Archaeometric characterisation of Late Antique pottery from the rural site of Ses Païsses de Cala d'Hort (Eivissa, Balearic Islands, Spain)

In memoriam Sara Santoro

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Abstract This paper presents the results of an archaeometric characterisation of Late Roman Pottery from a rural site on the island of Eivissa (Balearic Islands, Spain). The ceramic samples, including common wares, amphorae and cooking wares, have been analyzed using X Ray Fluorescence for the chemical characterization, optical microscopy by thin-section analysis for the mineralogical and petrographic characterization and X Ray diffraction for the mineralogical analysis.

The results show the importance of local/regional production for the common wares and amphorae, while for the cooking wares all the materials are imported, including some fabrics widely distributed in the Western Mediterranean.

Keywords coarse wares, cooking wares, Balearics, archaeometry, chemistry, petrography

Introduction

Late Antiquity is a complex period characterized by events such as the progressive dissolution of the Roman Empire and the rise of Barbarian States. During this period, the transformation of the old Roman imperial structures into a new Medieval socioeconomic reality took place. The Balearic Islands progressively changed from being an independent province within the western

Roman Empire, at least from the end of the 4th century, into being dominated first by the Vandals (AD 455), later by the Byzantine Empire (AD 534), and finally falling under the Muslim domination at the beginning of the 10th century AD (AD 902/903).

There is a long tradition of interest in the Balearic Islands during Late Antiquity, and advances in archaeological investigations during the last decades resulted in a substantial improvement in our knowledge of the material culture and, especially, in the understanding of the ceramic record (Arribas *et al*. 1973, 1978; Vegas 1973; Roca 1974; Navarro 1982; Palol 1982; Ramon 1986; Orfila 1988, 1989; Orfila and Cau 1994). Towards the end of the 1990s, the appearance of the first general syntheses took place (Cau *et al*. 1997a, 1997b; Gumà *et al*. 1998) as well as some revision of materials (Reynolds 1995) that made a significant advance in the state of the art.

It was at this time that we began a program of archaeological and archaeometric analyses of Late Antique pottery from several sites within the Balearic Islands, focused especially on cooking and common wares but including also amphorae (*e.g.* Cau 1996, 1999, 2003, 2007a, 2007b; Buxeda et *al.* 1997, 1998, 2005; Ramon and Cau 1997; Cau *et al.* 2004; Macias and Cau 2012; Cau et al. 2014). The aim has been to build a strong basis for establishing patterns of production, trade and consumption in this historical period. In the framework of this analytical program, this paper presents the archaeometric study of a large Late Antique pottery assemblage found at the rural site of Ses Païsses de Cala d'Hort in the island of Eivissa (or Ibiza), that includes both ceramic imports and presumably local/regional products. The ceramic groups present in Late Antique assemblages are characterized through petrographic, mineralogical and chemical analysis, in order to be able to differentiate the various products, determine their provenance and reconstruct some technological features. Through the provenance approach, this study will allow us to gain information on the patterns of pottery production and trade in Eivissa during Late Antiquity.

Ses Païsses de Cala d'Hort: a rural site on the island of Eivissa

The site is located in the vicinity of Cala d'Hort, Sant Josep, in the western part of the island of Eivissa (Figure 1). The property in which it is located is called Can Sorà, although it is also known as Ses Païsses de Cala d'Hort or Ses Hisendes d'En Sorà. The remains of structures are about 1700 m from the coastline and at an altitude of about 130–160 m above the current sea level. The settlement was of Punic foundation surviving into the Roman period. The first archaeological works were completed by Román, who carried out a first intervention in 1917.

Despite this early interest, systematic excavations only began in 1982, conducted by Ramon (1984, 1995) and focused on the so-called Building A.

The different architectural phases of the building have already been described (Ramon, 1995). The first traces of occupation date back to the 5th and 4th centuries BC. Walls and other structures from the 3rd and 2nd centuries BC have been documented that prove the occupation of the building in Late Punic times. In the Early Roman period, during the 1st and 2nd centuries AD, the complex featured a rectangular building with a surface of about 900 m^2, organized around a large central courtyard (Figure 2a) and comprising a series of rooms, an oil press, several buildings for the storage of products and a large cistern. This complex seems to enter a gradual decline between the 3rd and the 5th centuries. The building was destroyed by the mid-5th century, Ramon (1995) suggests as a result of violence related to the Vandal assault. A reoccupation of the building then took place in the mid-6th century, including a reorganization of the space (Figure 2b). The industrial facilities of the area disappeared, the pavements of *opus signinum* were used as building material, various rooms were refurbished and the Early Imperial cistern was used as a rubbish dump. Concerning the final date of the building and of the occupation of the site, the available data are not conclusive; Ramon (1994) suggests a definitive abandonment at the beginning of the 8th century in association with the first Muslim raids.

In geological terms, the site is located on Cretaceous deposits characterized by the presence of limestones and marls, and in the vicinity of Quaternary deposits with *marès* or eolianite (a sedimentary rock with sandy calcareous grains and a carbonate cement), conglomerates and clayey silts. The island of Eivissa is characterized by a sedimentary geology with calcareous formations of different periods, from the Triassic to the Quaternary (Rangheard 1971; IGME 1972). These include limestones, dolomites, dolomitic limestones, marls and clays, among others (Figure 3). The Quaternary deposits are well represented in the island, with numerous alluvial deposits in the plains.

Materials and methods

The ceramics chosen for this study have been sampled from a cistern used as a rubbish dump during Late Antiquity and from layers corresponding to the later phase of occupation of the Building A. The excavation of the cistern showed the existence of different archaeological layers providing a great quantity of ceramics (Ramon 1995). Layer IV of the cistern can be dated to the late 6th century (Byzantine period), as suggested particularly by the findings of African Red Slip Ware (ARS types Hayes 104B, 91A/B and 99A), while the formal repertoire of Layer V (ARS forms Hayes 61A, 67, 91A, 81, 80A, 73) might be dated to the first half of the

5th century, more specifically around AD 430–450. Layer II of the cistern was deposited later than Layer IV, thus dating probably to the late 6th or 7th century. The abandonment layers of Building A can be roughly dated to the 7th or early 8th century.

Ceramic materials from the different layers of the site have been included in this study in order to give a diachronic perspective of Late Antique Eivissa between the 5th and the 7th centuries. A total of 78 vessels were selected for archaeometric characterization (Table 1). Of these, 33 correspond to cooking wares, 34 to common wares and 11 to amphorae and/or large jars. It should be noted that 27 of these vessels (cooking wares in all cases) had already been subjected to an earlier analysis by Cau (1999, 2003). For the common wares and amphorae the macroscopic examination reveals a relatively homogeneous fabric in most cases and its characteristics suggest that these ceramics can be classified as the typical Roman Ebusitan pottery, while for the cooking wares a certain variability of macroscopic fabrics and compositions seems clear.

A sample of approximately 15 g was taken from each individual for X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Optical Microscopy (OM) analysis; for a few individuals the small sample size did not allow us to perform these three analyses (Table 1). For XRF and XRD a part of each specimen was pulverized and homogenized in a mill with a tungsten carbide cell, after removing its superficial layers, while for OM thin sections were prepared.

The chemical composition was determined by means of XRF, performed using a Phillips PW 2400 spectrometer with a Rh excitation source. A portion of the pulverized and homogenized specimens were dried at 100°C for 24 hours. Major and minor elements were determined by preparing duplicates of fused beads using 0.3 g of specimen in an alkaline fusion with lithium tetraborate (1/20 solution). Trace elements and Na_2O were determined by pressed pellets made from 5 g of specimen mixed with Elvacite agglutinating placed over boric acid in an aluminium capsule and pressed during 60 s at 200 kN. The quantification of the elemental concentrations was obtained by using a calibration line performed with 60 International Geological Standards. The quantified elements were the following: Fe_2O_3 (as total Fe), Al_2O_3, MnO, P_2O_5, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Mo, Th, Nb, Pb, Zr, Y, Sr, Sn, Ce, Co, Ga, V, Zn, W, Cu and Ni. The loss on ignition (LOI) was determined by firing 0.3 g of dried specimen, at 950°C for 3 hours. The chemical data were explored through the application of multivariate statistical techniques, using the additive log ratio (alr) transformed compositions (Aitchison 1986; Buxeda 1999). Some elements were discarded from the statistical treatment due to possible contamination problems during the sample preparation (W, Co), for analytical accuracy problems (MnO) or for analytical imprecision (Sn, W, Mo) (see discussion in Hein et al. 2002).

The mineralogical composition was identified through XRD analysis, carried out using approximately 1 g of the pulverized and homogenized specimens. The measurements were taken using a Siemens D-500 diffractometer, working with Cu-Kα radiation (λ=1.5406 Å), and a graphite monochromator in the diffracted beam, at 1.2 kW (40 kV, 30 mA). Spectra were recorded from 4 to 70°2Θ, at 1°2Θ/min, step-size of 0.05°2Θ and step-time of 3 seconds. The evaluation of the crystalline phases was carried out using the DIFFRACT/AT program by Siemens, which includes the Joint Committee of Powder Diffraction Standards (JCPDS) data bank. An estimation of equivalent firing temperatures (EFT) (Roberts 1963) was carried out, based on the mineral phases identified in each diffractogram (*e.g.* Maggetti 1982; Murad and Wagner 1996; Cultrone *et al*. 2001; Buxeda and Cau 2004; Maggetti *et al*. 2011).

Finally, for the petrographic analysis of thin sections, each ceramic specimen was impregnated with epoxy resin, mounted using Loctite UV glue and sectioned using a Struers Discoplan TS. The thin sections were finished by hand using an abrasive powder until reaching a thickness of 30 µm in which quartz presents a grey-white first order interference color. The analysis of the thin sections was performed using an Olympus BX41 polarizing microscope, working with a magnification between 20X and 200X. The ceramic fabrics were described based on the system proposed by Whitbread (1989, 1995) and modified by Quinn (2013).

Results and discussion

Petrographic and mineralogical characterization

The petrographic analysis of thin sections (OM) allowed us to identify a series of fabric groups and singletons. For each of these groups the XRD results provided additional information on the mineralogical composition, which is particularly important for the identification of firing phases that help to establish equivalent firing temperatures (Roberts 1963) and secondary phases formed during use and/or burial.

- Common wares and amphorae

Almost all of the 45 common wares and amphorae samples, with the only exception of CS0078, can be included into a same general ‘fine sedimentary fabric group’ characterized by very fine, well-elutriated inclusions (silt to very fine sand) and an almost complete absence of coarse fraction (Figure 4a-e). The inclusions comprise quartz, micas (mostly muscovite) and a variable presence of calcareous particles. The very scarce coarse fraction can include variable

frequencies of iron-rich argillaceous inclusions (clay pellets and/or iron nodules), usually not coarser than 0.5 mm, as well as occasional fragments of limestone, quartzarenite and calcareous fossils. It is usually a fine fabric, without any added temper. Only in very rare cases it is possible to suggest tempering, as occurs in CS0043, with more abundant coarse calcareous inclusions; this sample is an amphora, however in the other analyzed amphorae a fine untempered fabric is observed. A certain variability can be found within this large group based on variations in the relative abundance of some components of the fine fraction, in particular the calcareous inclusions and the very fine sand of quartz, while micas and silty grains of quartz are always abundant (Figure 4b-e). It must be noted, however, that a significant gradation exists, thus it is difficult to define clear subgroups or fabrics.

The porosity is not abundant and comprises small mesovesicles and mesovughs mainly. The clay matrix is usually calcareous, light brown to brown in PPL, in some cases orange-brown or greenish-brown, and does not display optical activity; more rarely it shows an orange-brown or reddish-brown color with low optical activity. It is, in most cases, a homogeneous matrix. In some samples (*e.g.* CS0070, 075) the presence of calcareous clay pellets and streaks containing fine quartz, mica and calcareous inclusions, similar to those of the fine fraction, suggests that the abundant fine fraction must derive from this clayey raw material (Figure 4a). The few samples with low optical activity of the matrix present only primary mineral phases in the XRD patterns, suggesting a low firing temperature (EFT ≤800/850ºC) (Figure 5a). The vast majority of the samples, instead, show peaks of both primary phases (*e.g.* illite-muscovite, calcite) and firing phases (*e.g.* gehlenite, pyroxene) that indicate an EFT between 850-950ºC (Figure 5b). In some cases, the advanced decomposition of the phyllosilicates and the increasing development of some firing phases, in particular pyroxenes, suggest a higher EFT (~950/1000ºC) (Figure 5c), while for other samples (CS0043, 069, 073) the complete decomposition of the illite-muscovite and the intensification of the pyroxene peaks evidence the presence of over-fired pottery (≥950/1000ºC) (Figure 5d). These latter three samples show a greenish-brown or greenish-yellow color of the matrix in PPL; CS0043 and especially CS0069 also present peaks of analcime in their XRD spectra, as a result of a post-depositional alteration (see Buxeda *et al*. 2002; Schwedt *et al*. 2006).

Of all the common wares analyzed in this work, the only one not belonging to the 'fine sedimentary fabric group' is CS0078. This sample shows again a fine untempered fabric, but with textural and compositional particularities (Figure 4f). It contains abundant fine inclusions, from silt to fine sand, of quartz, micas (muscovite and, to a lesser degree, biotite), calcite and some microfossils, in addition to few, small fragments of quartzite, quartz-muscovite schist, polycrystalline quartz and very rare coarse clinopyroxene. The clay matrix, with an orange color

in PPL, is optically active; this is associated with a low firing temperature (EFT ≤800/850ºC), as suggested by the absence of firing phases in the XRD patterns.

- Cooking wares

Concerning the analyzed samples of cooking wares, several different fabrics can be identified. For most of them, it is possible to find parallels with already known petrographic fabrics of cooking wares in the western Mediterranean (Fulford and Peacock 1984; Reynolds 1993; Cau 2003, 2007a, 2007b).

Three individuals (CS0021, 022, 068) correspond to a phyllitic fabric (Fabric 1.1 of Cau 2003), characterized by a predominant presence of elongated metamorphic rock fragments, especially phyllite but also some quartz-muscovite schist (Figure 6a). A clear bimodal distribution is observed, with predominance of a poorly sorted coarse fraction. Other inclusions of monocrystalline and polycrystalline quartz are present. The clay matrix is orange-red in color (PPL) and displays optical activity. Elongated voids are frequent. The XRD patterns, with peaks of illite-muscovite, quartz, hematite and alkali feldspar, as well as an initial development of spinel (Figure 7a), suggest and EFT of about 900ºC and an oxidizing firing atmosphere.

In three samples (CS0018, 019, 020) a muscovite-rich fabric is found (Figure 6b), equivalent to Fabric 2.5 of Cau (2003) and probably Fabric 1.6/1.7 of Fulford and Peacock (1984). It is mainly composed of abundant, heterometric inclusions of muscovite and quartz, as well as some rock fragments, possibly metamorphic rocks with quartz and muscovite crystals. The clay matrix is brown to grey-black in PPL, with low optical activity. The XRD patterns indicate the presence of primary phases only (Figure 7b); the intense peaks of phyllosilicates and the absence of firing phases suggest low firing temperatures (<900/950ºC).

Eleven samples (CS0002, 003, 004, 005, 006, 014, 023, 024, 064, 067, 074; possibly also CS0071) show a granodiorite/tonalite fabric (Figure 6c) which is equivalent to Fabric 3.2/3.3 of Cau (2003). It is characterized by a dominant coarse fraction (>0.25 mm) with angular, heterometric inclusions of plagioclase, quartz, alkali feldspar (orthoclase) and a characteristic presence of biotite. There is also a significant presence of coarse plutonic rock fragments ranging from granodiorite to tonalite. It is usually a porous fabric, including elongated voids as well as vughs and vesicles. The matrix is brown-orange in PPL and displays optical activity, in consistency with the low firing temperatures inferred from the absence of firing phases in XRD (Figure 7c).

Two main volcanic fabrics have been identified. One of them, defined as Fabric 1.2 by Fulford and Peacock (1984) or Fabric 3.1 by Cau (2003), is documented in six samples (CS0009, 010, 011, 015, 016, 017) (Figure 6d-e). It contains frequent coarse inclusions of volcanic glass, plagioclase, sanidine, quartz, biotite and volcanic rock fragments (rhyolite to dacite). These latter present either a porphyritic texture, with phenocrysts of plagioclase and quartz, or an aphanitic texture, with a certain devitrification; in some cases they show a clear perlitic texture (Figure 6e). A brown colored, optically active matrix is observed. The XRD spectra indicate the presence of primary phases (Figure 7d) and the absence of firing phases, thus suggesting low firing temperatures, lower than 900/950ºC.

A quite different volcanic fabric, observed in the samples CS0026 and 027 (Figure 6f), is characterized by a distinctive inclusion composition comprising abundant, poorly sorted crystals of alkali feldspar (anorthoclase), some plagioclase and, occasionally, volcanic rock fragments with porphyritic texture and trachytic or pilotaxitic texture of the groundmass, volcanic glass, clinopyroxene (aegirine and aegirine-augite) and aenigmatite (cossyrite). This fabric, defined as Fabric 1.1 by Fulford and Peacock (1984) or Fabric 3.4 by Cau (2003), shows in XRD rather particular patterns in which the very intense peaks of alkali feldspar predominate over other primary phases (Figure 7e); the EFT can be estimated under 900/950ºC, since there is not any firing phase. This fabric, associated with the so-called Pantellerian Ware, has been recently characterized in depth, including experimental work (Montana et al. 2005a, 2005b, 2007).

In a few samples, other individual fabrics have been found, that can be considered as petrographic loners (CS0007, 008, 013, 025, 076). The fabric in CS0007 is characterized by coarse inclusions of plagioclase (up to 2 mm), alkali feldspar, quartz, an abundant and distinctive presence of amphibole, and some plutonic rock fragments composed of these inclusions. CS0076 presents a coarse temper of angular quartz, alkali feldspar, plagioclase, fragments of acidic plutonic rocks and quartzarenite, with a quartz-rich and micaceous fine fraction. Another fabric with coarse plutonic rocks is observed in CS0008, with granitoid fragments composed of quartz, plagioclase and a minor amount of alkali feldspar inclusions. The sample CS0025 exhibits a fabric with frequent plagioclase, alkali feldspar and quartz, in addition to metamorphic rock fragments and fine micas, mostly muscovite. Finally, in sample CS0013 a sedimentary fabric is found, composed of quartz, limestone and iron oxides, as well as some argillite fragments and fine muscovite. All these five petrographic singletons were fired at relatively low temperatures, as indicated by the optical activity of the matrix and the XRD patterns, that show primary phases only.

Chemical characterization

The normalized chemical composition for the 75 individuals analyzed through XRF is presented in Table 2. A first assessment of these data reveal that all the 45 common wares and amphorae analyzed are characterized by a calcareous composition (CaO ≥5%), while the 30 samples of cooking wares are low calcareous, with CaO percentages always under 3.5%.

The chemical data were subjected to multivariate statistical treatment after an additive log ratio (alr) transformation of the compositions. A cluster analysis, using the squared Euclidean distance and the centroid agglomerative method, is presented in Figure 8. The cluster tree allows for the differentiation of a series of chemical groups, CG1 to CG8 (Table 3). These show a clear correspondence with the petrographic fabrics previously defined (Figure 8).

- Common wares and amphorae

A large cluster in Figure 8 comprises the 45 samples of common wares and amphorae. In addition to their calcareous composition, the majority of these samples show important chemical similarities and can be included into a same broad chemical group, CG2, leaving out the samples CS0047 and CS0078 that behave as outliers. All these samples in CG2 are included in the 'fine sedimentary fabric group' according to the petrographic analysis. In order to examine the chemical variability in CG2, the Compositional Variation Matrix (CVM) was calculated (Aitchison 1986, 1992; Buxeda *et al*. 1995; Buxeda 1999; Buxeda and Kilikoglou 2003). From this CVM, a total variation (vt) value of 0.91 was obtained, which is relatively high and seems to indicate a polygenic sample (Buxeda and Kilikoglou 2003). Even if we exclude some elements such as P_2O_5 and Pb, often associated with alteration or contamination problems, this value is still high (vt= 0.71). According to the CVM, there are four elements that explain more than 50% of the variability in this group (CaO, Na_2O, Sr and Cu), although the examination of the chemical data (Table 2) suggests that the variations in Cu are mainly associated with a much higher value for this element in the sample CS0048.

The chemical variability of this group can be better explored through a Principal Component Analysis (PCA), performed on a similar subcomposition as the cluster analysis of Figure 8 but excluding P_2O_5 and Pb and using in this case Nb as divisor in the alr transformation of the data. The biplot of the first two principal components PC1-PC2 (Figure 9), largely dominated by CaO, Na_2O and Sr, illustrates the variations related to these three elements. As seen in Table 2, there is a gradual variation in the calcareous content of the samples in this group, from some border calcareous samples (CaO 4.6-5.9%) to very calcareous ones (up to 25.5% CaO). This variation in CaO and Sr is related to the variable frequencies of calcareous inclusions observed

in the thin section analysis, although a direct correlation between these petrographic and chemical variations is not found, with a few exceptions. In fact, a number of samples with few calcareous inclusions (CS0029, 031, 034, 035, 037, 047, 057), present the lowest CaO percentages of the group (4.6-7.0%) and a strong similarity in their general chemical composition (Figure 8; Table 2).

There is also a gradual variation in the content of Na_2O, from very low (0.5%) in some samples to high in others (up to 2.4%). Variations in Na_2O could not be associated with any particular variation in the petrographic fabrics. In two samples the XRD analysis revealed the presence of analcime peaks (CS0043, 069) that should affect the concentrations of Na_2O and maybe K_2O, Rb and Pb (Buxeda *et al*. 2002; Schwedt *et al*. 2006). However only in CS0069, in which this post-depositional phase has developed more intensively, are these concentrations also paired with a much lower content of K_2O and Rb than the remaining samples in CG2, and a somewhat high concentration of Na_2O (Tables 2-3). In any case, other samples in this group present higher Na_2O percentages than CS0069 that do not seem to be related to the presence of analcime.

Apart from these variations, the chemical composition is rather similar for all the samples in CG2 (Tables 2-3). Indeed, the recalculation of the CVM without CaO, Na_2O and Sr yields a vt value of 0.23, so it cannot be excluded that this group might represent a monogenic population.

- Cooking wares

The cooking wares analyzed are associated with seven chemical groups (CG1, and CG3 to CG8) and a number of singletons (Figure 8), all characterized by a low calcareous composition. At the left end of the cluster tree, the samples CS0026 and CS0027, related to the so-called Pantellerian Ware, form a very distinctive group, CG1, clearly differentiated from the rest of the data set for particularities such as the very high Ce, Nb, Y, Zr and Ba concentrations, in addition to high percentages of Fe_2O_3, Al_2O_3, Na_2O and MnO (Tables 2-3).

A large cluster in Figure 8 includes 27 samples of cooking wares, in which six chemical groups, CG3 to CG8, can be identified (Table 3). The most distinctive of these groups is CG3, with very high levels of Pb, V and Zn, in addition to very high Fe_2O_3 and Al_2O_3 percentages (Table 3). The samples in CG3 are related to a phyllitic fabric (Cau Fabric 1.1) identified in thin section. The high levels of Pb do not seem to be caused by any post-depositional alteration, since they occur only in this fabric and have been reported also in other sherds from the same fabric from different archaeological sites (Cau 2003).

Concerning the chemical groups CG4 to CG8, their differentiation can be observed more clearly in the PCA in Figure 10, in which various elements dominate both PC1 (Y, CaO, Cu, Ce, Nb, Zr, Ba, Zn, TiO_2) and PC2 (Zn, Na_2O, Ni, Th, Ba, CaO, MgO, Sr). More or less significant differences in the concentrations of these elements account for the separation of these small groups in the biplot PC1-PC2, as shown in Table 3. The groups CG4 and CG6 include six individuals associated with a volcanic fabric (Fulford and Peacock Fabric 1.2 / Cau Fabric 3.1); they show a similar chemical composition, except for a higher content of Zn and Pb in CG6 than in CG4 (Figure 10). The chemical group CG5 corresponds well with a muscovite-rich fabric (Fulford and Peacock Fabric 1.6/1.7? / Cau Fabric 2.5). The samples included in chemical groups CG7 and CG8, as well as the singleton CS0064, are related to a granodiorite/tonalite fabric (Cau Fabric 3.2/3.3), what suggests a certain chemical variability of the individuals associated with this fabric. The only significant difference between these two chemical groups is a higher content of Na_2O in CG7 (1.2-2.0%) than in CG8 (0.6-0.7%), this latter being less represented than the former.

Local and imported fabrics: provenance, typology and chronology

The archaeometric analysis of 78 pottery samples from Ses Païsses de Cala d'Hort, or Can Sorà, provided information on the characterization, provenance and technology of various ceramics classes and forms (Table 4). Further details are obtained by also integrating the archaeological evidence, in particular the typology and chronology of the samples.

Almost all of the 45 common wares and amphorae analyzed revealed strong similarities in fabric (‘fine sedimentary fabric group’) and chemical composition (CG2), except for a certain internal variability that seem to indicate the use of related clayey raw materials, possibly from a same general source area. One significant point that emerges from the integration of the archaeological data for this large group is the lack of correspondence between the typology or function of the vessels and these variations in petrographic and/or chemical composition (Figure 11). Similar forms of common wares and amphorae are associated with different compositions within the range of variation of this group, while, conversely, samples with stronger similarities in fabric and chemical composition are related to quite different ceramics. It is worth mentioning that all the vessels coming from Layer V of the cistern, dated to the first half of the 5th century, show CaO percentages not higher than 11.7%. Conversely, the samples from Layer IV (late 6th century) and later layers (up to the abandonment layers of Building A) are more variable concerning their CaO percentages.

For all of these samples, both the archaeometric and archaeological characteristics suggest a local/regional provenance. On the basis of their chemical and petrographic composition, they can be associated with the so called Ebusitan production (*e.g.* Buxeda *et al.* 1997, 1998, 2005; Cau *et al.* 1997a, 2004; Ramon and Cau 1997; Buxeda and Cau 2004), while the typological repertoire is clearly comparable to the one described by Ramon (1986, 2008) for Late Antique Ebusitan pottery. One problem, related not only to the common wares and amphorae of Ses Païsses de Cala d'Hort included in this study but also more generally to all of the analyzed examples from the Balearic Islands, is their remarkable chemical similarity, combined with a lack of fully characterized, archaeologically excavated Late Antique kiln sites. The absence of reference groups therefore obliges us to work at a chemically overlapping level (Picon 1984; Buxeda *et al.* 1995). At the same time, chemically identified groups tend to be similar in petrographic terms and, consequently, petrography does not help to better differentiate the pottery from different production centers or areas. In addition, the lack of archaeological information on the characteristics of pottery production patterns during Late Antiquity in the Balearic Islands does not allow us to know the level of standardization in the manufacturing process of common wares and amphorae in various workshops or production centers.

There is only one sample of common ware in this study, CS0078, that was not included in the ‘fine sedimentary fabric group’ and, according to its petrographic composition and the general characteristics of the fabric, does not seem related to an Ebusitan or Balearic provenance. It is not possible to pose any specific hypothesis on the provenance of this sample at this stage.

With regard to the 33 analyzed samples of cooking wares, a general correspondence was observed between the chemical groups and the petrographic fabrics. In contrast to the certain compositional homogeneity found in the common wares and their local/regional provenance, the cooking wares in this study revealed an important variability of chemical-petrographic compositions that in almost all cases are not compatible with a Balearic provenance (Table 4). The only exception is the individual CS0013, for which a local/regional provenance cannot be excluded on petrographic grounds; however, its fabric is quite different to the known Roman and Late Antique Ebusitan fabrics, and its sedimentary composition may be related to many possible provenance areas.

For almost all of the analyzed cooking wares, the presence of fabrics with a volcanic, plutonic and/or metamorphic contribution indicates their incompatibility with the geology of Eivissa or, in general, the Balearic Islands. Even if some outcrops of volcanic rocks exist on the island, these are actually not very important and their lithology differs from the one found in the fabrics from the site (Cau 1999, 2003). Therefore, the archaeometric analysis indicates that the vast

majority of cooking wares in Ses Païsses de Cala d'Hort were imported. These include vessels from the various Late Antique layers in the site, that is, from the 5th to the 7th/early 8th centuries, but mainly from Layers V (first half of the 5th century) and IV (late 6th century). Based on the petrographic and chemical results, most of the imported cooking wares in this study (Table 4; Figure 12) can be associated with fabrics and wares which are already known in other western Mediterranean sites dated to the same period (see for example Hayes 1976; Fulford and Peacock 1984; CATHMA 1991; Reynolds 1993, 1995, 2010; Cau 2003, 2007a; Macias and Cau 2012):

- Fabric 3.2/3.3 (Cau 2003) / Handmade Ware 8 (Reynolds 1993): a granodiorite-tonalite fabric that is the most represented fabric for cooking wares in the site. In this study, it was found in 12 samples (Table 4) with some chemical variations (CG7, CG8 and singletone CS0064). It includes basically tall and short casseroles (Table 1; Figure 12a) (for further details on the forms related to this fabric, see Reynolds 1993, Cau 2003, 2007a). These forms are related mainly to Layer V of the site, with a few samples in Layer IV (residual materials?) and in the abandonment levels of Building A; the latter show slightly different chemical compositions (CG8 and CS0064) and might be representing a particular fabric with a later chronology. The provenance of this general fabric, which must be associated with an area of graniodiritic or tonalitic lithologies, remains uncertain. The area of Murcia or southern Alicante has been suggested as a possible hypothesis, however other areas, such as the Catalan coast or the central Mediterranean, cannot be excluded since no clear archaeological evidence exists thus far (Reynolds 1993, 2010; Cau 2003, 2007a; Macias and Cau 2012).

- Fabric 1.2-Black-burnished Ware (Fulford and Peacock 1984) / Fabric 3.1 (Cau 2003) / Handmade Ware 2 (Reynolds 1993): a volcanic fabric that is well represented in the site. Seven samples are included here (Table 4), with more or less similar chemical compositions (CG4 and CG6). Some of the analyzed samples (CS0015, 016) from Layer IV of the site show a typical sixth-century form for this fabric, the bowl Fulford HMW 8. Other samples (CS0009, 010, 011, 012) come from Layer V and can be associated with a possible early variant of this form (Figure 12c). Based on the petrographic composition a possible provenance from Lipari was proposed (Fulford and Peacock 1984) but also Sardinia has been suggested, though not excluding other possibilities (Cau 2003, 2007a; Cau *et al*. 2002; Buxeda *et al*. 2005; Macias and Cau 2012).

- Pantellerian Ware / Fabric 1.1 (Fulford and Peacock 1984) / Fabric 3.4 (Cau 2003) / Handmade Ware 1 (Reynolds 1993): another volcanic fabric with a distinctive chemical composition (CG1). It is represented here, in Layer V, by two samples of the form Fulford HMW 1 (Figure 12d), a short casserole that is typical of this fabric and was widely distributed between the mid-4th and mid-5th centuries. The provenance of this fabric has been pinpointed to the island of Pantelleria, to the south of Sicily, based on the presence of acidic volcanic rock

fragments and the rare association of aegirine, aenigmatite and anorthoclase (Peacock 1982a, 1982b; Fulford and Peacock 1984, Cau 2003, 2007a; Santoro *et al.* 2003; Santoro 2005; Montana *et al*. 2005a, 2005b, 2007; Macias and Cau 2012).

- Fabric 2.5 (Cau 2003) / Fabric 1.6-1.7? (Fulford and Peacock 1984): a muscovite-rich fabric with a particular chemistry (CG5). It is represented, in Layer IV, by the bowl Fulford HMW 20 (Figure 12e), a form widely distributed in the Mediterranean in the first half of the 6th century mainly. The provenance of this fabric remains indeterminate so far, some areas such as Sardinia, southern Italy or Sicily having been proposed. It seems to be associated with a slightly metamorphosed granitic lithology that can be compatible with many other areas in the Mediterranean (Fulford and Peacock 1984; Cau 2003, 2007a; Macias and Cau 2012).

- Fabric 1.1 (Cau 2003): a phyllitic fabric, with a distinctive chemical composition (CG3), found in three samples (Table 4). Two of them (CS0021, 022: Figure 12f), from Layer IV of the site, show a form of tall casserole that is quite abundant in fifth- and sixth-century contexts of Cartagena, SE Spain (Láiz and Ruiz 1988). The sample CS0068 is from a later layer, however the possibility of residuality should not be excluded in this case. For this fabric a probable provenance in the area of Cartagena has been proposed, on the basis of both the petrographic composition and the archaeological evidence, including the recent finding of a production centre (Láiz and Ruiz 1988; Cau 1996, 2003, 2007a; Ramallo *et al*. 1996; Macias and Cau 2012).

A series of petrographic singletons (CS0007, 008, 025, 076) provides further evidence of the diversity of cooking wares found at the site (Figure 12g). The presence of plutonic and/or metamorphic components in their fabrics, each with its particularities, might be associated with various possible source areas, but clearly not with Eivissa. Few other conclusions can be drawn from the available information for these poorly known fabrics.

Conclusions

The archaeometric characterization of Late Roman cooking wares, common wares and amphorae from Ses Païsses de Cala d'Hort reflects on a smaller scale the general trends of pottery production and distribution in the Balearic Islands during Late Antiquity.

The analysis of cooking wares reveals the existence of many imported products, with the presence of some of the most commonly traded of these ceramics in the Mediterranean during the 5th and 6th centuries. The most represented fabrics in this specific context are the biotite-rich Fabric 3.2/3.3 (Cau 2003) / HMW 8 (Reynolds 1993), the volcanic Fabric 1.2-Black-burnished Ware (Fulford and Peacock 1984) / Fabric 3.1 (Cau 2003), the phyllitic Fabric 1.1

(Cau 2003), the muscovitic Fabric 2.5 (Cau 2003) and the Pantellerian Ware / Fabric 1.1 (Fulford and Peacock 1984) / Fabric 3.4 (Cau 2003) / HMW 1 (Reynolds 1993). Even if these fabrics are well represented in many western Mediterranean contexts, their provenance in some cases remains uncertain. In any event, these and other less represented cookware fabrics at Ses Païsses de Cala d'Hort are clearly imported from outside the Balearic Islands. Their presence here, like in other rural sites of the islands — *e.g.* Sa Mesquida (Cau 1994, 2003) — proves that this site in particular and the region in general were taking part in larger trade networks in Late Antiquity. The wide distribution of these and other Late Roman cooking wares throughout the Mediterranean could have been related, among other reasons, to a series of technological advantages already discussed in previous works (see Cau 1999, 2003).

Unlike the cooking wares, that show a certain correspondence — with exceptions — between fabrics, chemical groups and ceramic types or forms, the common wares and amphorae seem to present a different complexity. A large, somewhat homogeneous chemical-petrographic group has been identified, in which the internal diversity is mainly related to differences in the calcareous content, in some textural variations in thin section and in the relative content of Na_2O. Nonetheless, the overall chemical variation suggests a similar geochemical origin for the whole group. This internal variability cannot be explained based on typological or chronological grounds. The archaeometric evidence points to the possible existence of small local or regional workshops producing pottery in a very similar way, although using raw materials from slightly different sources.

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Figure captions

Figure 1. Map of the Balearic Islands with the situation of Ses Païsses de Cala d'Hort

Figure 2. (a) Plan of the building A of Ses Païsses de Cala d'Hort (Ramon 1994). (b) Plan of the building A in the Late Antique period (Ramon 1994)

Figure 3. Geological map of Eivissa, with an indication of Ses Païsses de Cala d'Hort (modified from IGME 1972)

Figure 4. Microphotographs of thin sections of common wares and amphorae samples, all taken in crossed polarised light at the same magnification (40x), except for (a) that was taken at 100x. (a-e) 'fine sedimentary fabric group' (a, CS0070, calcareous clay streak; b, CS0049; c, CS0052; d, CS0034; e, CS0058). (f) CS0078

Figure 5. XRD spectra for selected samples of common wares and amphorae included in the 'fine sedimentary fabric group', showing a progressive increase of firing temperatures from (a) to (e). Abbreviations for minerals: an, analcime; c, calcite; g, gehlenite; h, hematite; i-m, illite-muscovite; kf, K-feldspar; p, plagioclase; px, pyroxene; q, quartz

Figure 6. Microphotographs of thin sections of the main cooking ware fabrics, all taken in crossed polarised light at the same magnification (40x), except for (d) that was taken at 100x. (a) CS0022. (b) CS0020. (c) CS0004. (d) CS0011. (e) CS0015. (f) CS0026

Figure 7. XRD spectra for selected samples of cooking wares related to the main fabrics defined from the petrographic analysis. Abbreviations for minerals: an, analcime; c, calcite; g, gehlenite; h, hematite; i-m, illite-muscovite; kf, K-feldspar; p, plagioclase; px, pyroxene; q, quartz

Figure 8. Dendrogram resulting from a cluster analysis (using the centroid agglomerative method and the squared Euclidean distance) on 75 samples, including the subcomposition Fe_2O_3, Al_2O_3, P_2O_5, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Th, Nb, Pb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu, and Ni, using TiO_2 as divisor in the log-ratio transformation of the data. CG: chemical group

Figure 9. PCA of the alr-transformed chemical data for the 43 samples of common wares and amphorae included into the chemical group CG2 in Figure 8; the analysis was performed on the covariance matrix. Plot of the two first principal components (PC1-PC2), based on the subcomposition Fe_2O_3, Al_2O_3, TiO_2, MgO, CaO, Na_2O, K_2O, SiO_2, Ba, Rb, Th, Zr, Y, Sr, Ce, Ga, V, Zn, Cu and Ni (Nb is used as divisor in the log-ratio transformation)

Figure 10. PCA of the alr-transformed chemical data for the cooking ware samples included into the chemical groups CG4 to CG8 in Figure 8, in addition to some loners (n= 24); the analysis was performed on the covariance matrix. Plot of the two first principal components (PC1-PC2), based on the subcomposition Fe_2O_3, Al_2O_3, TiO_2, MgO, CaO, Na_2O, K_2O, Ba, Rb, Th, Nb, Zr, Y, Sr, Ce, Ga, V, Zn, Cu and Ni (SiO_2 is used as divisor in the log-ratio transformation)

Figure 11. Illustrations of the analysed common wares and amphorae. All (except for CS0078) in the 'fine sedimentary fabric group'

Figure 12. Illustrations of the analysed cooking wares. (a) Granodiorite/tonalite fabric = Fabric 3.2/3.3 (Cau 2003). (b) Possibly related to the latter. (c) Volcanic fabric = Fabric 1.2 (Fulford and Peacock 1984) = Fabric 3.1 (Cau 2003). (d) Pantellerian ware = Fabric 1.1 (Fulford and Peacock 1984) = Fabric 3.4 (Cau

2003). (e) Muscovite-rich fabric = Fabric 2.5 (Cau 2003) = Fabric 1.6/1.7? (Fulford and Peacock 1984). (f) Phyllitic fabric = Fabric 1.1 (Cau 2003). (g) Petrographic loners

Table captions

Table 1. List of the analysed samples, with their main archaeological information

Table 2. Normalised chemical results of the 75 samples that were subjected to chemical analysis (XRF). Concentrations of major and minor oxides are in %, other minor and trace elements are in ppm

Table 3. Mean chemical composition of the groups CG1 to CG8. Mean (m) and standard deviation (sd) values are presented for each element

Table 4. Summary of the results obtained from the chemical, petrographic and mineralogical analysis, organised by fabric