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**Abstract:** The Roman city of Pollentia was founded in 123 BCE in the northern part of the island of Mallorca (Balearic Islands, Spain). The city developed through the Republican and Imperial periods. At the end of the third century CE, a large fire destroyed parts of the city, although it survived through the Vandal and the Byzantine periods. At the beginning of the tenth century, the Balearics were conquered by the Muslim forces. Recent excavations of the Late Roman fortification located at the area of the forum have revealed some layers with large quantities of utilitarian ceramics dated to the Islamic period. An archaeometric study was carried out to characterize these products, their provenance and technology. This was completed by utilizing a combination of techniques, including: Wavelength Dispersive X-Ray Fluorescence (WDXRF), X-Ray Diffraction (XRD) and Optical Microscopy by thin-section analysis (OM). The results show two main compositional groups, one of which might be local and a second one regional. This is a first step on the compositional characterization of utilitarian pottery from Pollentia under the Islamic rule, and contributes to a progressive and systematic characterization of ceramics from this particular period on the island.

**Résumé :** *La ville romaine de Pollentia a été fondée en 123 Av.-J.C. dans la partie nord de l'île de Majorque (Baléares, Espagne) et s'est développée au travers des périodes républicaines et impériales. À la fin du troisième siècle après J.C., un grand incendie détruit une partie de la ville. Cette dernière fut ensuite reconstruite et a pu survivre aux ères Vandale et Byzantine. Au début du dixième siècle, les Baléares furent conquises par les forces musulmanes. De récentes fouilles de la fortification romaine dans l'espace du forum ont révélé l'existence de niveaux contenant de grandes quantités de céramique utilitaire datant de la période islamique. Une étude archéométrique fut conduite afin de déterminer la nature de ces produits, leur origine ainsi que les technologies utilisées. Une combinaison de techniques ont été mises en œuvre, à savoir la spectrométrie de fluorescence des rayons X à dispersion de longueur d'onde (WD-XRF), la diffraction des rayons X (XRD) et la microscopie optique (OM) par l'analyse de lame mince. Les résultats montrent deux groupes principaux de composition, l'un pouvant être local et l'autre régional. Il s'agit là d'un premier pas vers la caractérisation de la céramique de Pollentia à l'époque islamique avec la volonté de contribuer à une caractérisation progressive et systématique de la céramique de Majorque en cette période particulière.*

**Keywords:** pottery, islamic period, geochemistry, petrography, archaeometry, Balearic Islands.

**Mots clés :** *céramique, période islamique, géochimie, pétrographie, archéométrie, Îles Baléares.*

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## 1. INTRODUCTION:
### THE ANCIENT CITY OF POLLENTIA

The Roman city of Pollentia (current Alcúdia) lies in the northern part of the island of Mallorca (Balearic Islands, Spain) (fig. 1). The written sources mention its foundation in the year 123 BCE (Orfila *et al.*, 2008). At the end of the third century CE, a large fire destroyed many parts of the city (Arribas *et al.*, 1973; Orfila *et al.*, 1999). However, traumatic as this event may have been, it did not mean the abandonment of the city that survived through the Vandal (455-534 CE) and the Byzantine (534 - 902/903 CE) periods. One of the most important features of these latter phases is the Late Roman or Byzantine fortification of the forum area (*e.g.* Riera *et al.*, 1999; Orfila *et al.*, 2000).

From the eighth century, written sources describe the first Muslim attacks to the Balearics, although it is not well known if these affected the city of Pollentia. At the beginning of the tenth century (902/903 CE), the Balearics were conquered by Muslim forces (Rosselló Bordoy, 1968, 1973) and their sovereign lasted until the Catalan conquest in 1229. Very little is known about the occupation of Pollentia during this period. However, since the early years of archaeological investigation pottery from the Muslim era was attested too, in different areas of the city. In the forum, large quantities of water jars were found in several areas but mainly in the northern part of the insula of *tabernae*. An interim study of some of these materials showed the presence of a vast majority of jars classified as type 3A – according to the typology proposed by Rosselló Bordoy (1978) – and dated mainly to the tenth
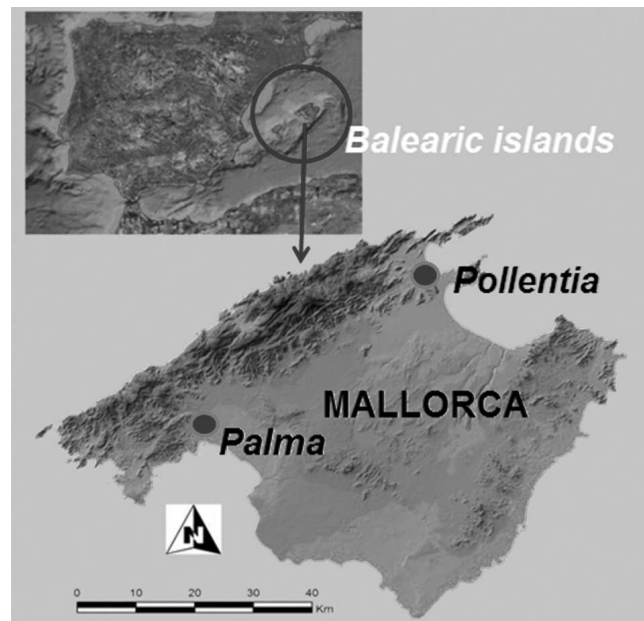


Figure 1: (See color plate I) Location of the archaeological site of Pollentia.
*Figure 1 : (Voir planche couleur I) Localisation du site archéologique de Pollentia.*

and eleventh centuries (Orfila & Riera, 2002). This predominance of water jars has been related to the existence of a well (Orfila & Riera, 2002). Although the occupation of the city is clear, as indicated by pottery finds, the Muslim phases have only been reviewed on occasion. As described in recent literature, the radiocarbon dating of the vast necropolis over
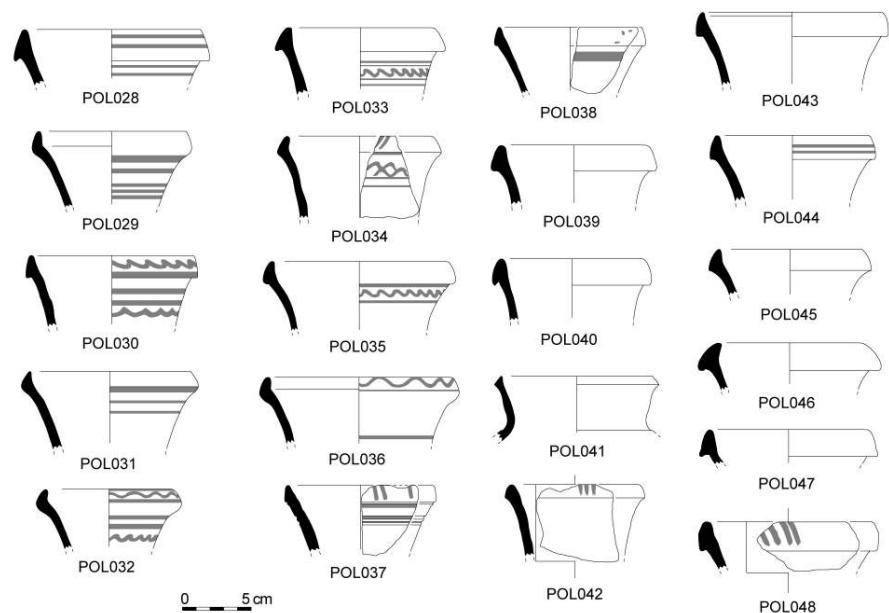


Figure 2: Drawings of the Islamic water jars analyzed.
*Figure 2 : Dessins des jarres à eau islamiques analysées.*

the old forum area has revealed that this cemetery dates to the Muslim period (Cau *et al.*, 2017). However, the deposition rituals observed do not follow common Muslim burial practices (i.e. the inhumation of the body in a lateral position), opening the possibility of non-Muslim communities being buried in the Muslim period. This also highlights an important aspect in the history of the city during this period.

Recent excavations of the Late Roman fortification at the forum area have revealed some layers (SU 8015/8017) with large assemblages of utilitarian ceramics, dated to the Muslim period. The materials recovered in these contexts are also dominated by water jars of the so-called Type 3A (Rosselló Bordoy, 1978). Within the ceramics, there are no over-fired materials, nor evidence of a possible workshop. However, the large quantities of pottery found leaves open the possibility of the existence of a local workshop. The initial hypothesis is that these utilitarian ceramics may be made in Pollentia, or areas nearby.

An archaeometric analysis was carried out on selected samples to identify provenance (local or not) and technological aspects. It must be pointed out that the archaeometric study of pottery from the Islamic period in the Balearic Islands is still in an incipient state. A brief examination of some tin glazes from eleventh-century jars (Molera *et al.*, 2001) and a very recent study of the Almohad ceramics found at the site of Puig de Sa Morisca (Albero Santacreu *et al.*, 2019) have been published. Therefore, it is essential to fill the gap in our knowledge of pottery production and distribution during this specific historical period and the materials from Pollentia can contribute to this.

## 2. Analytical methods

Twenty-one samples of water jars were selected for analysis, a large proportion of which were with painted decoration on the rim and/or the neck (fig. 2). An archaeometric characterization was applied using a combination of analytical methods, in particular: petrographic-mineralogical analysis by thin-section optical microscopy (OM), further mineralogical analysis using X-ray powder diffraction (XRD), and, finally, chemical analysis of the samples was performed utilizing wavelength dispersive X-ray fluorescence (WD-XRF). All the ceramic samples were analyzed using all the above techniques, except for POL037, which was not analyzed by OM.

The petrographic-mineralogical analysis of thin sections was performed using an optical microscope Olympus BX41, equipped with a digital camera Olympus DP-70. The analysis was carried out working with a magnification between ×20 and ×200. The descriptions of ceramic fabrics were based on the systems proposed by Whitbread (1989, 1995) and Quinn (2013). The grain-size classification for the inclusions in the petrographic descriptions followed the Udden-Wentworth scale. For the XRD mineralogical analysis, a PANalytical X'Pert PRO MPD alpha 1 diffractometer was used, working with the Cu–Kα radiation ($\lambda$ = 1.5406 Å), in the 2θ interval between 5 and 80°, with a step-size of 0.026° 2θ and a step-time of 47.5 s., tube current of 40 mA, and a voltage of 45 kV. Identification of crystalline phases was carried out using the High Score Plus by PANalytical software, which included the Joint Committee of Powder Diffraction Standards (JCPDS) data bank.

The chemical analysis was performed using a Panalytical-Axios PW 4400/40 spectrometer. A fragment of each individual was powdered and homogenized in a tungsten carbide mill, and dried at 100 °C for 24 hours. Fused beads were prepared for the determination of major and minor elements, using 0.3 g of a calcined specimen, in an alkaline fusion with lithium tetraborate (1/20 solution). This allowed for the identification of 10 major and minor elements, including $Fe_2O_3$, $Al_2O_3$, $MnO$, $P_2O_5$, $TiO_2$, $MgO$, $CaO$, $Na_2O$, $K_2O$ and $SiO_2$. At the time of writing, it was not possible to carry out the analysis of trace elements, but it is intended to perform this analysis in the future. Analytical data were subjected to various statistical procedures using the software S-PLUS 2000, after a log-ratio transformation of the values were obtained by XRF (Aitchison, 1986, 2005; Buxeda, 1999).

## 3. Analytical results

### OM petrographic-mineralogical analysis

The OM thin section analysis enabled the differentiation of two main petrographic fabrics both with a bimodal grain-size distribution of the inclusions, indicating a deliberated addition of temper and a calcareous matrix.

Fabric 1, observed in seven individuals (POL028, POL030, POL039, POL040, POL042, POL043, POL047), is characterized by the use of altered volcanic rocks for tempering (fig. 3). In fact, there is a coarse fraction with predominant reddish inclusions that resemble iron-rich nodules to the naked eye, but, in thin section, they can be identified as fragments of altered basic volcanic rocks – probably altered basalts or spillites – showing in some cases, a vesicular texture and plagioclase microlites. These rock fragments range from angular to subrounded (mostly subangular-subrounded), poorly sorted, with grain sizes from fine sand to very coarse sand. Some other red-colored fragments without internal textures are more difficult to

interpret, since they could either be altered volcanic rocks or iron-rich mudstones. On the whole, however, the volcanic rock fragments are the dominant feature. The coarse fraction (>0.20 mm) also contains few limestone fragments (with micrite or sparry calcite); only in rare cases (*e.g.* POL042) these fragments are common, but still lower in abundance to the volcanic inclusions. Very rare calcareous microfossils, quartzarenite and quartz can also be found in the coarse fraction. The micromass is calcareous, with an abundant fine fraction (mode <0.10 mm) formed by carbonate inclusions, i.e. calcite and marine microfossils, especially foraminifera. There are also abundant fine inclusions of micas (muscovite and biotite) and quartz. The matrix varies from slightly optically active to optically inactive. In many samples, secondary calcite is observed, possibly formed (at least partially) from the recrystallization of carbonate material that was already present in the initial clay paste.

The other main petrographic fabric, Fabric 2, observed in 12 samples (POL029, POL031, POL032, POL033, POL034, POL035, POL036, POL038, POL041, POL044, POL045 and POL046) also shows a bimodal grain size distribution with a clear coarse fraction that was added as temper. However, in this fabric, this coarse fraction (>0.20 mm) is composed of dominant sedimentary carbonate rocks (fig. 4), mostly limestone fragments with micrite or sparry calcite. These are poorly sorted, from angular to rounded,

and with variable size between medium sand and granules. The coarse fraction also contains fragments of quartz-sandstone, mudstone, iron nodules and very rare quartz. The fine fraction, formed by silt to fine sand inclusions, is very abundant and consists of predominant carbonate fragments, as well as rhomboedral crystals (usually <0.20 mm) of calcite; these latter are present in all the samples, but are more frequent in some of them (POL029, POL031, POL034, POL035, POL038, POL041, POL046). Calcareous microfossils (*e.g.* foraminifera) are common to few. The fine fraction contains also frequent inclusions of quartz and micas (muscovite and biotite), mostly <0.10 mm. The micromass is optically inactive, except for a few individuals displaying low optical activity (POL031, POL034). Secondary calcite is commonly observed, scattered throughout the micromass and, less frequently, filling voids.

In addition to these two main petrographic fabrics, there is a third fabric, Fabric 3, which is represented only by one sample (POL048) (fig. 5). In this case, the coarse fraction is poorly sorted (from fine sand to very coarse sand) and consists of dominant limestone and few mudstone fragments, but also contains accessory altered volcanic rocks similar to those observed with much higher frequency in Fabric 1. The fine fraction is rich in carbonate inclusions i.e. calcite and some microfossils (foraminifera mainly), as well as in quartz and micas (muscovite and, in lesser amount, biotite), which are
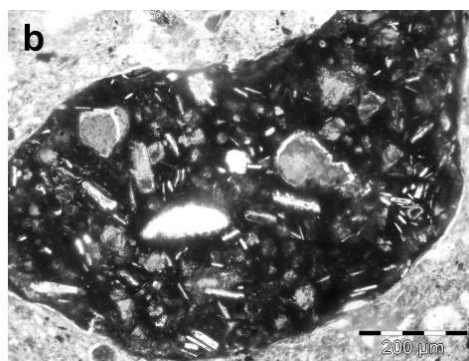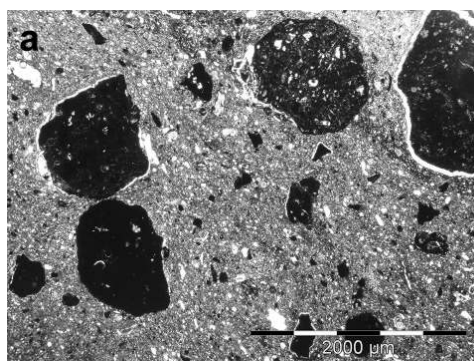


Figure 3: (See color plate I) Photomicrographs of ceramic of Fabric 1, taken under plane polarized light. (a) Sample POL042. (b) Sample POL043. *Figure 3 : (Voir planche couleur I) Photomicrographies des lames minces des céramiques du groupe de pâtes céramiques 1, prises sous polariseurs parallèles : (a) échantillon POL042 40x. (b) échantillon POL043, 200x.*
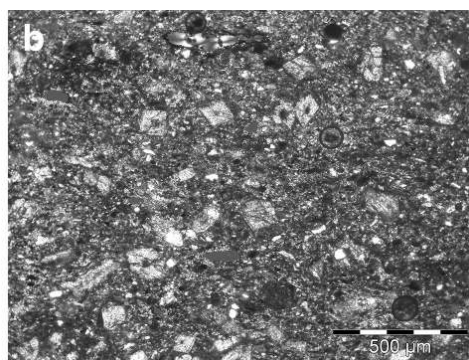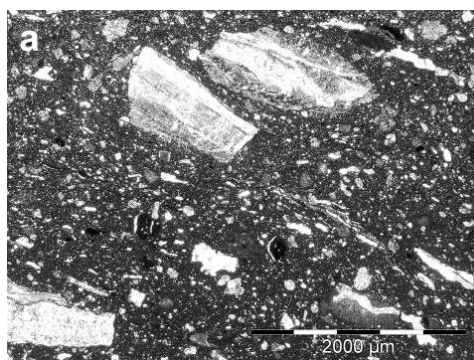
Figure 4: (See color plate I) Photomicrographs of ceramic of Fabric 2, taken under crossed polars. (a) Sample POL032. (b) Sample POL034. *Figure 4 : (Voir planche couleur I) Photomicrographies des lames minces des céramiques du groupe de pâtes céramiques 2, prises sous polariseurs croisés. (a) échantillon POL032, 40x. (b) échantillon POL034, 100x.*

| Sample | $Fe_2O_3$ | $MnO$ | $TiO_2$ | $CaO$ | $K_2O$ | $P_2O_5$ | $SiO_2$ | $Al_2O_3$ | $MgO$ | $Na_2O$ |
|---|---|---|---|---|---|---|---|---|---|---|
| *Fabric 1* | | | | | | | | | | |
| POL028 | 6.73 | 0.09 | 0.97 | 23.31 | 2.71 | 0.29 | 47.75 | 14.22 | 3.42 | 0.49 |
| POL030 | 7.37 | 0.07 | 1.05 | 16.43 | 3.41 | 0.21 | 50.87 | 17.08 | 2.94 | 0.58 |
| POL039 | 7.97 | 0.10 | 1.14 | 16.95 | 3.25 | 0.23 | 50.63 | 15.73 | 3.52 | 0.48 |
| POL040 | 7.15 | 0.07 | 1.03 | 17.45 | 3.16 | 0.22 | 49.99 | 17.02 | 3.41 | 0.50 |
| POL042 | 6.88 | 0.08 | 1.04 | 20.14 | 3.30 | 0.21 | 49.25 | 16.06 | 2.58 | 0.48 |
| POL043 | 7.29 | 0.07 | 1.07 | 15.00 | 3.35 | 0.25 | 53.26 | 16.26 | 2.89 | 0.56 |
| POL047 | 8.03 | 0.07 | 1.21 | 13.88 | 3.54 | 0.27 | 52.21 | 17.56 | 2.66 | 0.57 |
| *min.* | *6.73* | *0.07* | *0.97* | *13.88* | *2.71* | *0.21* | *47.75* | *14.22* | *2.58* | *0.48* |
| *max.* | *8.03* | *0.10* | *1.21* | *23.31* | *3.54* | *0.29* | *53.26* | *17.56* | *3.52* | *0.58* |
| *mean* | *7.35* | *0.08* | *1.07* | *17.59* | *3.24* | *0.24* | *50.57* | *16.27* | *3.06* | *0.52* |
| *sd* | *0.50* | *0.01* | *0.08* | *3.20* | *0.26* | *0.03* | *1.83* | *1.11* | *0.39* | *0.04* |
| *Fabric 2* | | | | | | | | | | |
| POL029 | 4.90 | 0.06 | 0.77 | 34.14 | 2.06 | 0.21 | 40.47 | 14.51 | 2.56 | 0.33 |
| POL031 | 4.81 | 0.06 | 0.84 | 23.76 | 2.59 | 0.19 | 48.18 | 16.88 | 2.43 | 0.26 |
| POL032 | 5.19 | 0.07 | 0.80 | 31.09 | 1.79 | 0.21 | 42.21 | 15.11 | 3.19 | 0.35 |
| POL033 | 5.47 | 0.06 | 0.82 | 20.73 | 2.01 | 0.17 | 49.06 | 17.75 | 3.61 | 0.32 |
| POL034 | 4.62 | 0.06 | 0.84 | 23.01 | 2.61 | 0.18 | 48.80 | 17.01 | 2.56 | 0.32 |
| POL035 | 4.90 | 0.06 | 0.85 | 20.91 | 2.58 | 0.19 | 49.53 | 17.30 | 3.35 | 0.32 |
| POL036 | 5.20 | 0.06 | 0.77 | 33.00 | 2.07 | 0.20 | 40.93 | 14.64 | 2.77 | 0.34 |
| POL037 | 4.84 | 0.07 | 0.78 | 19.71 | 2.56 | 0.21 | 50.82 | 17.35 | 3.37 | 0.29 |
| POL038 | 4.01 | 0.04 | 0.73 | 20.77 | 2.92 | 0.18 | 51.18 | 16.91 | 3.03 | 0.24 |
| POL041 | 4.99 | 0.09 | 0.73 | 24.55 | 2.64 | 0.23 | 47.03 | 16.13 | 3.33 | 0.29 |
| POL044 | 4.51 | 0.04 | 0.83 | 16.41 | 2.75 | 0.16 | 53.86 | 18.29 | 2.81 | 0.35 |
| POL045 | 4.86 | 0.06 | 0.85 | 15.73 | 3.13 | 0.19 | 53.11 | 19.03 | 2.74 | 0.30 |
| POL046 | 4.81 | 0.07 | 0.79 | 18.28 | 2.96 | 0.20 | 51.74 | 17.88 | 2.96 | 0.32 |
| *min.* | *4.01* | *0.04* | *0.73* | *15.73* | *1.79* | *0.16* | *40.47* | *14.51* | *2.43* | *0.24* |
| *max.* | *5.47* | *0.09* | *0.85* | *34.14* | *3.13* | *0.23* | *53.86* | *19.03* | *3.61* | *0.35* |
| *mean* | *4.85* | *0.06* | *0.80* | *23.24* | *2.51* | *0.19* | *48.22* | *16.83* | *2.98* | *0.31* |
| *sd* | *0.36* | *0.01* | *0.04* | *6.03* | *0.41* | *0.02* | *4.45* | *1.39* | *0.37* | *0.03* |
| *Fabric 3* | | | | | | | | | | |
| POL048 | 5.40 | 0.03 | 0.69 | 13.87 | 3.22 | 0.14 | 48.29 | 17.38 | 1.68 | 0.43 |

Table 1: Normalized chemical composition (major and minor elements in % of the oxide) organized according to the three petrographic fabrics; and mean and standard deviation of petrographic fabrics 1 and 2.
*Table 1 : Moyenne normalisée des compositions chimiques (éléments majeurs et mineurs en % d'oxyde) des trois groupes pétrographiques de pâtes céramiques.*

mostly < 0.10 mm. The rhomboedral calcite crystals which are frequent in Fabric 2 are not observed in Fabric 3. Unlike the previous fabrics, the micromass is red-colored in the walls, yellowish in the core, and shows a few streaks, some richer in carbonates and others with a red color (probably more ferru-ginous). This suggests the possibility of clay mixing practices. In any case, it is a carbonate-rich fabric, as indicated by the inclusions and partially by the micromass. The matrix displays slight optical activity with crystalitic b-fabric.
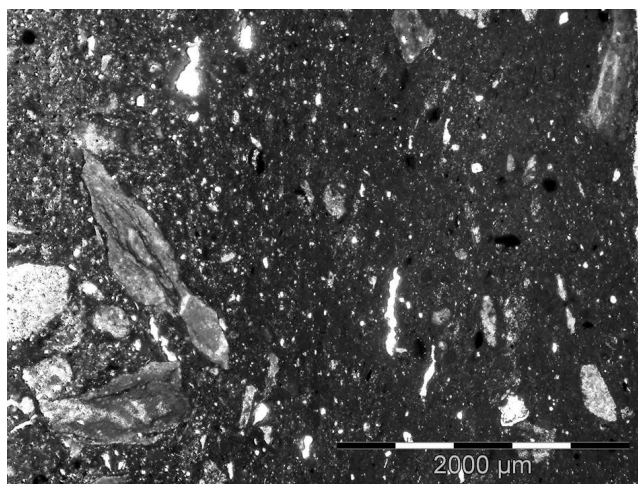
Figure 5: (See color plate II) Photomicrograph of ceramic of Fabric 3 (sample POL048), taken under crossed polars.
*Figure 5 : (Voir planche couleur II) Photomicrographie des lames minces des céramiques du groupe de pâtes céramiques 3 (échantillon POL048), prises sous polariseurs croisés à 40x.*



Figure 6: Binary diagram, using normalized data, of $Fe_2O_3$ vs $TiO_2$ for the ceramic samples analyzed.
*Figure 6 : Diagramme binaire, avec données normalisées, du $Fe_2O_3$ vs $TiO_2$ pour les échantillons de céramiques analysés.*

## Chemical analysis

The XRF chemical results indicated well-differentiated compositions for each of these fabrics (table 1). The three fabrics are characterized by a Ca-rich composition, with variable CaO percentages but always high (>15%), and with differences in other major and minor elements such as $Fe_2O_3$, $Al_2O_3$, $TiO_2$, MgO and $K_2O$. Fabric 1 differentiated from Fabric 2 by a higher content in $Fe_2O_3$, $TiO_2$, $K_2O$ and $Na_2O$; all these elements with relatively low standard deviation values in both groups (table 1). The bivariate plot $Fe_2O_3$ *vs* $TiO_2$ (fig. 6) indicates a linear correlation between these elements (r Pearson = 0.92) and shows the use of a clay paste richer in iron in Fabric 1, likely due to the presence of iron-rich inclusions observed in thin section.

Multivariate statistical analysis of the XRF chemical data was carried out, after an additive log-ratio transformation (alr) of the concentrations using $TiO_2$ as a divisor (MnO was excluded due to possible analytical imprecision). Cluster analysis, using the centroid agglomerative method and squared Euclidean distance, shows the existence of two chemical groups (fig. 7a), which are equivalent to the petrographic Fabrics 1 and 2 identified in thin section. The sample POL048, with a distinct Fabric (Fabric 3), also behaves as a chemical loner in the cluster analysis.

A better examination of the chemical differences between these groups is obtained through principal component analysis (PCA). The scatter plot of the first two principal components (fig. 7b: 79% of the total variance) shows a clear
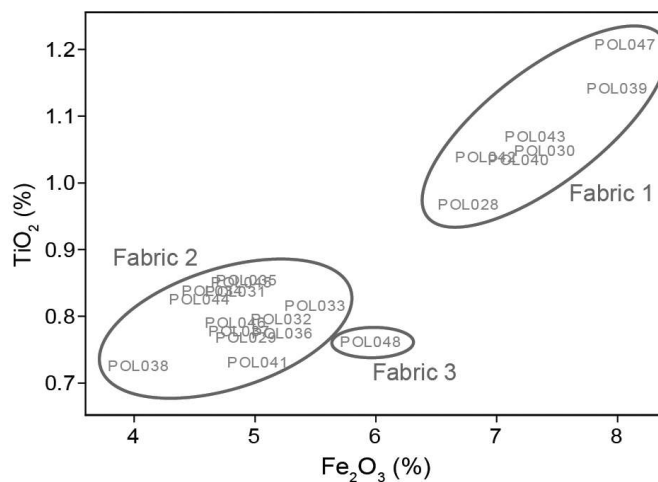
differentiation between the three fabrics as well. Samples in Fabric 1 present positive values of PC1 and negative of PC2, due to the higher content in $Fe_2O_3$ and $Na_2O$ and lower in $TiO_2$ and $K_2O$ than samples in Fabric 2 (table 1). Conversely, these latter tend to show negative values of PC1, although with a certain compositional variability, as also suggested by the cluster analysis (fig. 7). In fact, two chemical subgroups may be differentiated in this group; one of them (defined as 2A), including only three individuals (POL029, POL032 and POL036), contains lower $SiO_2$ (40-42%) and higher CaO (31-34%) than the other subgroup 2B (47-54% and 16-25%, respectively), represented by 10 individuals (fig. 7). This is better observed in the bivariate plot CaO *vs* $SiO_2$ (fig. 8), where the subgroup 2A is clearly differentiated from the rest of the assemblage. Conversely, the samples in subgroup 2B, also related to Fabric 2, cannot be separated from the samples in Fabric 1 and 3 based on the content of these two major elements (fig. 8). In any case, no significant differences were observed in thin section between the samples of Fabric 2 that could account for these differences in chemical composition.

In addition to providing further evidence for the differentiation between the main Fabrics 1 and 2, the chemical analysis also supports the distinction between Fabrics 2 and 3, both tempered with dominant carbonate rocks. The only sample in Fabric 3, POL048, is characterized by a higher content in $Fe_2O_3$, $Al_2O_3$ and $K_2O$, and lower in CaO and MgO, than the samples in Fabric 2 (table 1; fig. 7). This
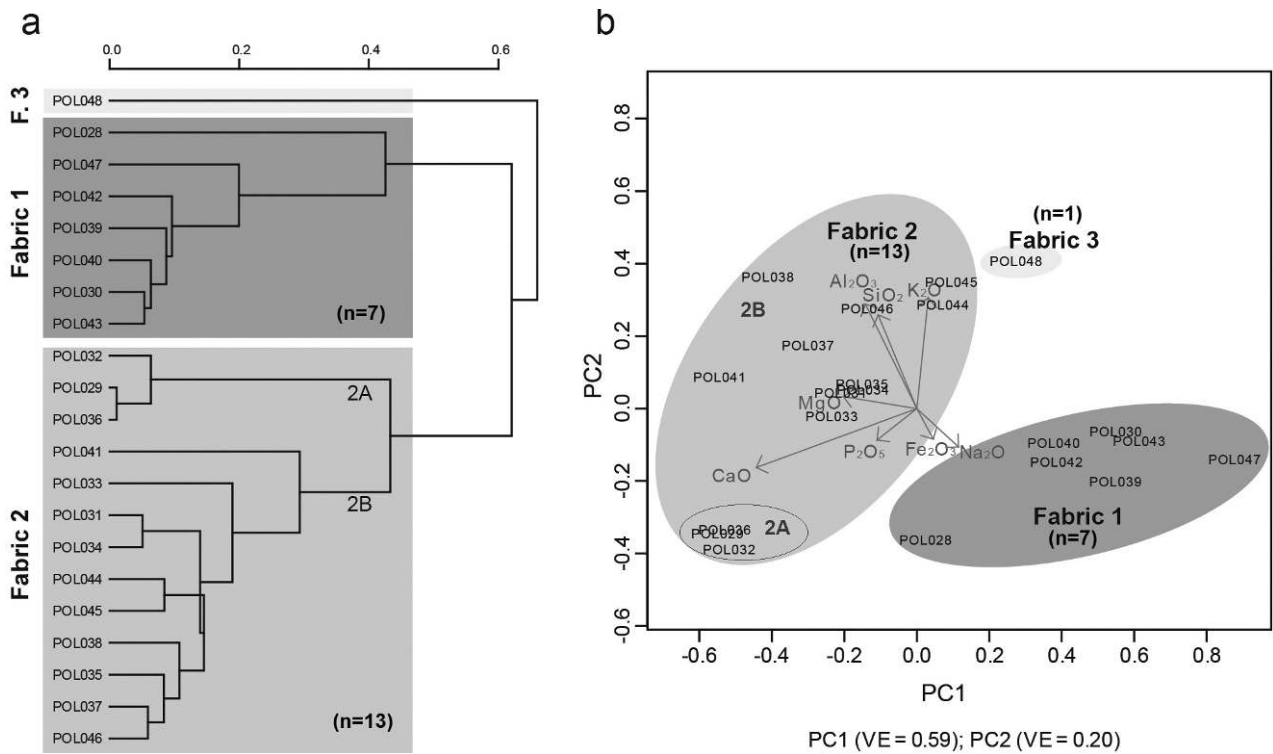
Figure 7: (See color plate II) (a) Dendrogram obtained from the cluster analysis based on the alr (additive log-ratio transformation) transformed subcomposition $Fe_2O_3$, $Al_2O_3$, $P_2O_5$, MgO, CaO, $Na_2O$, $K_2O$, $SiO_2$, using $TiO_2$ as divisor. (b) PCA based on the same alr transformed subcomposition as the cluster analysis; plot of the two first principal components (explaining 79% of the total variance).
*Figure 7 : (Voir planche couleur II) (a) Cluster basé sur la sous-composition transformée par alr (additive log-ratio transformation): $Fe_2O_3$, $Al_2O_3$, $P_2O_5$, MgO, CaO, $Na_2O$, $K_2O$, $SiO_2$, avec $TiO_2$ comme diviseur. (b) PCA basé sur la même sous composition transformé par alr que pour cluster de la Figure 7(a). Représentation des deux premières composantes principales (exprimant 79 % de la variance totale).*

might be related to the less calcareous content of the used base clay observed in thin section for Fabric 3.

## XRD mineralogical analysis

The XRD analysis of the 21 samples of water jars provided further information on their mineralogical composition, including the identification of primary mineral phases as well as, eventually, phases newly formed during firing and/ or secondary phases due to use or post-depositional processes. On this basis, it was possible to gain knowledge on some technological aspects of their manufacture, especially concerning the estimation of equivalent firing temperatures (EFT) (Roberts, 1963) (table 2).

The samples in petrographic Fabric 1 are related to four distinct associations of mineral phases (table 2). Samples POL030, POL039 and POL042 contain quartz, calcite, illite-muscovite and alkali feldspar as primary phases, as well as very low hematite, suggesting an EFT under 800/850 °C
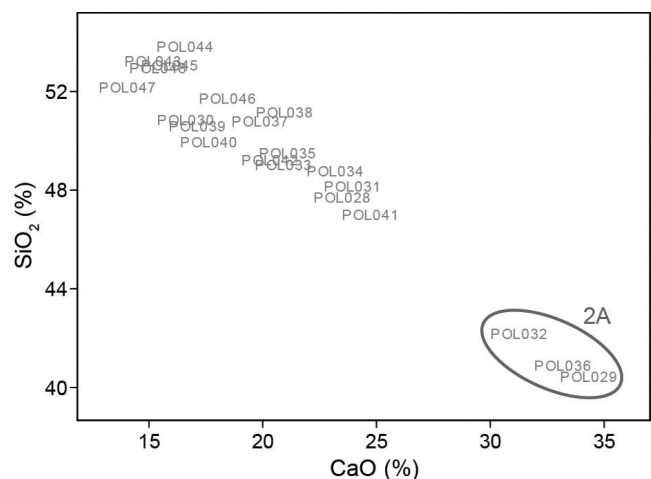


Figure 8: Binary diagram, using normalized data, of CaO vs $SiO_2$ for the ceramic samples analyzed.
*Figure 8 : Diagramme binaire, avec données normalisées, du CaO vs $SiO_2$ pour les échantillons de céramiques analysés.*

| Fabric | EFT (ºC) | Mineral phases (XRD) | Samples |
|---|---|---|---|
| Fabric 1 | ≤800/850 | Quartz, calcite, illite-muscovite, alkali feldspar, hematite (trace) | POL030, POL039, POL042 |
| | 850-950 | Quartz, calcite, illite-muscovite, gehlenite, plagioclase, diopside (trace) | POL040 |
| | | Quartz, calcite, gehlenite, alkali feldspar, diopside (trace), illite-muscovite (trace), hematite (trace) | POL028 |
| | 900-1000 | Quartz, calcite, plagioclase, gehlenite, diopside, alkali feldspar, illite-muscovite (trace), hematite (trace) | POL043, POL047 |
| Fabric 2 | ≤800/850 | Quartz, calcite, illite-muscovite (lower in POL029), hematite (trace; absent in POL029 and POL034) | POL029, POL031, POL034, POL035, POL038, POL041, POL046 |
| | 850-950 | Quartz, calcite, gehlenite, plagioclase, illite-muscovite, hematite (trace; absent in POL044) | POL037, POL044 |
| | | Quartz, calcite, gehlenite, illite-muscovite (low) | POL036 |
| | 850-950 (most probably 900-950) | Quartz, calcite, gehlenite, plagioclase, illite-muscovite (low), diopside (trace), hematite (trace) | POL033, POL045 |
| | | Quartz, calcite, gehlenite, illite-muscovite (trace), diopside (trace) | POL032 |
| Fabric 3 | ≤800/850 | Quartz, calcite, illite-muscovite, plagioclase, alkali feldspar (low), hematite (trace) | POL048 |

Table 2: XRD mineralogical composition and equivalent firing temperature (EFT) of the 21 ceramic individuals, organized by Fabric according to the results of the petrographic analysis.
*Table 2 : Composition minéralogique par XRD et température de cuisson équivalente (EFT) des 21 céramiques, organisées par groupes de pâtes céramiques selon les résultats de l'analyse pétrographique.*

(for the EFT and estimation of temperatures see for instance Maggetti, 1982; Riccardi *et al.*, 1999; Cultrone *et al.*, 2001; Buxeda & Cau, 2004; Maritan *et al.*, 2006; Nodari *et al.* 2007; Maggetti *et al.*, 2011). Samples POL028 and POL040 still show dominant peaks of quartz and calcite, while there is a decrease in the intensity of illite-muscovite and a development of firing phases, especially gehlenite (more in POL028), as well as plagioclase (only in POL040) and low diopside; the EFT of these samples can be established in the range 850-950 ℃. A higher EFT can be estimated for samples POL043 and POL047, since diopside and plagioclase are higher developed than in previous samples; however, a small peak of illite-muscovite is still observed, what indicates an EFT around 900-1000 ℃ (table 2).

Concerning Fabric 2, the XRD patterns showed that seven samples contained primary crystalline phases (quartz, calcite and illite-muscovite), as well as very low hematite in most cases (table 2). The EFT for these individuals can be established to be below 800/850 ℃. Another three (POL036, POL037 and POL044) contain gehlenite as firing phase, as well as plagioclase (except in POL036), suggesting an EFT in the range of 850-950 ℃. In samples POL032, POL033

and POL045, plagioclase (except in POL032) and gehlenite tend to increase in intensity, low peaks of diopside are found as an additional firing phase, and illite-muscovite decreases (table 2). The presence of these minerals suggests, again, an EFT between 850-950 ℃, but most likely over 900 ℃, since there is a higher development of firing phases compared with the other samples of the fabric.

Besides these mineralogical differences in Fabric 2, associated with variations in firing temperature, it is also possible to observe differences in the XRD patterns between the samples related to the two subgroups identified in the chemical analysis (2A and 2B). The three samples in subgroup 2A (POL029, POL032 and POL036) exhibit lower peaks for illite-muscovite than the samples in subgroup 2B, even when comparing low-fired samples (*e.g.* POL029). Very low hematite can be found in most of the samples in 2B, however it is completely absent in 2A. In addition, plagioclase develops as a firing phase in 2B (POL033, POL037, POL044, POL045), but not in 2A, as observed in samples POL032 and POL036, with an EFT of 850-950 ℃ due to the presence of gehlenite and, in POL032, diopside. These mineralogical differences between the samples in 2A and 2B

support the division of Fabric 2 into two subgroups, as suggested by the chemical analysis.

Finally, the XRD spectra of POL048 (Fabric 3) shows quartz, calcite, illite-muscovite and plagioclase, as well as low alkali feldspar and very low hematite. The absence of firing phases such as gehlenite or diopside suggests that the plagioclase might be primary phase, therefore the EFT would not be higher than 800/850 °C (table 2).

## 4. DISCUSSION AND FINAL REMARKS

The three fabrics defined in the petrographic analysis show a clear chemical variation which indicates a well-defined compositional patterning. In addition, within Fabric 2, the chemical analysis suggests the existence of two distinct compositional subgroups -based on differences in CaO/SiO$_2$- despite similarities in thin section. The XRD evidence further supports this subdivision.

Concerning the provenance of these fabrics, Fabric 2 has dominant carbonate inclusions and a complete absence of volcanic and/or metamorphic inclusions, and is compatible with a local provenance. However a regional provenance, connected with other part/s of the island, cannot be excluded thus far.

It can be evaluated that the volcanic rock fragments observed in Fabric 1 and, as an accessory component, in Fabric 3, are not compatible with a local provenance in Pollentia (currently Alcúdia), since the geology of the area close to the site is associated exclusively with sedimentary units (ITGE, 1992). In general, sedimentary formations are widespread in Mallorca and largely dominate the geological background of the island (IGME, 1972). However, there are volcanic deposits of the Upper Triassic (Keuper) outcropping (of limited occurrence) in some parts of the Serra de Tramuntana, and, to an even lesser degree, the Serres de Llevant (Colom, 1975; Pomar & Fontboté, 1983), which are located in the northern and eastern part of Mallorca respectively. The main outcrops can be found between Soller and Pollença, the latter located 10 km north-west of the archaeological site of Pollentia. These outcrops predominantly include basalts and dolerites (Pomar & Fontboté, 1983), and in many cases are referred to as altered (Colom, 1975; ITGE, 1992); in fact, these rocks were first described as spillites by Fallot (1922). The rock fragments found in the petrographic Fabrics 1 and 3 from Pollentia seem to have been derived from this type of outcrops. Taking into account the regional geology of Mallorca, and especially the presence of volcanic deposits of the Serra de Tramuntana, the hypothesis of a regional provenance for these two fabrics seems highly plausible. Of course, an alternative hypothesis might be that the raw materials for temper could have been brought from a more distant site, but this is difficult to evaluate based on the existing evidence. It is therefore deemed more convenient, at the time of writing this paper, to argue for the larger likelihood of a regional provenance originating from northern Mallorca, for Fabrics 1 and 3.

From a technological point of view, the three fabrics identified show a poorly sorted coarse fraction which can be interpreted as added temper. This feature, observed in all the Muslim period jars analyzed in this study, reflects an important technological change in comparison with the Late Antique common wares produced in the Balearic Islands, which were mainly fine grained and with no temper (Buxeda *et al.*, 2005; Cau *et al.*, 2010, 2019). Nonetheless, each of the three fabrics in this study is associated with the use of different raw materials, including both clays and temper: volcanic temper and calcareous clay in Fabric 1; carbonate temper and calcareous clay in Fabric 2; and carbonate temper and calcareous-ferruginous clay in Fabric 3. The calcareous clay used in Fabric 2 seems different from the one used in Fabric 1, as suggested by the very abundant fine carbonate inclusions with rhombic shape in the former, which are not seen in the latter. On the other hand, the presence of accessory volcanic rocks in Fabric 3, similar to those in Fabric 1, suggests a possible provenance relation between these fabrics but in association with the use of clearly different raw materials; in any case, the interpretation of Fabric 3 as a result of a distinct technological practice or production unit should be taken with caution, as it is based, for the moment, only on one sample.

The water jars recovered in the excavations of the Late Antique fortification of the forum of Pollentia provide a significant insight of the city's material culture in the Muslim period. The chronology of the relevant stratigraphic units is not very precise but a date to the tenth-eleventh centuries can be suggested within reason, considering the typology of the ceramic materials. The possible existence of a local production of common wares in the city itself or its outskirts would reflects the vitality of the city still in this period. The definition of three major fabrics opens, however, a further complexity in order to understand the production and distribution of these materials. The presence of two fabrics (Fabric 1 and 3) with volcanic temper might be illustrative for the arrival of other regional products from areas not far from the city itself, probably from the northeastern part of Mallorca. Alternatively, it could reflect distinct raw materials procurement strategies, concerning the available resources for temper.

In any case, further research is needed in order to verify these hypotheses. Although the quantity of ceramics analyzed in this study is admittedly limited, the results of this research provide a first insight into the compositional characteristics of utilitarian pottery of the Muslim period in Pollentia helping to shed more light on the production, distribution and consumption of ceramics during the Muslim period in Mallorca.

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Figure 1 : Miguel Ángel Cau Ontiveros *et al.*, Archaeometric characterization of water jars from the Muslim period at the city of Pollentia (p. 8)
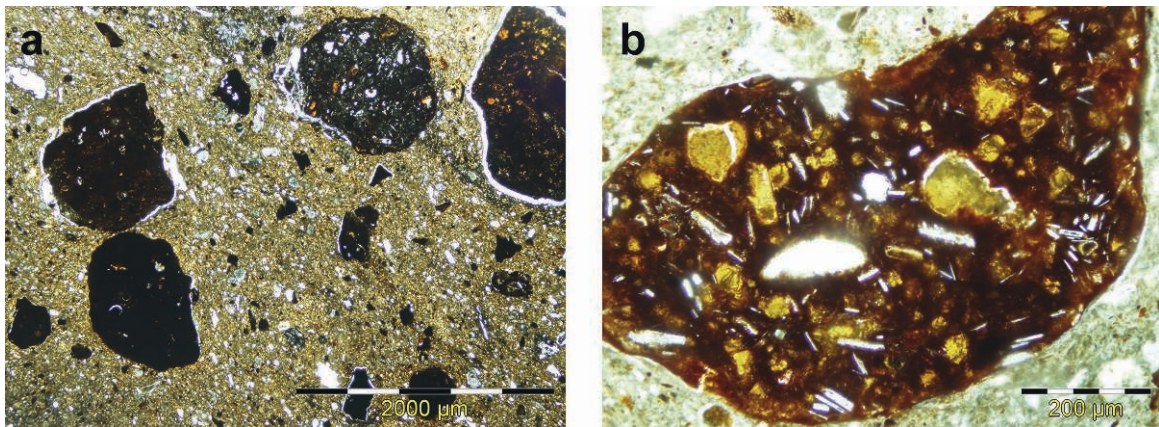


Figure 3 : Miguel Ángel Cau Ontiveros *et al.*, Archaeometric characterization of water jars from the Muslim period at the city of Pollentia (p. 10)
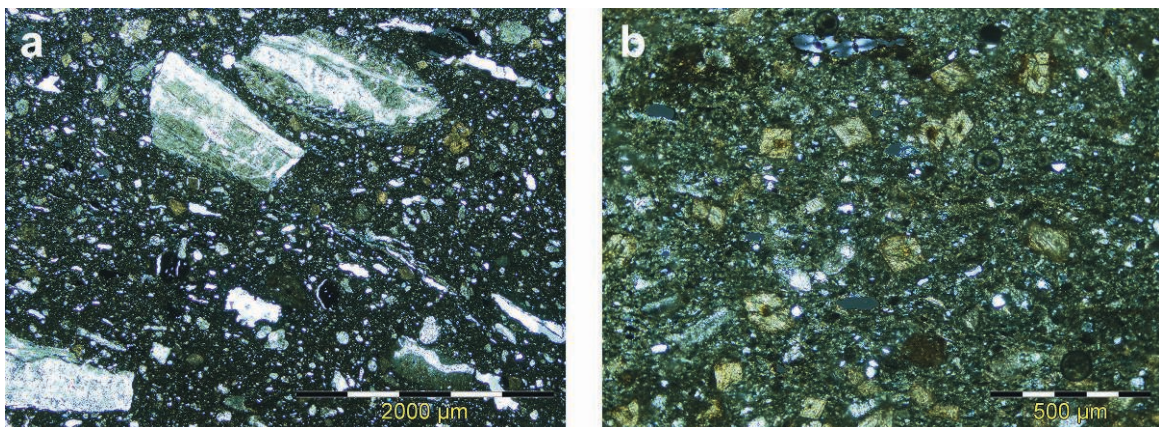


Figure 4 : Miguel Ángel Cau Ontiveros *et al.*, Archaeometric characterization of water jars from the Muslim period at the city of Pollentia (p. 10)
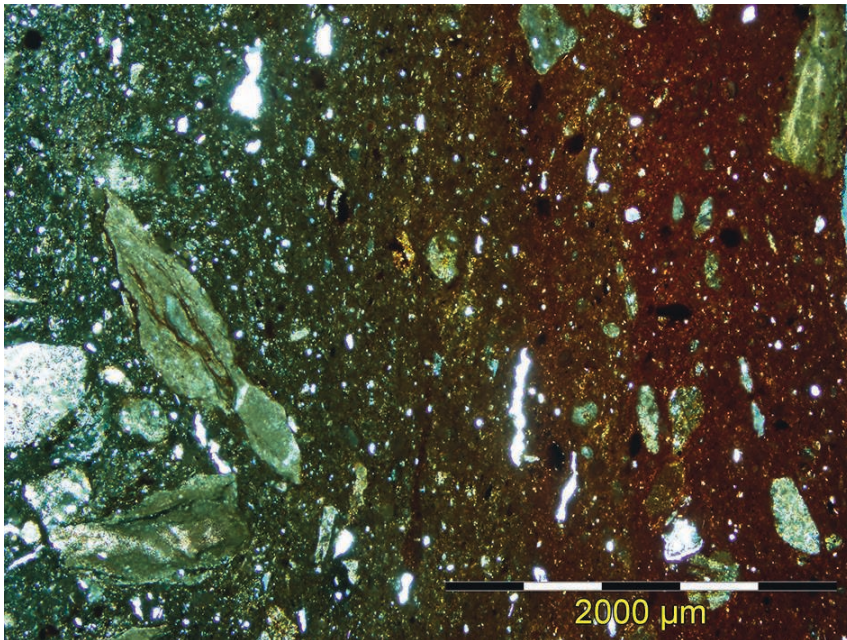
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Figure 5 : Miguel Ángel Cau Ontiveros *et al.*, Archaeometric characterization of water jars from the Muslim period at the city of Pollentia (p. 12)
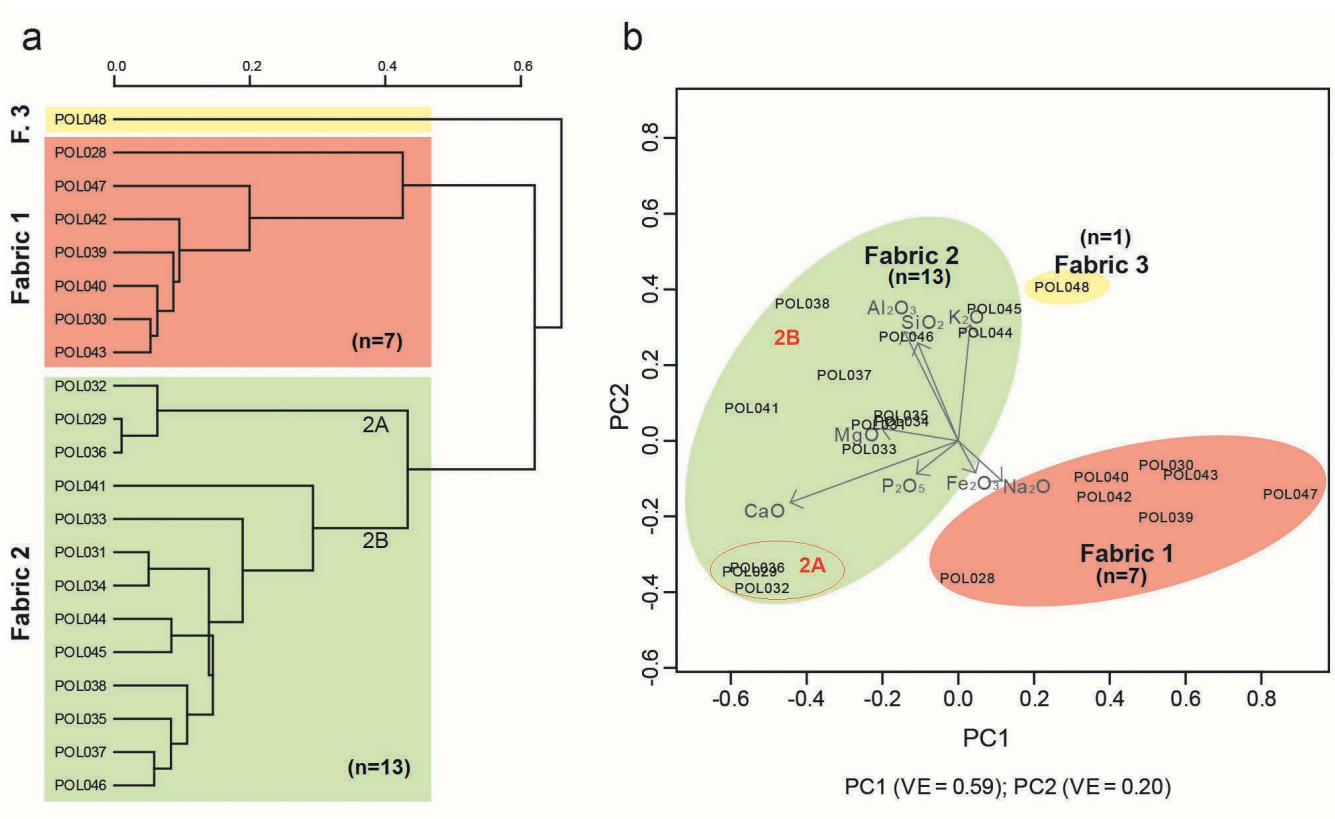


Figure 7 : Miguel Ángel Cau Ontiveros *et al.*, Archaeometric characterization of water jars from the Muslim period at the city of Pollentia (p. 13)

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