pottery	Oxidizing
HD_6	10YR 4/1	10YR 4/1	10YR 4/1	Coarse	Common pottery	Reducing
HD_7	10YR 6/1	10YR 6/1	10YR 4/1	Coarse	Common pottery	Reducing
HD_8	2.5YR 6/6	2.5YR 6/6	10YR 4/1	Fine	Common pottery	Irregular
HD_9	2.5YR 5/6	2.5YR 5/6	2.5YR 5/2	Coarse	*Tegula*	Irregular
HD_10	2.5YR 5/6	2.5YR 5/6	2.5YR 5/6	Coarse	*Tegula*	Oxidizing
LT_1	2.5YR 5/8	2.5YR 5/8	2.5YR 5/8	Fine	Hispanic *terra sigillata*	Oxidizing
LT_2	2.5YR 6/8	2.5YR 6/8	2.5YR 6/8	Fine	Hispanic *terra sigillata*	Oxidizing
LT_3	2.5YR 5/8	2.5YR 5/8	10YR 6/1	Fine	Common pottery	Irregular
LT-4	2.5YR 6/4	2.5YR 6/8	2.5YR 6/4	Coarse	Common pottery	Oxidizing
LT_5	2.5YR 6/4	10YR 5/4	10YR 5/4	Coarse	Common pottery	Irregular
LT_6	10YR 3/2	10YR 3/2	10YR 3/2	Coarse	Common pottery	Reducing
LT_7	10YR 5/1	10YR 5/1	10YR 5/1	Coarse	Common pottery	Reducing
LT_8	10YR 2/1	10YR 2/1	10YR 2/1	Coarse	Common pottery	Reducing
LT_9	2.5YR 6/8	2.5YR 6/8	2.5YR 6/8	Coarse	*Tegula*	Oxidizing
LT_10	2.5YR 5/8	2.5YR 5/8	2.5YR 5/2	Coarse	*Tegula*	Irregular
LV_1	2.5YR 4/8	2.5YR 4/8	2.5YR 4/8	Fine	Hispanic *terra sigillata*	Oxidizing
LV_2	2.5YR 6/8	2.5YR 6/8	2.5YR 6/8	Fine	Hispanic *terra sigillata*	Oxidizing
LV_3	2.5YR 6/4	2.5YR 6/8	2.5YR 6/4	Fine	Common pottery	Oxidizing
LV_4	2.5YR 5/3	2.5YR 5/3	2.5YR 5/3	Coarse	Common pottery	Oxidizing
LV_5	2.5YR 5/6	10YR 7/1	10YR 6/1	Coarse	Common pottery	Irregular
LV_6	2.5YR 5/2	2.5YR 5/2	2.5YR 5/2	Coarse	Common pottery	Oxidizing
LV_7	2.5YR 6/4	2.5YR 6/6	2.5YR 6/6	Coarse	Common pottery	Oxidizing
LV_8	10YR 3/1	10YR 3/1	10YR 3/1	Coarse	Common pottery	Reducing
LV_9	2.5YR 6/8	2.5YR 6/8	2.5YR 6/1	Coarse	*Tegula*	Irregular
LV_10	2.5YR 6/8	2.5YR 6/8	2.5YR 6/8	Coarse	*Tegula*	Oxidizing

3.2 Mineralogical and Textural Study

XRD data on the ceramic samples and soil samples show the marked homogeneity of the mineralogical composition in all specimens. Quartz was always the most abundant mineral, followed by K-feldspar, plagioclase and phyllosilicates in decreasing order of abundance (Table II). In addition, variable amounts of dolomite, calcite, and hematite were also identified in some samples. The same minerals were found in the raw materials with different proportions.

According to the textural analysis, the ceramic samples could be divided into two textural groups: fine and coarse texture (Table I). The fine texture is characteristic for ceramics with a homogeneous groundmass, in which small and sub to well-rounded grains of tectosilicates (quartz, feldspars and plagioclase) are incorporated in a matrix of phyllosilicates (Figure 3A). In contrast, the coarse fabric is characteristic of ceramics with a poor phyllosilicate matrix, where abundant non-plastic inclusions were found (Figure 3B). Table I show that most of the samples had a coarse texture. The fine texture always corresponds to the *terra sigillata hispanica* group. This observation indicates that the non-plastic inclusions were added intentionally or otherwise in the initial clay, depending on the typology of the sample.

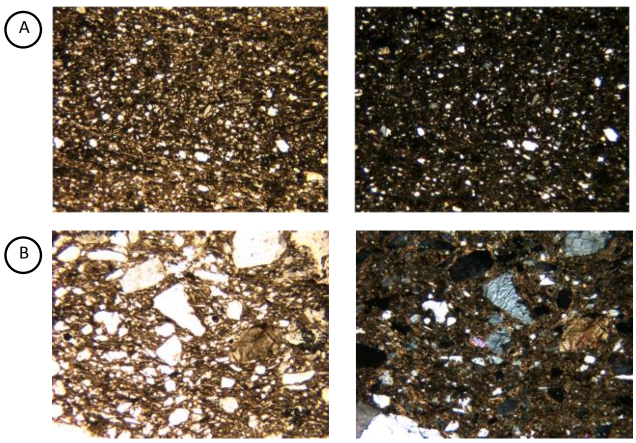

Figure 3. Thin-sections of the ceramic samples (x 230). A: Sample with fine texture (HD-8). Light: white light- Right with cross light. B: Sample with coarse texture (HD-6). Light: white light- Right with cross light

Examination of thin-sections revealed that the most abundant non-plastic inclusions were quartz, feldspars and plagioclase (abundant minerals in the archaeological site). Therefore, these inclusions are clearly related to the geological environment area. The inclusions are large angular to sub-angular grains compared with the fine-grained minerals from the raw material (Figure 3B). Quartz, feldspars and plagioclases were intentionally added to improve the refractoriness of the samples (Hein *et al.*, 2007).

Table II. Mineralogical composition of the ceramics and raw materials (%)

Sample	P (%)	Qtz (%)	F K (%)	Pl (%)	Ca (%)	Do (%)	Others
HD_1	29	39	10	22	Trc	Trc	Illite
HD_2	27	51	10	12	Trc	Trc	Illite
HD_3	9	32	27	17	1	14	Illite
HD_4	29	18	15	38	-	Trc	Illite
HD_5	12	86	2	-	Trc	Trc	Illite, hematite (trc)
HD_6	18	47	15	14	3	3	Illite, gehlenite
HD_7	23	47	12	18	Trc	Trc	Illite
HD_8	30	46	15	9	Trc	Trc	Illite
HD_9	Trc	23	51	15	7	4	Illite
HD_10	11	19	53	9	5	3	Illite, gehlenite
HD_S	**Trc**	**64**	**27**	-	-	**9**	**Illite**
LT_1	Trc	91	9	-	-	-	-
LT_2	19	48	7	13	9	4	Illite
LT_3	16	52	17	15	-	-	Illite, hematite (trc)
LT-4	8	42	43	7	Trc	-	Illite
LT_5	Trc	57	29	14	-	-	Illite
LT_6	31	9	55	5	-	Trc	Illite, gehlenite
LT_7	28	33	37	2	Trc	Trc	Illite, gehlenite
LT_8	7	33	42	18	Trc	Trc	Illite
LT_9	20	42	33	5	Trc	Trc	Illite, gehlenite
LT_10	18	30	36	16	Trc	Trc	Illite, hematite (trc)
LT_S	**20**	**41**	**14**	**25**	**Trc**	**Trc**	**Illite**
LV_1	20	45	20	3	3	9	Illite, hematite (trc)
LV_2	30	46	2	18	2	2	Illite, hematite (trc)
LV_3	15	36	7	38	1	3	Illite, hematite (trc)
LV_4	17	71	6	6	Trc	Trc	Illite, hematite (trc)
LV_5	Trc	27	70	1	1	1	Illite, hematite (trc)
LV_6	Trc	20	3	74	3	Trc	Illite, hematite (trc)
LV_7	Trc	68	7	25	Trc	Trc	Illite, hematite (trc)
LV_8	Trc	75	15	10	-	-	Illite, hematite (trc)
LV_9	Trc	70	22	8	-	-	Illite, hematite (trc)
LV_10	Trc	71	11	8	6	4	Illite, hematite (trc)
LV_S	**12**	**61**	**22**	**4**	**1**	**Trc**	**Illite**

The presence or absence of specific mineral assemblages is often used for the estimation of the firing temperature of pottery (Cultrone *et al.*, 2001; Iordanidis *et al.*, 2009). According to the mineralogical study by XRD, some samples presented small crystals of gehlenite (HD-6, HD-10, LT-6, LT-7, LT-9). The presence of gehlenite crystals, calcite and illite revealed a firing temperature of over 850°C. Thermal decomposition of carbonates (calcite and dolomite) starts at approximately at 600°C and is completed around 800–850 °C (Cultrone *et al.*, 2001), giving rise to high temperature calcium silicates or alumino-calcosilicates, such as gehlenite (which grows around clay minerals at 800 ºC), wollastonite and diopside (which appear at 1000ºC) (Ramos *et al.*, 1990; Riccardi *et al.*, 1999; Cultrone *et al.*, 2001; Iordanidis *et al.*, 2009; Maritain *et al.*, 2006)). The formation of gehlenite, wollastonite and diposide occur according to the following reactions (Cultrone *et al.*, 2001):

$KAl_2(Si_3Al)O_{10}(OH)_2$ (illite) + $6CaCO_3$ (calcite) → $3Ca_2Al_2SiO_7$ (gehlenite)+ $6CO_2$ + $2H_2O$ + K_2O + $3SiO_2$ **(1)**

$CaO + SiO_2 \rightarrow CaSiO_3$ (wollastonite) **(2)**

$2SiO_2$ + $CaMg(CO_3)_2$ (dolomite) → $CaMgSi_2O_6$ (diopside) + 2CO **(3)**

Quartz and feldspars persist at firing temperatures of up to 1000 °C (Iordanidis *et al.*, 2009). Quartz grains do not reveal any appreciable chemical and morphological transformation until the temperature of 1050ºC. At this point, quartz grains could show microtextures dominated by the presence of a thin coronitic layer (Riccardi *et al.*, 2001). Therefore, dolomite disappears at 700°C, while calcite is still present at 800°C until 850ºC. Gehlenite appears at 800°C by reaction of calcite with clay minerals, reducing its concentration above 1000°C (Riccardi *et al.*, 1999;

Cultrone *et al.*, 2001). Finally, quartz and feldspars persist at firing temperatures of up to 1000ºC. In view of the above consideration, it is possible to define the firing temperature of some samples, by studying the presence or absence of these minerals:

- Firing temperature higher than 900Cº: samples with mainly quartz and feldspars (LT-1, LT-3, LV-8 and LV-9)
- Firing temperature between 900 – 800ºC: samples with gehlenite and illite (LT-6, LT-7 and LT-9).
- Temperature between 800– 600ºC: samples with illite, gehlenite and calcite (HD-6, HD-10).

The study of thin-sections revealed further important data. Organic matter was found in two samples (LT-8 and LV-9). The organic material might have been added as a binder in the preparation of the clay or the raw material itself might have contained organic material (Maritain *et al.*, 2006; Palanivel and Kumar, 2011). The existence of organic matter in the samples might also indicate that the firing conditions were not acceptable, due to unsatisfactory conditions; some organic matter may have completely burnt up, contributing to secondary porosity (Maritain *et al.*, 2006), which was observed in samples LV-10, LT-1 and LT-9.

Finally, ferric oxides, such as hematite, were found in all the samples from LV and in some samples at the two other archaeological sites (HD-5, LT-3 and LT-10). The presence of this mineral indicates that the samples were fired in the open air or in a perfectly oxidizing atmosphere at the time of their manufacture (Feliu *et al.*, 2004; Ravisankar *et al.*, 2011).

3.3 Chemical Study and Statistical Analysis

3.3.1. Major Element Compositions

The chemical study of glazed Roman ceramics by Pérez-Arantegui (1996) revealed two separate major production lines for objects found in *Hispania*. There was a production line of objects with non-calcareous bodies and a calcareous production. In this case, the samples may be classified by non-calcareous bodies, as on the left of Figure 4. Only one sample is located in the centre of the ternary diagram (HD-1). Therefore, the samples are fairly homogenous and were characterized by Al concentrations of over 50%, K, Na and Ca concentrations of over 70%, and Fe and Mg concentrations of below 50%. Sample HD-1 showed higher Fe and Mg contents and lower amounts of the other elements.

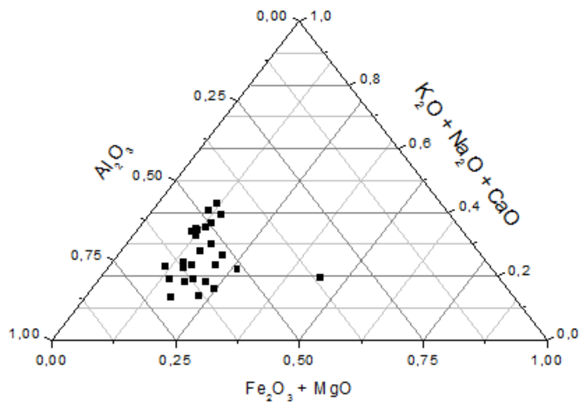

Figure 4. Ternary diagram (Al2O3 - Fe2O3+MgO - K2O+Na2O+CaO)

The pottery samples were all quite homogeneous in view of these chemical features and the same results were obtained with a box and whiskers graph of the major element concentrations (Figure 5). Variability was only found for the concentration of Na, Al and Si.

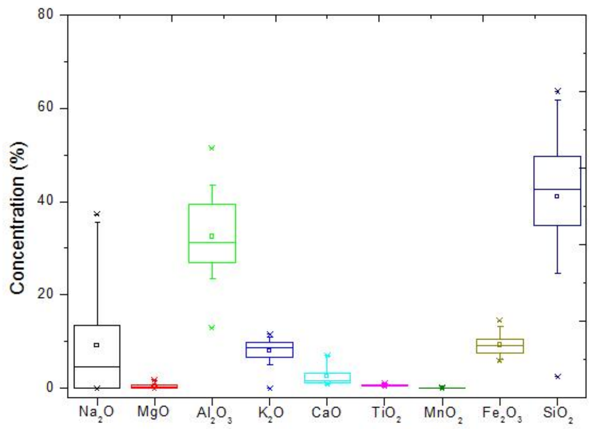

Figure 5. Box and whiskers plot of the major elements

The samples could be divided into three groups depending on their typology: G1, G2 and G3 (Table I). In view of this classification, the major element compositions were represented in another box and whisker diagram for each component (Figure 6). SiO_2 showed a content of over 50% for the G1 group, while it had a wider range and a content of over 30% for G2 and G3 groups. SiO_2 and silicates (quartz, phyllosilicates and feldspars) were respectively the major element in the samples, due to the presence of minerals in the ceramic samples and in the soil samples.

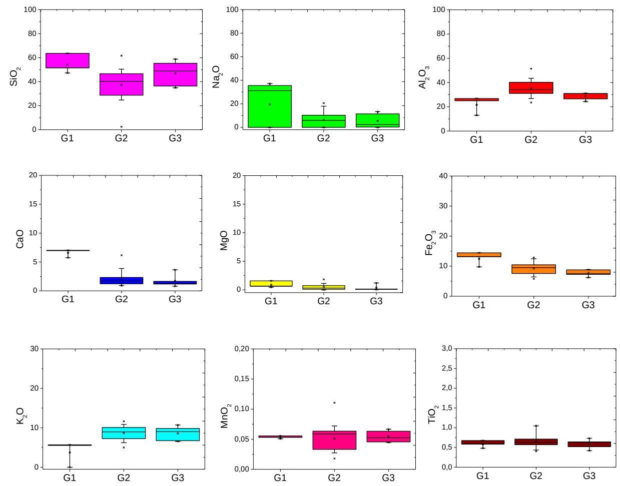

Figure 6. Box and whiskers graph of the major elements of the samples according to the three groups of typologies (G1: Terra Sigillata Hispanica; G2: common pottery; and, G3: Tegulae)

3.3.2. Minor Element Compositions

The ceramic samples were quite homogeneous in terms of their mineralogical composition and mayor element concentrations. In this case chemical characterisation can be extremely helpful in defining the provenance (Sparato, 2011). For this reason, the study of the minor element concentrations then took place (Tables III and IV). Two different linear discriminant analyses were performed using the minor element compositions of the samples. First, the analyses were developed using the typology of the samples and second, the analysis was performed according to the origin of the samples.

The ceramic samples are represented as a function of two of the most outstanding canonical discriminant functions, thereby establishing a classification of the samples by their typology (G1, G2 and G2) and their minor and trace element chemical compositions. Function 1 is a linear combination of the different variables and the elements with the most significant standardized coefficients are Dy, Ga and Mo on the positive axis and Zr, Y and Sm on the negative one. In the case of function 2, these are Dy, Zr and Pr on the positive axis and Nd, Y and Yb on the negative one. The samples found in each group are framed within an enclosure and are characterized by a centroid, represented by a small black symbol in Figure 7A. This symbol represents the average for each group (unique values in the classification factor field) that uses the discriminant functions. Linear Discriminant Analysis showed that there were three clearly differentiated groups. G1 samples were characterized by their content of Y, Zr, Sm, Dy and Pr, G2 by their content of Mo, Dy, Ga, Zr and Pr, and finally, G3 samples were characterised by their concentrations of Mo, Dy, Ga, Nd, Yb and Y. This means that the raw materials were chosen depending on their final product.

Table III. Minor and trace elements concentrations (expressed in ppm)

Sample	Li	Be	B	Sc	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Se	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba
HD_1	37	7	n.d.	1	93	103	18	55	40	131	21	n.d.	18	215	398	n.d.	n.d.	6	n.d.	16	n.d.	14	929
HD_2	68	6	n.d.	20	242	143	19	64	27	115	27	n.d.	n.d.	184	214	5	n.d.	10	n.d.	9	2	10	950
HD_3	43	6	16913	39	267	62	15	23	28	309	24	1	n.d.	122	170	19	31	19	n.d.	10	5	4	1508
HD_4	124	6	17624	17	104	42	10	28	46	140	30	n.d.	n.d.	183	122	18	197	15	1	15	1	11	515
HD_5	45	5	8131	17	251	54	8	24	19	39	29	1	n.d.	154	95	8	68	10	n.d.	8	2	7	556
HD_6	28	5	8002	14	24	12	6	3	27	n.d.	25	n.d.	n.d.	159	131	7	n.d.	11	n.d.	4	n.d.	5	1035
HD_7	88	7	n.d.	13	202	47	13	17	141	141	35	1	2	213	120	13	n.d.	21	n.d.	12	1	7	1241
HD_8	48	5	n.d.	10	n.d.	40	9	20	31	19	22	n.d.	13	145	205	11	n.d.	15	n.d.	7	n.d.	7	1871
HD_9	48	5	12093	12	223	41	8	58	14	17	22	1	1	162	102	17	39	12	n.d.	4	11	4	615
HD_10	155	8	420504	643	240	76	16	64	69	86	47	1	10	210	133	51	1675	30	33	22	7	7	650
HD_S	37	7	n.d.	1	93	103	18	55	40	131	21	n.d.	18	215	398	n.d.	n.d.	6	1	6	1	2	969
LT_1	142	6	472713	290	n.d.	104	16	67	16	697	36	n.d.	n.d.	179	392	55	2485	29	44	2	6	11	577
LT_2	69	4	91964	341	n.d.	122	20	99	7	537	14	n.d.	n.d.	142	213	12	n.d.	10	n.d.	2	n.d.	8	618
LT_3	82	4	104408	370	373	90	15	34	20	151	19	n.d.	n.d.	118	126	20	99	12	1	6	1	7	731
LT-4	69	4	190093	429	78	41	9	44	10	536	15	n.d.	n.d.	148	133	25	379	12	8	5	n.d.	7	698
LT_5	53	4	129716	390	145	36	8	21	24	227	18	n.d.	n.d.	123	79	15	348	11	5	3	n.d.	3	498
LT_6	27	4	51665	210	141	23	9	15	18	157	13	n.d.	n.d.	114	77	11	64	8	n.d.	3	n.d.	3	455
LT_7	52	3	87001	145	n.d.	38	8	26	5	291	17	n.d.	n.d.	188	463	16	134	10	2	5	n.d.	17	676
LT_8	62	4	73166	167	69	16	12	14	12	125	17	n.d.	n.d.	163	146	23	54	14	1	6	n.d.	8	629
LT_9	43	5	47762	260	358	60	13	25	13	168	12	n.d.	n.d.	97	47	6	n.d.	9	n.d.	2	n.d.	2	529
LT_10	45	4	6886	3	n.d.	7	8	20	6	148	13	n.d.	n.d.	137	98	18	76	8	1	2	n.d.	6	497
LT_S	30	3	95813	182	26	28	14	21	18	131	12	n.d.	n.d.	104	80	12	270	8	4	1	1	3	371
LV_1	82	5	63909	33	n.d.	22	23	61	28	193	27	n.d.	n.d.	119	195	19	650	17	10	11	3	6	614
LV_2	113	6	232982	290	5	75	26	90	45	217	38	n.d.	n.d.	116	197	23	1119	20	20	8	6	4	887
LV_3	62	5	43094	4	n.d.	n.d.	12	44	34	417	29	n.d.	n.d.	106	83	21	571	20	7	15	4	5	539
LV_4	55	4	25327	n.d.	n.d.	n.d.	8	37	15	143	20	n.d.	n.d.	108	56	16	371	13	5	4	1	4	433
LV_5	56	6	46648	75	n.d.	n.d.	8	16	18	233	26	n.d.	n.d.	180	98	32	288	17	4	8	1	7	439
LV_6	55	5	29165	n.d.	n.d.	n.d.	8	23	16	173	22	n.d.	n.d.	169	102	24	330	13	5	5	1	7	561
LV_7	53	4	11171	7	n.d.	22	7	17	25	178	31	n.d.	n.d.	92	98	22	176	20	1	17	n.d.	5	666
LV_8	33	4	18879	1	n.d.	n.d.	6	23	19	79	20	n.d.	n.d.	106	75	10	218	13	3	5	n.d.	4	495
LV_9	55	4	67174	10	n.d.	10	11	43	23	182	23	n.d.	n.d.	97	72	15	385	13	6	4	1	3	545
LV_10	43	4	23184	n.d.	n.d.	n.d.	14	61	33	110	21	n.d.	n.d.	99	121	26	367	11	6	6	2	3	548
LV_S	16	2	5561	n.d.	n.d.	n.d.	4	9	12	32	9	n.d.	n.d.	89	94	13	119	5	1	1	n.d.	2	393

n.d.= not detected (below quantification limit)

In order to verify the attribution of the pottery samples to the local production, we had compared the chemical composition of the pottery samples with the raw reference materials by a linear discriminant analysis using minor elements composition (Figure 7B). Function 1 was a linear combination of the different variables and the elements with the most significant standardized coefficients were Y, Sm and B, on the positive axis, and Tm, Pr and Li, on the negative one. Function 2 consisted of Zr, Ho and Eu on the positive axis and Mo, Ga and Tm on the negative one.

Table IV. Minor and trace elements concentrations (expressed in ppm)

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Hg	Tl	Pb	Bi	Th	U
HD_1	30	62	7	26	4	1	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2	n.d.	n.d.	1	45	16	3	n.d.
HD_2	34	70	8	29	4	1	4	1	2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1	3	n.d.	n.d.	1	37	11	9	3
HD_3	28	61	7	27	5	1	5	1	4	1	2	n.d.	1	n.d.	1	2	6	n.d.	n.d.	1	69	4	11	10
HD_4	33	72	9	33	7	1	6	1	4	1	2	n.d.	1	n.d.	6	2	3	n.d.	n.d.	1	46	8	15	19
HD_5	22	42	5	19	3	1	3	n.d.	2	n.d.	1	n.d.	n.d.	n.d.	2	1	3	n.d.	n.d.	1	29	1	11	7
HD_6	202	39	6	23	4	1	4	1	2	n.d.	1	n.d.	n.d.	n.d.	1	1	1	n.d.	n.d.	1	21	n.d.	12	7
HD_7	39	80	11	40	9	1	6	1	3	1	1	n.d.	1	n.d.	n.d.	2	6	n.d.	n.d.	1	27	3	26	31
HD_8	35	68	9	33	6	1	5	1	3	n.d.	11	n.d.	n.d.	n.d.	n.d.	2	4	n.d.	n.d.	1	21	1	14	8
HD_9	32	71	9	32	6	1	6	1	4	1	11	n.d.	1	n.d.	2	1	1	n.d.	n.d.	1	23	n.d.	14	7
HD_10	47	106	13	50	12	1	11	2	9	2	5	1	5	1	43	3	9	n.d.	n.d.	1	50	7	27	47
HD_S	16	32	4	16	3	1	3	n.d.	2	n.d.	1	n.d.	1	n.d.	5	1	1	n.d.	n.d.	1	27	n.d.	6	5
LT_1	77	185	19	68	11	2	12	2	10	2	6	1	7	1	69	3	3	n.d.	n.d.	1	16	n.d.	31	n.d.
LT_2	33	61	8	27	5	1	5	1	3	1	1	n.d.	1	n.d.	1	1	2	n.d.	n.d.	n.d.	15	n.d.	11	13
LT_3	32	74	9	31	6	1	6	1	4	1	2	n.d.	2	n.d.	4	1	3	n.d.	11	1	13	n.d.	13	15
LT-4	30	60	8	29	7	1	6	1	5	1	2	n.d.	2	n.d.	14	1	2	n.d.	4	1	33	n.d.	14	16
LT_5	18	35	5	18	3	1	4	1	3	1	2	n.d.	1	n.d.	11	1	2	n.d.	1	1	6	n.d.	10	12
LT_6	14	28	4	14	3	1	3	n.d.	2	n.d.	1	n.d.	1	n.d.	3	1	2	n.d.	1	1	3	n.d.	8	10
LT_7	34	75	8	29	5	1	5	1	3	1	2	n.d.	2	n.d.	5	1	3	n.d.	3	1	n.d.	n.d.	14	13
LT_8	36	85	10	34	8	1	7	1	5	1	3	n.d.	2	n.d.	3	2	4	n.d.	n.d.	1	255	n.d.	17	n.d.
LT_9	6	6	2	7	2	1	2	n.d.	1	n.d.	1	n.d.	1	n.d.	n.d.	1	3	n.d.	4	1	64	n.d.	4	10
LT_10	37	90	9	34	6	1	6	1	4	1	2	n.d.	2	n.d.	3	1	2	n.d.	n.d.	1	17	n.d.	26	n.d.
LT_S	12	26	3	11	2	1	2	n.d.	2	n.d.	1	n.d.	1	n.d.	8	1	2	n.d.	n.d.	1	4	n.d.	5	10
LV_1	41	89	10	35	8	1	6	6	1	4	1	2	n.d.	2	n.d.	16	1	3	n.d.	n.d.	n.d.	30	7	15
LV_2	45	103	12	40	8	1	7	7	1	5	1	3	n.d.	3	n.d.	30	2	4	n.d.	1	1	40	n.d.	19
LV_3	37	77	10	37	9	1	7	7	1	5	1	3	n.d.	2	n.d.	15	2	9	n.d.	n.d.	1	37	n.d.	21
LV_4	28	64	7	26	6	1	5	5	1	4	2	2	n.d.	1	n.d.	10	1	2	n.d.	n.d.	n.d.	30	n.d.	14
LV_5	33	69	9	33	9	1	7	7	1	6	1	3	n.d.	3	n.d.	8	2	3	n.d.	n.d.	1	32	n.d.	21
LV_6	37	84	10	34	7	1	6	6	1	5	1	2	n.d.	2	n.d.	9	1	2	n.d.	n.d.	1	33	n.d.	18
LV_7	39	75	11	39	8	1	7	7	1	5	1	2	n.d.	2	n.d.	6	2	12	n.d.	1	1	35	1	24
LV_8	19	43	5	19	4	1	3	3	1	3	1	1	n.d.	1	n.d.	5	1	3	n.d.	1	1	19	n.d.	13
LV_9	19	42	5	19	4	1	4	4	1	3	1	2	n.d.	1	n.d.	10	1	2	n.d.	n.d.	1	28	n.d.	9
LV_10	30	73	8	29	6	1	6	6	1	5	1	3	n.d.	2	n.d.	10	1	2	n.d.	2	1	59	n.d.	16
LV_S	18	43	5	17	4	1	3	3	n.d.	3	1	1	n.d.	1	n.d.	4	1	1	n.d.	n.d.	n.d.	21	n.d.	8

n.d.= not detected (below quantification limit)

The samples could be divided into three groups according to the composition of their minor elements and the chemical composition of the soils of each site. The ceramics were therefore undoubtedly fabricated with clay from the vicinity of each archaeological site, and there is no indication of sample transport. Due to the fact that there are three different typologies in each deposit (*terra sigillata hispanica*, common pottery and *tegulae*), the clay deposit from each archaeological site was used to make ceramic vessels following different technological choices (Santacreu and Vicens, 2012).

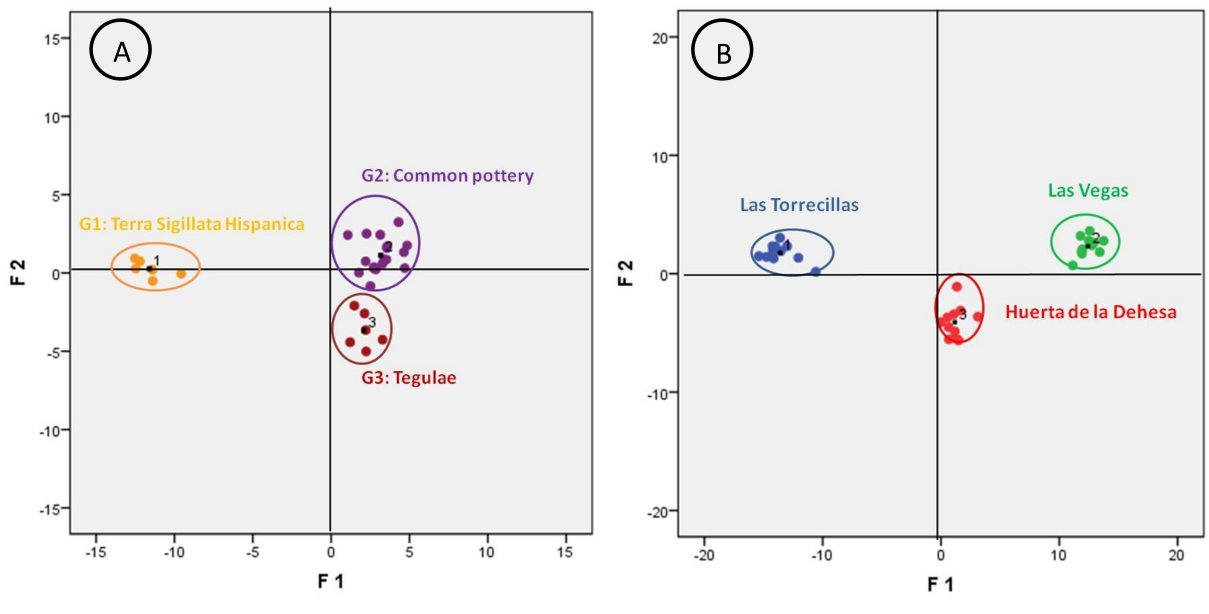

Figure 7. Graphical representation of the samples as a function of two canonical discriminant functions. A: According to their typology. B: According to the sample origin

4. CONCLUSIONS

There is a gap in scientific and technical knowledge of the mineralogical and chemical properties of Roman ceramics from Ávila region (Centre of Spain). Hence, this present study report a novel study of the samples found in three archaeological deposits of this region which include a visual, mineralogical, textural and statistical study of the ancient pottery samples and their potential local/regional raw materials. Manufacturing conditions and the origin of the samples from three Roman archaeological sites were determined from the pottery samples, so as to gain mineralogical, textural and chemical information.

Two kinds of manufacturing process were deduced from the analyses of the ceramic fragments: the addition of non-plastic inclusions (coarse texture) into the clay body to improve its refractory properties and fine ceramic without non-plastic inclusions (fine texture). The non-plastic inclusions were added, intentionally or otherwise, into the clay body depending on the final typology of the sample.

The presence of firing minerals revealed the temperature of the manufacturing process. The samples were manufactured under three different temperature conditions: temperatures higher than 900Cº, temperatures of between 900 – 800ºC and temperatures of between 800– 600ºC. In addition, examination of the pottery fragments revealed firing processes with three different redox environments: samples fired under oxidizing conditions (most important); samples fired under reductive conditions; and, samples fired under irregular conditions. The choice of one particular firing process with its oxidizing conditions would have determined the use to which the clay vessels were put (typology).

The results had showed that the raw materials were initially chosen in view of the final use (typology of the samples; *terra sigillata hispanica*, common pottery and *tegulae*) following different technological choices. And finally, the raw materials, used in the manufacture of the ceramics, were extracted from an area nearby the archaeological site. There was no indication of sample transport.

ACKNOWLEDGEMENTS

This research was carried out in the framework of a grant of the Junta de Castilla y León y Fondo Social Europeo for doing a Ph. D. We thank J. A. Mutiloa for assistance in field sampling.

REFERENCES

Ariño, E. (2006) Modelos de poblamiento rural en la provincia de Salamanca (España) entre la Antigüedad y la Alta Edad Media. *Zephyrus*, vol. 59, 317-337.

Barone, G., Mazzoleni, P., Spagnolo, G. and Aquilia E. (2012) The transport amphorae of Gela: a multidisciplinary study on provenance and technological aspects. *Journal of Archaeological Science*, vol. 39, 11-22.

Barone, G., Mazzoleni, P., Aquilia E. and Barbera, G. (2014) The Hellenistic and Roman Syracuse (Sicily) fine pottery production explored by chemical and petrographic analysis. *Archaeometry*, vol. 56, 70-87.

Barrios Neira, J., Montealegre, L., López, L.A. and Romero, L. (2009) Ceramics of Ategua (Córdoba, Spain): Mineralogical and petrographic study. *Applied Clay Science*, vol. 42, 529–537.

Baxter, M. J. (1995) Standardization and Transformation in Principal Component Analysis, with Applications to Archaeometry. *Journal of the Royal Statistical Society*. *Series C (Applied Statistics)*, vol. 44, No 4, 513-527.

Blanco, A. (2009) Tendencias del uso del suelo en el valle Amblés (Ávila, España). De la Edad del Hierro al Medievo. *Zephyrus*, vol. 63, 155-183.

Brindley, G. W. and Brown, G. (1984) *Crystal Structures of Clay Minerals and Their X -Ray Identification*. Mineralogical Society Monograph, London.

Butzer, K. W. (1989) *Arqueología. Una ecología del hombre: método y teoría para un enfoque contextual*, Bellaterra, Barcelona.

Carmona, E., Palmero, S., and Arnaiz, M.A. (2014) Análisis químico de cerámicas calcolíticas de la Cuenca Media del Arlanzón (Burgos): un medio para la valoración de la procedencia y el intercambio. *Boletín de la Sociedad Española de Cerámica y Vidrio*, vol. 53, No 2, 81-92.

Cultrone, G., Rodriguez-Navarro, C., Sebastian, E., Cazalla, O. and De la Torre, M.J. (2001) Carbonate and silicate phase reactions during ceramic firing. *European Journal of Mineralogy*, vol. 13, 621-634.

De Soto, M. R. (2010) Prospección arqueológica extensiva en el Valle del Río Almar (Salamanca). Estructuras de poblamiento de la II Edad del Hierro, Época Romana y Alta Edad Media. Master dissertation, Department of Prehistory, Ancien History and Archaeology, University of Salamanca.

Dias, M. I., and Prudencio, M. I. (2008) On the importance of using scandium to normalize geochemical data preceding multivariate analyses applied to archaeometric pottery studies. *Microchemical Journal*, vol. 88, 136-141.

Eiland, M. L. and Williams, Q. (2001) Investigation of Islamic Ceramics from Tell Tuneinir Using X-Ray Diffraction. *Geoarchaeology: An International Journal*, vol. 8, No. 6, 875–903.

Feliu, M. J., Edreira, M.C. and Martín, J. (2004) Application of physical–chemical analytical techniques in the study of ancient ceramics. *Analytica Chimica Acta*, vol. 502, 241–250.

Finlay A.J., McComish J.M., Ottley C. J., Bates C. R. and Selby D. (2012) Trace element fingerprinting of ceramic building material from Carpow and York Roman fortresses manufactured by the VI Legion. *Journal of Archaeological Science*, vol. 39, 2385-2391.

García Giménez, R., Vigil de la Villa, R., Recio de la Rosa, P., Petit Dominguez, M. D. and Rucandio, M. I. (2005) Analytical and multivariate study of Roman age architectural terracotta from Northeast of Spain. *Talanta*, vol. 65, 861-868.

García Heras, M. and Olaetxea, P. (1992) Métodos y análisis para la caracterización de cerámicas arqueológicas. Estado actual de la investigación en España. *Archivo Español de Arqueología*, vol. 65, 263-289.

Gallart, M. D. and Mata, M. P. (2005) Análisis mineralógico de las cerámicas. *Bolskan*, vol. 12, 171-180.

Hein, A., Kilikoglou, V. and Kassianidou, V. (2007) Chemical and mineralogical examination of metallurgical ceramics from a Late Bronze Age copper smelting site in Cyprus. *Journal of Archaeological Science*, vol. 34, No. 1, 141-154.

Hernando, M. R. (2005) *Epigrafía romana de Ávila*, Ausonius Éditions-Archivo Epigráfico de Hispania, Bordeaux-Madrid.

Iordanidis, A., Garcia-Guinea J. and Karamitrou-Mentessidi G. (2009) Analytical study of ancient pottery from the archaeological site of Aiani, northern Greece. *Materials characterization*, vol. 60, 292-302.

Islam, A. K. M. E. and Lotse, E. G. (1986) Quantitative Mineralogical Analysis of Some Bangladesh Soil with X-Ray, Iron Exchange and Selective Dissolution Techniques. *Clay Minerals*, vol. 21, 31-42.

Marengo, E., Aceto, M., Robotti, E., Liparota, M. C., Bobba, M. and Pantó, G. (2005) Archaeometric characterisation of ancient pottery belonging to the archaeological site of Novalesa Abbey (Piedmont, Italy) by ICP–MS and spectroscopic techniques coupled to multivariate statistical tools. *Analytica Chimica Acta*, vol. 537, 359-375.

Maritain L., Nodari L., Mazzoli C., Milano A. and Russo U. (2006) Influence of firing conditions on ceramic products: Experimental study on clay rich in organic matter. *Applied Clay Science*, vol. 31, 1–15.

Munsell, A. H. (1975) *Munsell Soil Color Chart*. Macbeth division of Kollmorgen Corporation, Baltimore.

Orton, C., Tyers, P. and Vince, A. (1997) *La cerámica en Arqueología*. Crítica, Barcelona.

Palanivel R. and Kumar U. (2011) The mineralogical and fabric analysis of ancient pottery artifacts. *Cerâmica*, vol. 57, 56-62.

Pérez Arantegui, J. Aguaroto, O., Lapuente Mercadal, M. P., Feliz Ortega, M. J. and Pernot, M. (1996) *Arqueometría y caracterización de materiales arqueológicos*, Cuadernos del Instituto Aragonés de Arqueología, Teruel.

Ramos, M. L., Vigil de la Villa, R. and García Giménez, R. (1990) Empleo de la Técnica de Difracción de Rayos X, en el estudio de Terracotas Aquitectónicas Romanas de Ampurias y Tarraco. *CuPAUAM*, vol. 17, 121-136.

Ravisankar, R., Kiruba, S., Naseerutheen, A., Chandrasekaran, A., Raja Annamalai, G., Seran, M. and Balaji, P.D. (2011) Estimation of the firing temperature of archaeological pottery excavated from Thiruverkadu, Tamilnadu, India by FT-IR spectroscopy. *Archives of Physics Research*, vol. 2, No. 4, 108-114.

Riccardi, M. P., Messiga, B. and Duminuco, P. (1999) An approach to the dynamics of clay firing. *Applied Clay Science*, vol. 15, 393–409.

Rodríguez, E. (2003) *Ávila romana. Notas para la arqueología, la topografía y la epigrafía romanas de la ciudad y su territorio*, Caja General de Ahorros y Monte de Piedad de Ávila, Ávila.

Santacreu, D. A. and Vicens, M. (2012) Raw Materials and Pottery Production at the Late Bronze and Iron Age Site of Puig de Sa Morisca, Mallorca, Spain. *Geoarchaeology: An International Journal*, vol. 27, 285–299.

Sociedad Geológica de España e Instituto Geológico y Minero de España (2004). *Geología de España*, IGME, Madrid.

Schultz, L. (1964) *Quantitative Interpretation of Mineralogical Composition from X- Ray and Chemical Data for Pierce Shale*, U.S. Geological Survey professional paper, Washington.

Segvic, B., Seselj, L., Slovenec, L., Lugovi, B. and Mahlmann, R. F. (2012) Composition, Technology of Manufacture, and Circulation of Hellenistic Pottery from the Eastern Adriatic: A Case Study of Three Archaeological Sites along the Dalmatian Coast, Croatia. *Geoarchaeology: An International Journal*, vol. 27, 63–87.

Sparato, M. (2011) A comparison of chemical and petrographic analyses of Neolithic pottery from Southeastern Europe. *Journal of Archaeological Science*, vol. 38, 255-269.

Vigil de la Villa, R., García Giménez, R., Cuevas, J. and Bernal, D. (1998) An assay on simulation of the late Roman amphoric ceramic raw materials. *Thermochimica Acta*, vol. 322, 9-16.

Vigil de la Villa, R. and García Giménez, R. (2005) Cerámica y su caracterización. In *La Ciencia y el Arte: Ciencias experimentales y conservación del patrimonio histórico,* S. Prous, (ed.), Ministerio de Cultura, Subdirección General de Publicaciones, Información y Documentación, Madrid.

Waksman, S. Y., Morozova Y., Zelenko, S. and Colak M. (2014) Archaeological and archeometric investigations of the amphore cargo of a Late Roman shipwreck sunk near the cape of plaka (Crimea, Ukraine). In *Late Roman Coarse Wares, Cooking Wares and Amphorae in the Mediterranean: Archaeology an archaeometry. The Mediterranean: a market without froniers*, N. Poulou-Papadimitriou, E. Nodarou, and V. Kilikoglou, (eds.), Archaeopress, Oxford.

Williams, D. F. (2005) An integrated archaeometric approach to ceramic fabric recognition. A study case on Late Roman amphora 1 from the Eastern Mediterranean. In *Late Roman Coarse Wares, Cooking wares and amphorae in the Mediterranean Archaeology and Archaeometry*, in J. M. Gurt, J. Buxeda and M.A. Cau, (eds.), BAR International Series, Oxford.