



United We Stand: Handmade Pottery Production at Cap de Barbaria II (Formentera, Spain) During the Bronze Age

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ABSTRACT

In this article, we describe petrographical, mineralogical and typological analyses of handmade pottery recovered from the Bronze Age site of Cap de Barbaria II, which is located on the island of Formentera (Balearic Islands, Spain). In addition, the mineralogy and texture of several clay deposits present within the study area are also characterized using X-ray powder diffraction and laser diffraction particle size analysis. The goals of this research are, first, to identify the different technological choices made by the community of potters that inhabited this settlement in various stages of the chaîne opératoire (i.e., the procurement of raw materials, preparation of pastes, shaping of the vessels, and firing); second, we aim to determine the relationships between the technological choices identified at this site and the prehistoric technological traditions observed on the other islands of the Balearic archipelago. The results provide evidence that the Bronze Age potters from Cap de Barbaria II developed a very cohesive production system for the procurement of raw materials and the paste recipes used to produce the vessels. Moreover, the results indicate a clear preference for the long-term use of decalcified clays and spathic calcite temper, thus reflecting a consistent community of practice among the potters that shared several technological choices with artisans located at other sites on Formentera and other islands within the archipelago.

Keywords: handmade pottery; technological choices; petrography; XRPD; archaeometry.

INTRODUCTION

The characterization of archaeological ceramics through archaeometric methods allows us to approach the manner in which people from past societies made diverse technological choices related to the use of certain raw materials and techniques. Technological choices (Lemmonier, 1993) define operational sequences that are loaded with social and symbolic meanings that are

often unconscious and related to the *habitus* (Dietler and Herbich, 1998). These choices thus lead to pottery-making traditions that synthesize a particular know-how and provide a medium of expression by which individuals can develop their agency through material culture (Dobres and Hoffman, 1994; Dobres, 2000; Albero Santacreu, 2014). These social and symbolic meanings are even embedded in the mineral raw materials used in pottery production

(Barley, 1994; Boivin, 2004), one of the technological practices that can be approached through the analysis of ceramic pastes.

Technological traditions are embedded in specific social, functional and ecological contexts in which knowledge transmission and human interactions occur; thus, they promote the emergence of certain ways of doing within society. Hence, common practices may lead to the appearance of technological traditions that are well defined in time and space and strengthen the identity bonds between individuals. The concept of technological tradition makes sense when we consider that individuals can choose to continue with or disrupt the practices that they have followed when they must replace a discarded vessel. This replacement, in which individuals and objects are actively involved, allows the emergence, maintenance or disruption of traditions. This fact leads us to consider the possibility that certain technological choices and traditions persist throughout time according to specific social and historical contexts.

Based on this theoretical perspective, this paper aims to confront and interpret some of the technological choices made by the community of potters that inhabited the archaeological site of Cap de Barbaria II (CBII) (Figure 1), which is located on Formentera (Balearic Islands, Spain), during the Bronze Age (*c.* 1740-730 BC). We focus particularly on identifying and interpreting the technological choices made in several stages of the *chaîne opératoire*. These concerns require the petrographical and mineralogical characterization of the ceramic assemblage recovered from this archaeological site and the identification of certain aspects of the pottery-making traditions existing in the area. These aspects include the manner in which potters managed the raw materials (*i.e.*, clays and tempers), prioritized certain paste recipes, used certain firing strategies and applied specific knowledge and skills to produce handmade ceramics for utilitarian purposes. Our final aim is to assess the degree of continuity or the changes that occurred at this site in certain technological choices made by potters; we also address social phenomena (*e.g.*, social organization, learning strategies, knowledge transfer, and identity) related to the handmade pottery production developed by the prehistoric community of potters at Cap de Barbaria II. Therefore, the study of ceramic technology, which is understood to be a reflection of social interactions, will allow us to address the social dynamics that underlie the features observed in the record.

Finally, it should also be highlighted that archaeology has traditionally paid more attention to the study of larger islands, whereas small islands have been neglected (Fitzpatrick et al., 2016). The Balearic Islands are not an exception; many technological and archaeometric studies

have been conducted since the 1980s on prehistoric pottery from Mallorca and Menorca (see Albero Santacreu, 2011). However, apart from one exception (Marlasca et al., 2013), this type of research is mostly absent on Formentera, and petrographical studies of archaeological pottery found on this island are totally non-existent. Hence, this study will allow us to fill an important gap in current research on the Balearic Islands by connecting the technological choices identified at Cap de Barbaria II with the social dynamics that ruled the human communities from other islands, thus eventually promoting a better understanding of the archipelago as a whole.

ARCHAEOLOGICAL AND GEOLOGICAL CONTEXT

The site of Cap de Barbaria II

Cap de Barbaria II is an open-air village composed of up to nine habitations and collective structures. It is located on the southwestern cape of the island of Formentera (Figure 1). CBII is the largest prehistoric village on the island (Sureda et al., 2013). It covers an area of ca. 1,500 m² and contains prehistoric houses similar to those found on Majorca and Menorca. These structures, which are called naviforms (boat-shaped structures constructed with a cyclopean technique), were the places where domestic activities were centered during the Balearic Bronze Age and were also the loci of political decisions (Guerrero et al., 2007; Fornés et al., 2009).

CBII was first excavated between 1979 and 1987 (Costa and Fernández, 1992); further excavations have been carried out since 2012 that have yielded new findings and radiocarbon dates (Sureda et al., 2013, 2017 a,b). Poor sedimentation processes on Formentera have produced a simple stratigraphy at CBII, and only three overlapping levels can typically be differentiated at the site. The radiocarbon dates available to date indicate that the site was first occupied between 1737 and 1629 cal BC, before the naviform structures were built (pre-use phase). The construction of these structures took place between 1624 and 1558 cal BC, and the naviforms were first used between 1580 and 1531 cal BC (Phase I). All of the evidence suggests that the village was continually occupied during the second half of the II millennium BC. Finally, a second phase of use (Phase II) is recorded at the site between 997 and 927 cal BC, and the site was peacefully abandoned at a poorly defined time between 994 and 728 cal BC.

Geological context of Formentera

Formentera is an island with flat relief and little stratigraphic and petrological complexity, and it contains only Miocene sedimentary formations and Quaternary materials (Cabra et al., 1996). The highest formations are located on the east side of the island and do not exceed

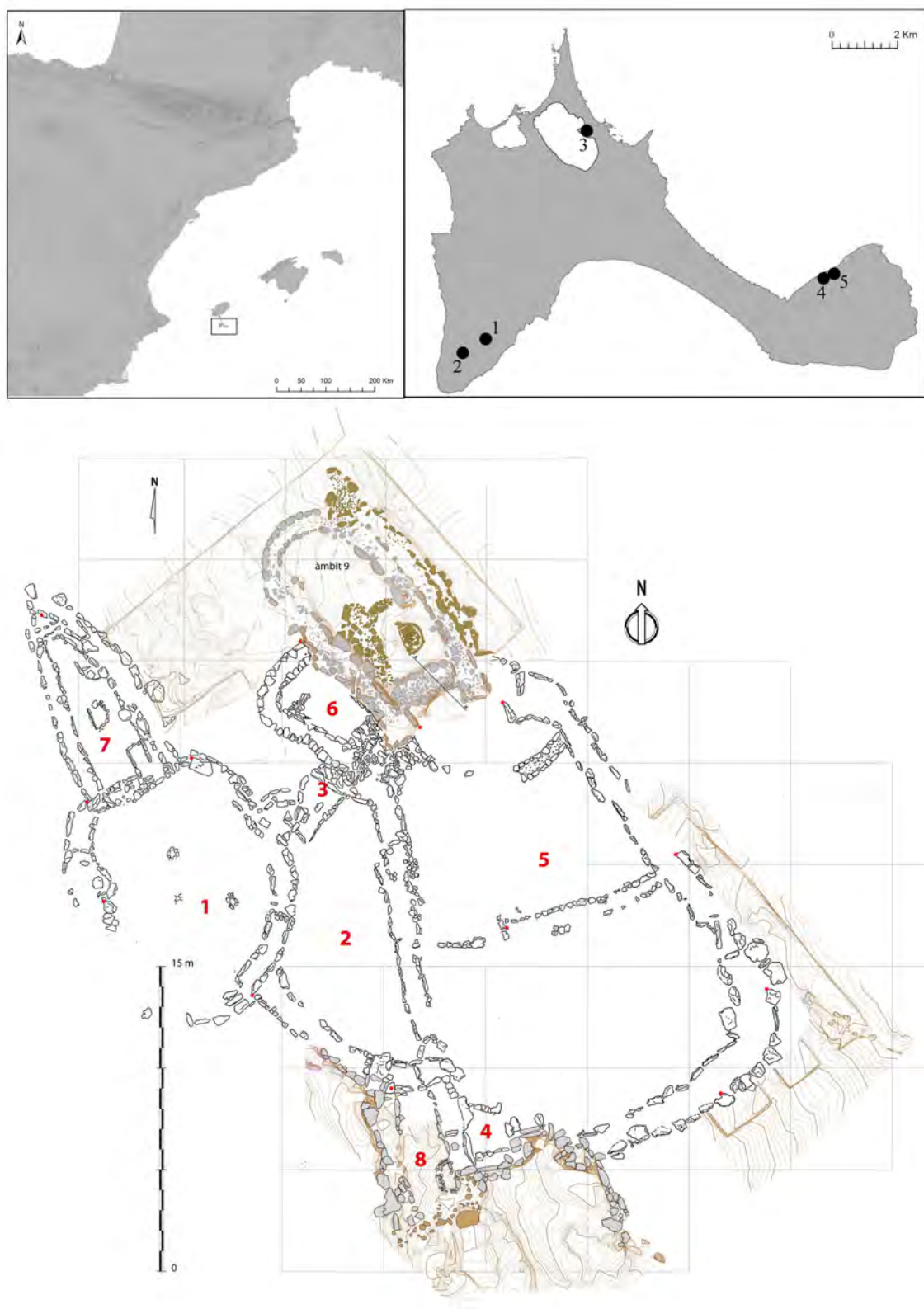


Figure 1. Geographic location of Formentera and the archaeological sites mentioned in the text (1: Cap de Barbaria II; 2: Cap de Barbaria I; 3: Ca na Costa; 4: Cova des Riuets; 5: Sa Cala). Floor plan of the archaeological site showing the diverse architectural structures and areas excavated.

200 m. The geological origin of Formentera is closely associated with the processes observed on Ibiza and the other Balearic Islands, even though the materials that make up this small island are much more recent (Figure 2). The oldest geological formations date from the Miocene and include calcarenite outcrops located on the east and west sides of the island (where the most important cliffs are located) and some limestone and deposits of clay and sand located on the west coast of the island (mainly in the Cala Saona area).

These Tertiary deposits are widely covered by Quaternary formations that are very abundant on the island. Formentera acquired its current contours during the Quaternary. Almost all of the island is virtually covered by fossil Quaternary sand dunes made up of calcareous particles and cemented marine microfossils. Additionally, some limestone crusts that contain a few small detrital quartz grains are observed to cover the underlying Tortonian limestone formations. There are also

Pleistocene and Holocene red and yellowish clay, silty and sandy deposits that display lesser or greater degrees of calcification that contain some gravel originating from the Tortonian calcareous rocks. It is also worth mentioning the existence of Holocene clay deposits that are very rich in salt and organic matter. These materials are found within two lagoon areas located on the north side of the island (i.e., Estany Pudent and Estany des Peix).

SAMPLING AND METHODOLOGY

Sampling: pottery and clays

Handmade pottery is abundant at the site and has been recovered from all of the areas excavated (Figure 1). The ceramic assemblage seems to be related to the daily domestic and production activities carried out in the structures: storage, cooking and the consumption of food and other products. The most abundant documented forms are hemispherical shapes (bowls), S-shaped pots (globular vessels), troncoconical or V-shaped bowls (vases);

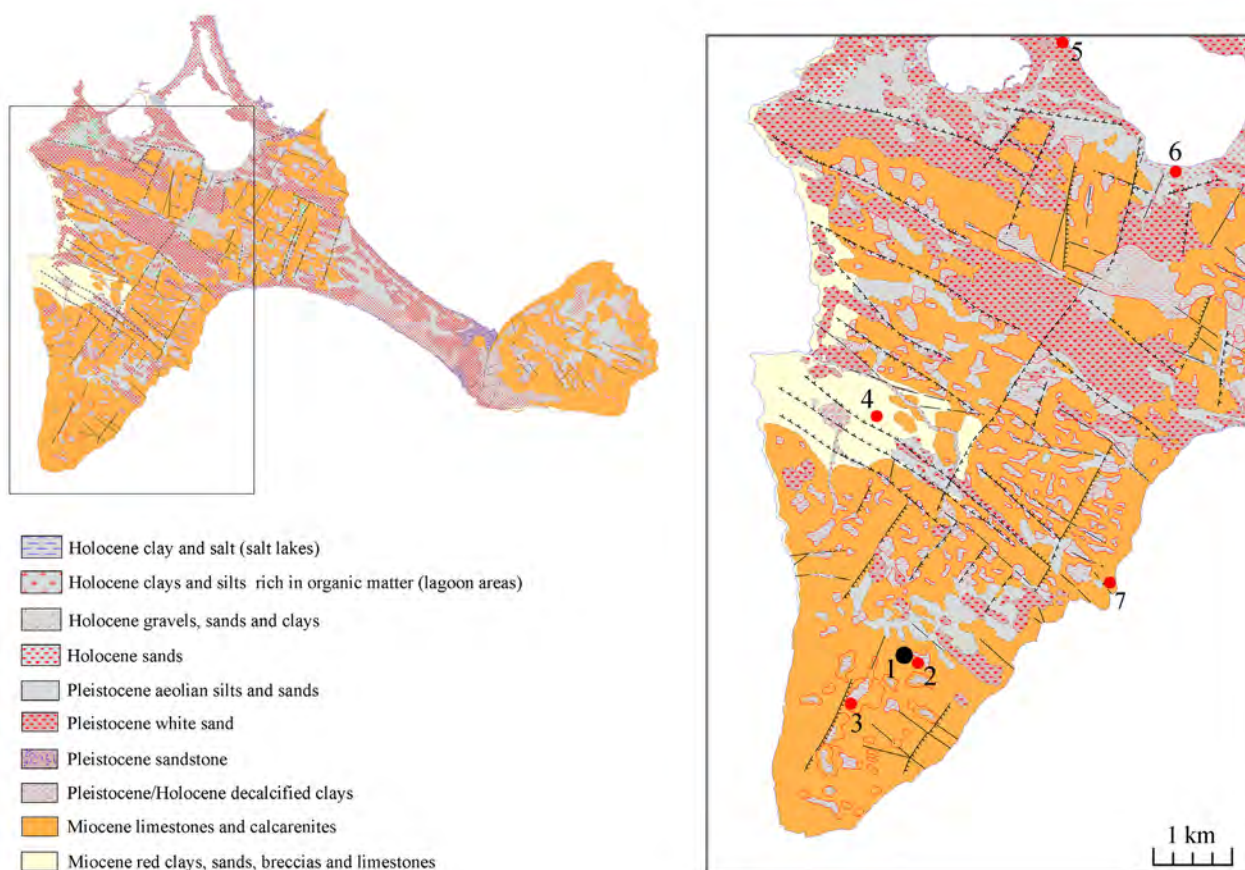


Figure 2. Simplified geological map of the study area showing the locations of the archaeological sites and the clay and temper sources mentioned in the text (Modified from IGME; 1: Cap de Barbaria II site; 2: clay sample CB2; 3: clay sample CB1; 4: clay sample CS1; 5: clay sample AS1; 6: clay sample EP1; 7: Cova de Sant Valero).

carinated shapes and cylindrical profiles associated with large storage pots are present to a lesser degree (Table 1, Figures 3 and 4). The vessels are not usually decorated, except for a ceramic plate and a globular vessel that have dotted decoration (CB-1172) and a few rims decorated with finger imprints (e.g., CB-198) (Figure 4b and 5 a,b). In addition, plastic elements are abundant in the ceramic assemblage; these elements consist mainly of perforated handles and nipple-shaped reliefs of different types (e.g., circular, conical, oval) (Figure 3 e,f,h and 4 a-d).

We conducted a study of 51 pottery samples recovered from both the excavations carried out on CBII in the 1980s and those performed since 2012. All of the selected samples are related to ceramic shapes and represent the wide range of types and the diverse chronological phases recorded at the site (Table 1). In addition, the typology of some of these vessels (e.g. CB-161, CB-162 and CB-163) is characteristic of the Early Bronze Age (Guerrero et al., 2007), thus suggesting that they were produced during the preconstruction phase or the first use of the structures.

Along with the study of these archaeological materials, we carried out archaeological prospecting in the territory located between the area of Cap de Barbaria, Cala Saona and La Savina following the criteria proposed by J. García Rosselló and D. Albero Santacreu (2011). According to the “ecological approach” (Matson, 1965; Arnold, 1985, 2006; Wilshulsen and Stone, 1990), our prospecting was centered on the environment nearest the archaeological site (up to 8 km from the site). As previously noted, Formentera contains a wide range of sedimentary deposits. Five clay samples from different geological deposits were identified (Table 2, Figure 2), collected and sampled, and plasticity tests and mineralogical and textural analyses were conducted. These analyses were conducted to reach two goals: first, to carry out archaeometric analyses of the nearby clays and the pottery assemblages to provide a basis for comparison; second, to determine the suitability of the raw materials for pottery production.

Methodology

The 51 selected pottery samples were sectioned and polished for petrographical characterization by optical microscopy. The optical examination of the thin sections was performed using a Leica DM2500P petrographic microscope, which incorporates a micrometer. The magnifications of the lenses ranged from x16 to x400. Photomicrographs of the samples were taken with a Leica DFC295 digital camera. The quantity of each compound was established using comparative charts (Matthew et al., 1991). Descriptions of the thin sections were made following the procedure developed and described by I. Whitbread (1995). In addition, textural concentration features (TCF) were characterized considering the

observations made by I. Whitbread (1986) and N. Cuomo Di Caprio and S. Vaughan (1993). In addition to identification of the minerals and rock fragments present in the thin sections (Table 1), a wide range of aspects (Table 3) were recorded in each sample (i.e., the orientations of the pores and particles; the homogeneity and optical state of the groundmass; the sizes and shapes of the pores, the texture of the samples; the size, shape and distribution of the particles; the presence of secondary calcite; and the firing atmosphere). The presence of reduced and oxidizing atmospheres reflected by the cores and margins of the vessels was recorded following procedures published elsewhere (García Rosselló and Calvo, 2006; Albero Santacreu, 2014).

The determination of crystalline phases on a selection of 16 pottery samples (representing the diverse fabrics and subfabrics identified in the ceramic record from thin sections) and five clay samples was conducted by means of X-ray powder diffraction (XRPD). The instrument used to perform these analyses was a Bruker D8 Advance equipped with a silicon strip detector and a vertical XYZ sample stage. Diffraction data were recorded with Cu K α radiation; the tube was operated at 40 kV and 40 mA. The incident beam was collimated to a diameter of 500 μ m. The measurements were taken from 3 to 70° using a collection time of 384 s. We used the EVA and X-powder software package to evaluate the crystalline phases against intensity and spacing tables drawn from the data bank of the Joint Committee of Powder Diffraction Standards (JCPDS 2003). The phases were determined semi-quantitatively using the normalized reference intensity ratio method (Martín, 2004).

Finally, to determine the textures of the natural clays, we conducted laser diffraction particle size analysis (LDPSA) using a *Malvern Mastersizer Hydro 2000G* analyzer with a detection range of 0.02 μ m to 2000 μ m. The basic statistics of the grain-size distributions were calculated using the GRADISTAT software packages (Blott and Pye, 2001). The colors of the different clay samples were recorded using the Munsell Soil Color Charts, and plasticity, elasticity and consistency tests were carried out to determine the physical properties of the raw materials following the procedure described in García Rosselló and Albero Santacreu (2011).

RESULTS

Pottery: petrographical analysis

The petrographical analyses conducted in this study allow us to classify the pottery samples obtained from CBII into three different fabrics that have particular features (Figure 6 and 7). Fabric 1 consists in a fine-textured quartz-rich clay that was tempered with spathic calcite crystals. Fabric 2 is related to a very fine-textured

Table 1. Archaeological characteristics and petrological compositions of the pottery samples analyzed in this study. Keys: Qzt=quartz, SC=spathic calcite, CM=calcimudstone, Cher=chert, Amo=amorphous material, Mud=mudstone, PQ=polycrystalline quartz, Sa=sandstone, Silt=siltstone, Glau=glaucinite, Musc=muscovite, xxx=dominant (50-70%), xxx=frequent (30-50 %), xx=common/few (15-30%), x=few to very rare (<15%). The chronology of the samples is based on their stratigraphic positions and is associated with a previously published Bayesian model (Sureda et al., 2017b).

Sample	Sector	Phase	Chronology (cal BC)	Shape	Fabric	Inclusions											
						Qzt	SC	CM	Chal	Cher	Amo	Mud	PQ	Sa	Silt	Glau	Musc
CB-176	1	2	994-728	Bowl	1.2.2	xxx	xx	x			x					x	x
CB-231	1	1	1586-958	Ovoid	1.2.3	xxx	xxx	xx	x		x		x	x			x
CB-158	1	Ext	-	"S" shape	1.3.2	xx	xx	x			x	x	x				x
CB-1259	7	1	1586-958	Hemispherical Bowl	1.2.2	xxx	xx	x	x	x	x		x				x
CB-173	1	0/1	1624-958	Cylindrical storage pot	1.2.2	xxx	xx	x									
CB-1331	6	1/2	1586-927	"S" shape	1.2.2	xxx	xx	x			x		x				x
CB-161	-	EXT	-	Globular pot	1.1.1	xxxx	x	x			x	x	x	x	x		x
CB-162	SO	EXT	-	Globular pot	1.1.1	xxxx	x	x	x		x		x	x	x		x
CB-163	1	EXT	-	Bowl	1.1.1	xxxx	x			x	x		x		x		x
CB-1341	7	0/1	1624-958	Troncoconic vase	1.1.2	xxxx	xx			x	x		x				x
CB-1268	7	1	1586-958	"S" shape	1.2.2	xxx	xx	x	x		x	x	x				x
CB-502	9	1	1586-958	Bowl	1.2.1	xxx	x	x							x		x
CB-225	9	1	1586-958	Bowl	1.1.1	xxxx	x	xx			x	x			x	x	x
CB-198	2	1	1586-958	Troncoconic storage pot	1.2.2	xxx	xx	xx					x				
CB-1115	5 (A2)	EXT	-	Troncoconic vase	1.2.2	xxx	xx	x				x	x		x		x
CB-1279	7	0/1	1624-958	Troncoconic vase	1.2.3	xxx	xxx	x	x	x			x		x		x
CB-1183	3	INDET	-	Bowl	1.2.1	xxx	x	x		x		x					x
CB-157	1	EXT	-	Bowl	1.2.1	xxx	x	x			x		x			x	x
CB-202	1	1	1586-958	Bowl	1.2.2	xxx	xx	x				x			x		x
CB-1340	7	0/1	1624-958	Troncoconic convergent	1.2.2	xxx	xx	x			x						x
CB-227	1	1	1586-958	Cylindrical pot	1.3.3	xx	xxx	x									x
CB-1302	5 (B3)	1?	1586-958?	Carenated pot	1.3.1	xx	x	x			x						x
CB-203	1	1	1586-958	Rim	1.3.1	xx	x	x			x		x	x	x		x
CB-179	1	2	994-728	Bowl	1.3.1	xx	x	x				x					x
CB-260	9	0/1	1624-958	Bowl	1.3.2	xx	xx	x			x	x	x				x
CB-1264	7	1	1586-958	"S" shape	1.3.3	xx	xxx	x			x						x
CB-1333	6	1/2	1586-927	Troncoconic convergent	1.3.1	xx	x	x				x	x	x	x		x
CB-167	1	2	994-728	Bowl	1.3.3	xx	xxx	x									x
CB-199	1	1	1586-958	Bowl	1.3.3	xx	xxx	x	x			x	x				x

Table 1. ... Continued

Sample	Sector	Phase	Chronology (cal BC)	Shape	Fabric	Inclusions											
						Qzt	SC	CM	Chal	Cher	Amo	Mud	PQ	Sa	Silt	Glau	Musc
CB-1279b	7	0/1	1624-958	Troncoconic vase	1.1.2	xxxx	xx			x	x		x				x
CB-1172	2	EXT	-	Impressed decoration	1.2.3	xxx	xxx	x		x			x				x
CB-1262	7	1	1586-958	Troncoconic convergent	1.3.3	xxx	xxx	x		x	x		x			x	x
CB-168	1	2	994-728	Bowl	1.3.3	xxx	xxx	x					x			x	x
CB-1176	2	2	994-728	Rim	1.2.3	xxx	xxx	xx								x	x
CB-1249	2	2	994-728	Storage pot	1.2.3	xxx	xxx	x			x		x	x			x
CB-1330	6	1/2	1586-927	Globular pot	1.2.2	xxx	xx	x				x				x	x
CB-170	9	0/1	1624-958	Ovoid divergent	1.3.2	xx	xx	x									x
CB-1338	6	2	994-728	Gran C	1.3.3	xx	xxx				x	x	x	x			x
CB-1113	5 (D4)	1?	1586-958?	“S” shape	1.3.3	xx	xxx	x			x	x					x
CB-1256	7	1/2	1586-728	“S” shape	1.3.3	xx	xxxx	xx							x		
CB-1320	5b	1?	1586-958?	Troncoconic divergent	1.3.3	xx	xxx	x				x	x				
CB-1100	5 (D6)	EXT	-	Troncoconic vase	1.3.1	xx	x	x				x	x	x			
CB-1329	6	1/2	1586-927	Bowl	1.1.1	xxxx	x	x			x	x				x	x
CB-1334	6	1/2	1586-927	Bowl	1.1.2	xxxx	xx	x						x			x
CB-1257	7	1/2	1586-728	“S” shape	1.2.1	xxx	x	x	xx			x	x	x			x
CB-1150	5 (C5)	1?	1586-958?	Ovoid divergent	1.3.1	xx	x	x				x					x
CB-1200	5	1?	1586-958?	Bowl	1.3.2	x	xx	x									x
CB-508	9	0/1	1624-958	Ovoid divergent	2	x	xx				x		x				x
CB-511	9	1	1586-958	Globular pot	3	xx	x	xxx		x			x			x	
CB-151	1	1	1586-958	“S” shape	3	x	xx	xxx				x					x

non-calcareous material tempered with spathic calcite temper. However, the amount of quartz recorded in this coarse fabric is much lower than in Fabric 1. Finally, Fabric 3 is associated with a calcareous raw material with abundant peloids. The vast majority of the analyzed samples (94%) were grouped into Fabric 1; the other fabrics recorded are rare at the site and include only a few samples (Table 1). In the following paragraphs, we describe in detail the characteristics that define each fabric, and we subsequently relate the petrographical data to the results obtained using XRPD.

Fabric 1: Quartz-rich fabric (Figure 6)

The microstructure of these samples include few to very few voids (1-7%), which are primarily macro- or

mesovesicles and macrovughs; rare megavughs are present. Pores are single or double spaced and not oriented parallel to the vessel margins. The non-plastic inclusions are close to single-spaced and poorly to well oriented parallel to or at an angle to the vessel margins. The orientation is mainly seen in elongated prismatic inclusions and in the inclusions closer to the vessel walls. The groundmass is homogeneous and dominant throughout the sections, except in some samples (CB-227, CB-203) that have secondary micritic calcite. The number of inclusions ranges from 25 to 50%. The color is brown to reddish brown (PPL/XPL, x400), and the micromass is optically active.

The inclusions appear to have a bimodal grain size distribution with few moderately sorted angular to

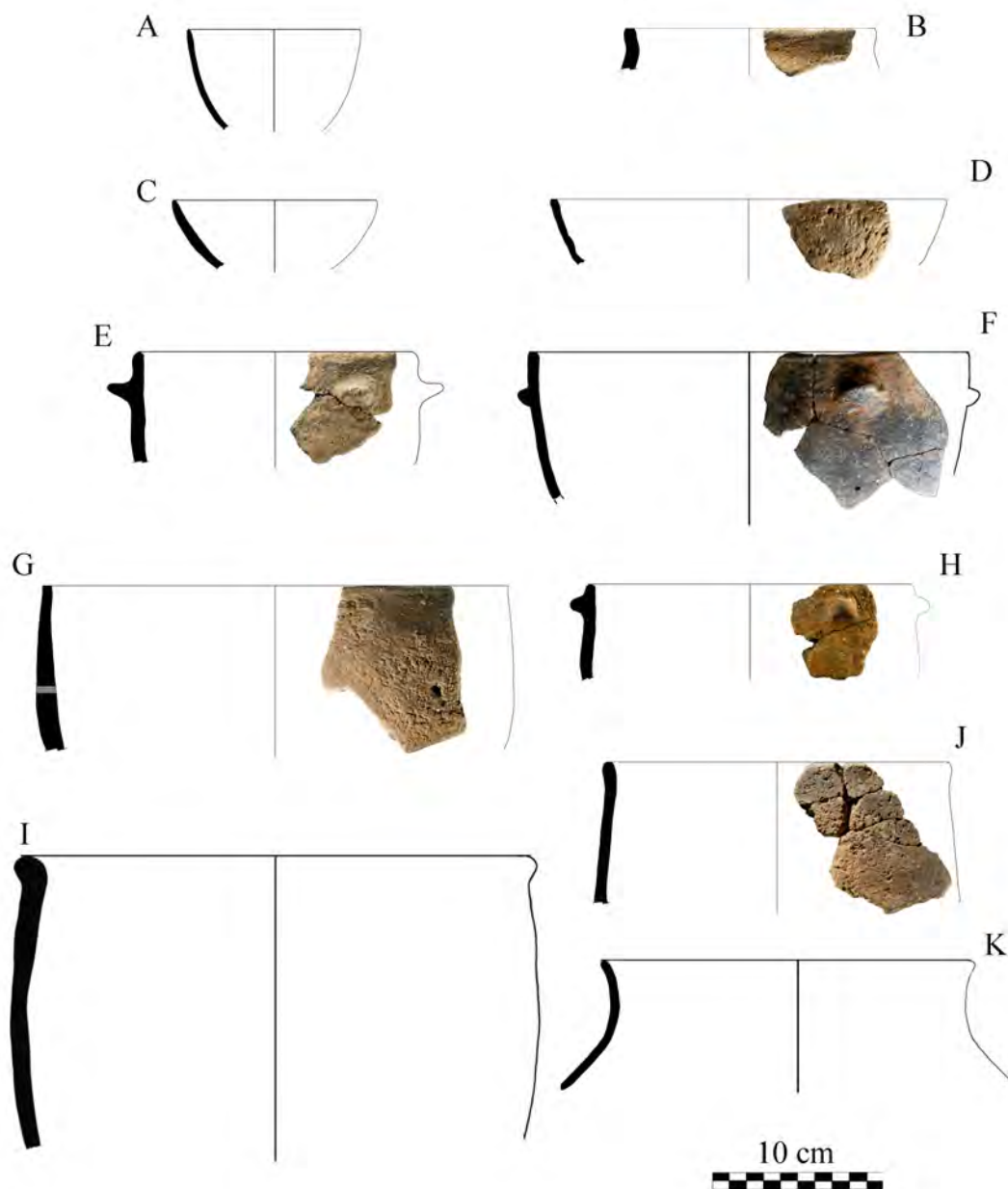


Figure 3. Drawings showing the diverse pottery types recorded at Cap de Barbaria II. A) CB-260, B) CB-151, C) CB-157, D) CB-163, E) CB-167, F) CB-1338, G) CB-202, H) CB-206, I) CB-1335, J) CB-227, K) CB-1384.

rounded coarse inclusions and rock fragments (4.2 mm-0.12 mm; fine granules to fine sand) set in a much finer-grained groundmass with abundant rounded inclusions. The fine fraction is usually dominant in all of the samples ($c:f_{10\mu}:v=45:50:5/13:77:10$) and displays a modal grain size of 0.06 mm in the long dimension. The texture of the samples is greatly conditioned by the addition of mineral temper to the clay, and the paste is coarser in those cases in which abundant spathic calcite was added.

The coarse fraction is made up mainly of predominant to common rounded and subrounded monocrystalline quartz (<0.8 mm; mode=0.15 mm) and euhedral elongated and prismatic spathic calcite crystals (<3.1 mm; mode=0.8 mm), some of which are zoned or show zebra structure. The temper in some samples was coarsely crushed, and huge polycrystalline spathic calcite fragments were introduced into the paste (e.g., CB-1262, CB-1172). In addition, very few to absent calcimudstone,



Figure 4. Photographs showing some pottery types recorded at Cap de Barbaria II. A) CB-368, B) CB-941, C) CB-511, D) CB-1335, E) CB-1352, F) CB-502. Note the presence of black patches in the surface of the vessel CB-941.



Figure 5. A) Ceramic rim decorated with finger imprints in sample CB-198. B) Dotted decoration on sample CB-1172.

mudstone and moderately impregnated segregations and hypocoatings (which appear around voids generated after the combustion of organic matter) are also present in the samples. Calcareous rock fragments, sandstone, siltstone, greywacke, chalcedony, polycrystalline quartz, chert, K feldspar, gastropods, mica laths and amorphous

nodules and impregnations (pisolites) are few to absent in the samples. Monocrystalline quartz is predominant in the fine fraction, while few to rare calcimudstone is also present. There are also rare muscovite laths and rare to absent quartz spherulites, glauconite and polycrystalline quartz.

Table 2. Clay samples identified in the prospecting carried out in the study area.

Sample	Altitude	Color	Munsell's Color	UTM X	UTM Y	Distance to CBII site	Geological Period	Observations
CB1	86 m	Reddish-brown	5YR 4/4	0361113	4280270	100 m	Pleistocene/ Holocene	Presence of organic matter
CB2	85 m	Light brown	7.5YR 6/3	0360467	4279826	750 m	Pleistocene/ Holocene	Presence of organic matter
CS1	39 m	Very pale brown	10 YR 7/3	0361284	4282971	2,500 m	Miocene	Presence of gravel and pebbles
AS1	3 m	Light brownish gray	10YR 6/2	0362925	4287987	7,800 m	Holocene	Presence of organic matter
EP1	2 m	Pale brown	10YR 6/3	0364135	4286363	7,000 m	Holocene	Presence of organic matter

It is possible to establish different subfabrics within Fabric 1 by considering the amount of monocrystalline quartz present (which ranges from 10 to 25% in Subfabrics 1.1 to 1.3). The third digit that defines each subfabric in this fabric was established according to the amount of spathic calcite present in the samples (which ranges from 5 to 35%). The samples that contain up to 10% of this temper were labeled with a “1” in this digit, whereas those that contain more than 30% of spathic calcite were labeled with a “3”.

Several types of textural feature concentrations (TFCs) could be identified in some samples. These TFCs include rare diffuse TFCs (up to 1.8 mm in length) with rounded to prolate shapes and neutral optical densities with features discordant from those of the matrix. The groundmass is optically active and pale brown (PPL, x400) to brown (XPL, x400). The features are relatively coarse-textured and related to argillaceous rock fragments containing calcimudstone, quartz and spathic calcite. In addition, we observed sharp to clear subrounded and rounded equant TFCs with high to low optical density that are optically active and features that are concordant (with quartz silt and muscovite) or discordant (with fine-textured mudstones or greater amounts of calcimudstone).

Fabric 2: Quartz-poor fabric

This fabric (Figure 7a) is represented by a single sample (CB-508) with very few voids (5%) that are predominantly macrovughs; rare megavughs are also present. The pores are close to open-spaced and oriented parallel to the vessel margins. The non-plastic inclusions (10%) are close-spaced and poorly oriented in parallel with the vessel margins. The groundmass is non-calcareous and homogeneous throughout the section. The color is brown to orangish brown (PPL/XPL, x400), and the micromass is optically active.

The inclusions display a bimodal grain size distribution with common moderately sorted angular to subrounded coarse inclusions and rock fragments (up to 2 mm, very

fine granules) set in a fine-grained groundmass with subrounded to rounded inclusions. The coarse fraction is dominant ($c:f_{10\mu}:v=55:13:22$) because the fine fraction is very scarce (<3%), with a modal grain size of 0.5 mm in the long dimension. Euhedral and prismatic crystals of spathic calcite (mode=0.5 mm) dominate the coarse fraction. There are also very few monocrystalline quartz and calcareous sandstone and rare pure amorphous nodules and polycrystalline quartz. Monocrystalline quartz is dominant in the fine fraction, and mica laths are also present.

Fabric 3: Peloid fabric (Figure 7 b-d)

There are very few voids in the microstructures of these two samples (3%). These voids are primarily macrovughs and mesovesicles that are double to open-spaced and oriented parallel to the vessel margins. The non-plastic inclusions (30-40%) are close-spaced and poorly to not oriented parallel to the vessel margins. The groundmass is calcareous and homogeneous throughout the sections. The color is brown and reddish brown (PPL/XPL, x400), and the micromass is optically active. This fabric is a crystallitic b-fabric.

The inclusions appear to display a polymodal grain size distribution; common moderately sorted angular to rounded coarse inclusions and rock fragments (up to 1.5 mm; very coarse sand) are set in a finer-grained calcareous groundmass with rounded inclusions. The fine fraction is dominant in all of the samples ($c:f_{10\mu}:v=23:70:7/21:75:4$) and has a modal grain size of 0.1 mm in the long dimension. Reworked peloids and euhedral crystals of spathic calcite, which show clear polyhedral growth in some rare cases, are the dominant components within the coarse fraction. Nevertheless, very few to absent monocrystalline and polycrystalline quartz grains are also observed. Siltstone and chert are very rare to absent. The fine fraction is made up predominantly of calcimudstone, very few monocrystalline quartz grains and very rare to absent mica laths.

Table 3. Features of the pottery samples analyzed in thin section regarding to groundmass (Optical state: M. act.=moderately active; Orientation: PO=poorly oriented, O=oriented, NO=non-oriented), pores (Shape: Ch=channels, Pv=planar voids, Ve=vesicles, Vu=voids), inclusions (c:f10:v ratio=coarse/fine up to 10 µm/voids ratio; Coarse and fine particles distribution (c:f related dist.): CS=close-spaced, SS=single-spaced; Grain size distribution: BIM=bimodal, POL=polymodal; Shape: A=angular, SA=sub-angular, SR=sub-rounded, R=rounded), presence of secondary calcite (Is= in the inner surface, Es= in the external surface, C= in the core) and firing atmosphere (IM= in the inner margin, C= in the core, EM= in the external margin; O=oxidized, R=reduced; Low case=thin layer, Upper case=thick layer).

Sample	Groundmass			Pores				Inclusions				Secondary calcite				Firing atmosphere							
	Homogeneity	Optical state	Orientation	%	Max. size	Shape				c:f ₀ :v ratio	c:f related dist.	Grain size distribution	Max. size (mm)	Shape				Is	Es	C	IM	C	EM
						Ch	Pv	Ve	Vu					A	SA	SR	R						
CB-176	Homogeneous	Active	PO	3	2.4			x	X	15:75:10	CS	BIM	4.2	x	x	x				O	O	O	O
CB-231	Homogeneous	Active	O	3	1.5			x	X	45:50:5	CS	BIM	1.2	x	x	x				O	O	O	O
CB-158	Homogeneous	Active	O	4	2.2			x	X	25:62:13	CS	BIM	2.5	x	x	x				O	O	O	O
CB-1259	Homogeneous	Active	O	1	1			x	X	28:69:9	CS	BIM	1.2	x	x	x				O	O/R	O	
CB-173	Homogeneous	Active	PO	2	1.2			x	X	20:73:7	CS	BIM	3.1	x	x	x				R	R		
CB-1331	Homogeneous	Active	PO	3	1				X	15:75:10	CS	BIM	3.2	x	x	x	x			O	O		
CB-161	Homogeneous	Active	PO	1	0.5			x	X	6:90:3	CS	BIM	1.1		x	x	x			O	O	O	O
CB-162	Homogeneous	Active	PO	3	1			x	X	8:86:6	CS	BIM	1.1	x	x	x	x			O	O	O	O
CB-163	Homogeneous	Active	PO	1	0.5			x	X	7:89:3	CS	BIM	1	x	x	x	x			O	O	O	O
CB-1341	Homogeneous	Active	PO	3	0.5			x	X	15:77:8	CS	BIM	1.8	x	x	x	x			O	O	O	O
CB-1268	Heterogeneous	Active	PO	2	0.4			x	X	17:73:10	CS	BIM	0.7	x	x	x	x			O	O	O	O
CB-502	Homogeneous	Active	PO	1	1.2			x	X	12:85:3	CS	BIM	1.1	x	x	x	x			O	O	O	O
CB-225	Homogeneous	Active	PO	1	0.6			x		3:94:3	CS	BIM	0.6	x	x	x	x			-	-		
CB-198	Homogeneous	Mod. act	PO	2	1.3			x	X	13:81:6	CS	BIM	1.7	x	x	x	x			O	O	O	O
CB-1115	Homogeneous	Active	PO	3	2.4				X	23:70:7	CS	BIM	2	x	x	x	x			R	r/o		
CB-1279	Homogeneous	Active	O	1	0.6			x	X	32:65:3	CS	BIM	1.4	x	x	x	x			O	O	O	O
CB-1183	Homogeneous	Active	NO	3	0.6			x	X	8:79:13	CS	BIM	0.6		x	x	x			R	R	O	O
CB-157	Homogeneous	Active	PO	3	0.4			x		11:79:10	CS	BIM	1.3		x	x	x			O	O	O	O
CB-202	Homogeneous	Active	PO	1	0.5			x	X	30:65:5	CS	BIM	1.2	x	x	x	x			O	R	O	O
CB-1340	Homogeneous	Active	PO	2	1				X	35:57:8	CS	BIM	0.6	x	x	x	x			O	O	O	O
CB-227	Heterogeneous	Active	O	3	1.2			x	X	43:43:14	CS	POL	2.5	x	x	x	x	x		r	O	r	
CB-1302	Heterogeneous	Active	NO	7	1.2				X	37:37:26	CS	BIM	0.8	x	x	x	x			O	O	O	O
CB-203	Heterogeneous	Active	PO	3	0.9				X	22:65:13	CS	BIM	1.5	x	x	x	x	x		O	O	R	
CB-179	Homogeneous	Active	PO	3	1.5			x	X	13:77:10	SS	BIM	2.5	x	x	x	x			O	O	O	O
CB-260	Homogeneous	Active	O	4	0.7				X	45:45:10	CS	BIM	2	x	x	x	x			O	O	O	O

Table 3. ... Continued

Sample	Groundmass		Pores				Inclusions				Secondary calcite			Firing atmosphere							
	Homogeneity	Optical state	Orientation	%	Max. size	Shape				c.f. related dist.	Grain size distribution	Max. size (mm)	Shape			Is	Es	C	Firing atmosphere		
						Ch	Pv	Ve	Vu				A	SA	SR				R	IM	C
CB-1264	Homogeneous	Active	PO	3	1.2			x	X	65:26:9	CS	POL	2	x	x	x		O	o/r	R	
CB-1333	Heterogeneous	Active	PO	3	2.4			x	X	18:70:12	CS	BIM	2.4	x	x	x	x	o	R	O	
CB-167	Homogeneous	Active	O	3	1			x	X	50:34:16	CS	POL	1.3	x	x	x	x	o	R	R	
CB-199	Homogeneous	Active	PO	3	1.2			x	X	60:30:10	CS	POL	1.8	x	x	x	x	O	r	O	
CB-1335	Homogeneous	Active	O	2	0.8			x	X	27:67:6	CS	POL	1.9	x	x	x	x	O	O	O	
CB-1279b	Homogeneous	Active	O	1	1				X	16:80:4	CS	BIM	1.5	x	x	x	x	O	O	r	
CB-1172	Homogeneous	Active	NO	2	1				X	40:54:6	CS	POL	1		x	x	x	O	O	O	
CB-1262	Homogeneous	Active	NO	2	1				X	31:62:7	CS	POL	1.5	x	x	x	x	O	r	O	
CB-168	Homogeneous	Active	PO	1	0.8				X	28:69:3	CS	POL	1.2		x	x	x	O	O	O	
CB-1176	Homogeneous	Active	O	2	1.8			x	X	39:55:6	CS	POL	2.8	x	x	x	x	O	O	O	
CB-1249	Homogeneous	Mod. act.	O	1	1.8			x	X	40:54:6	CS	POL	2.5	x	x	x	x	o	R	o	
CB-1330	Homogeneous	Active	PO	1	0.6	x		x	X	19:77:4	CS	BIM	1.5	x	x	x	x	O	O	O	
CB-170	Heterogeneous	Active	PO	3	2	x		x	X	18:71:11	CS	BIM	2	x	x	x	x	R	R	O	
CB-1338	Homogeneous	Active	PO	7	1.3				X	62:23:15	CS	POL	1.8	x	x	x	x	O	O	O	
CB-1113	Homogeneous	Active	O	3	1				X	69:19:12	CS	POL	2.4	x	x	x	x	o	R	o	
CB-1256	Homogeneous	Active	PO	2	0.8				X	71:24:5	CS	POL	1.8	x	x	x	x	O	O	O	
CB-1320	Homogeneous	Active	O	4	0.6				X	60:30:10	CS	POL	1.8	x	x	x	x	O	R	O	
CB-1100	Homogeneous	Active	PO	1	0.6			x	X	37:55:8	SS	BIM	1		x	x	x	O	O	O	
CB-1329	Homogeneous	Active	PO	1	0.5			x		9:88:3	CS	BIM	1.5		x	x	x	O	O	O	
CB-1334	Homogeneous	Active	PO	3	1.2			x	X	20:71:9	CS	BIM	1.2	x	x	x	x	O	O	O	
CB-1257	Homogeneous	Active	PO	3	0.8				X	22:70:8	CS	BIM	2	x	x	x	x	O	O	O	
CB-1150	Homogeneous	Active	PO	2	1			x	X	22:68:10	SS	BIM	1.5	x	x	x	x	O	O	O	
CB-1200	Homogeneous	Active	PO	1	0.2			x		31:62:7	CS	BIM	1.5	x	x	x	x	O	O	O	
CB-508	Homogeneous	Active	PO	5	2.4				X	55:13:22	CS	BIM	2	x	x	x	x	R	R	o	
CB-511	Homogeneous	Active	PO	3	1.2				X	23:70:7	CS	POL	1.4		x	x	x	O	O	O	
CB-151	Homogeneous	Active	NO	3	0.6			x	X	21:75:4	CS	BIM	1.2		x	x	x	O	O	O	

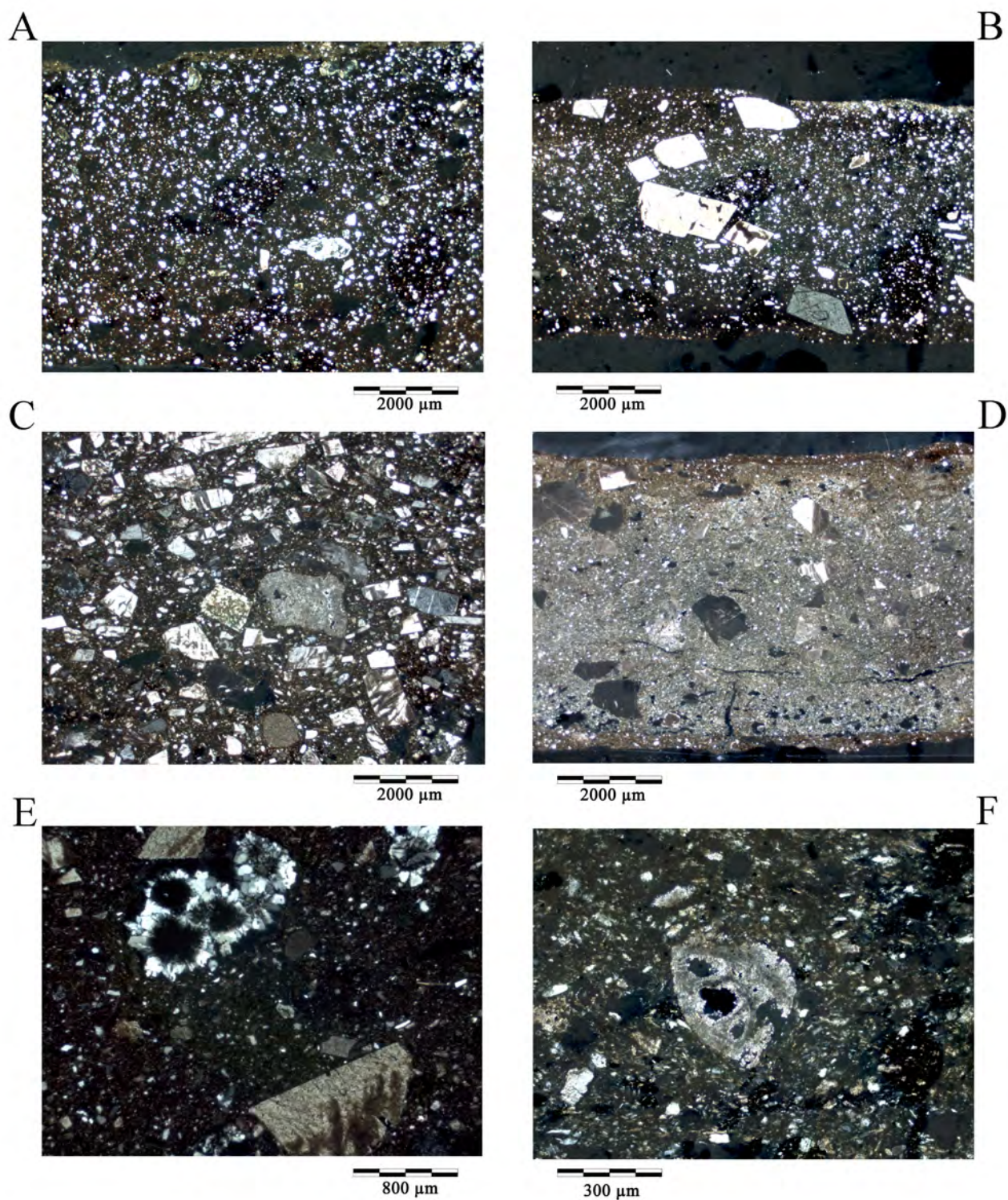


Figure 6. Photomicrographs of ceramic thin sections related to Fabric 1: A) CB-162 (XPL), B) CB-1341 (XPL), C) CB-1256 (XPL), D) CB-1200 (XPL), E) CB-1257 (XPL), F) CB-179 (XPL).

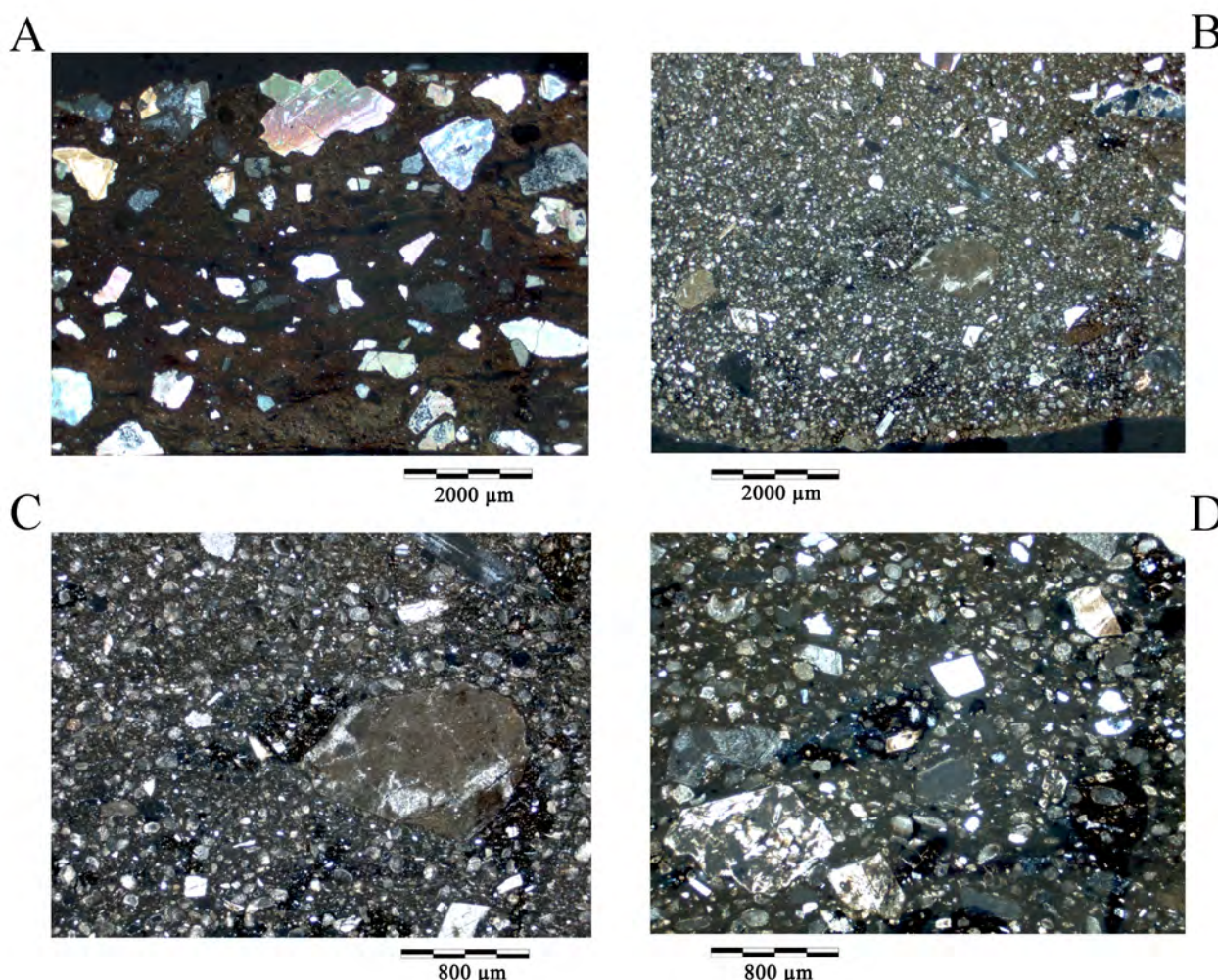


Figure 7. Photomicrographs of ceramic thin sections A) Fabric 2 (CB-508, XPL), B) Fabric 3 (CB-151, XPL), C) Fabric 3 (CB-151, XPL), D) Fabric 3 (CB-511, XPL).

X-ray powder diffraction analysis

Analysis of the crystalline phases identified in the XRPD diffractograms reflects a very homogeneous mineralogical composition in all of the selected samples in qualitative terms because they are made up largely of quartz, calcite, Na-Ca and K feldspars (probably microcline and albite) and phyllosilicates (Table 4, Figure 8). As observed in other Bronze Age ceramics from Menorca (Gómez-Gras and Risch, 1999; García Orellana et al., 2001) and Mallorca (Albero Santacreu, 2011), the XRPD analyses indicate the presence of illitic clays (illite-muscovite) in all of the samples from CBII.

Although the mineralogical phases detected are recurrent in all of the pottery samples, there are significant quantitative differences in the ceramic assemblages, depending on the intensity of the quartz, calcite and feldspar peaks. The variations detected in the XRPD analyses are in agreement with the data obtained from

optical analysis by thin section microscopy. Thus, the samples of Fabric 1, which features a silica-rich paste in the thin sections, also show higher concentrations of quartz in the XRPD diffractograms. For instance, the samples classified as Subfabric 1.1 (which has the highest quartz content) have quartz percentages of up to 76% in the XRPD analyses (samples CB-161, CB-162 and CB-163). In the same way, the samples that contain greater amounts of spathic calcite crystals in the thin sections also have the highest percentages of this mineral in the diffractograms. This proportion is as high as 52% calcite in Fabric 1 (sample CB-227) and 49-56% in Fabric 3, which has a clear calcareous nature.

Natural clays

We have identified five clay deposits related to different geological periods, formations and characteristics (Table 2) during the prospecting carried out in the study area.

Table 4. Mineralogical composition of the pottery and clay samples established by means of X-ray powder diffraction (+= \leq 10%, ++=10-25%, +++=25-50%, ++++ = \geq 50%).

Sample	Petrographic group	Illite-Muscovite	Kaolinite	Quartz	Calcite	Feldspars	Gypsum	Halite	Aragonite	Dolomite
CB-151	3	++	-	+++	++++	+	-	-	-	-
CB-158	1.3.2	+	-	++++	+++	+	-	-	-	-
CB-161	1.1.1	++	-	++++	+	+	-	-	-	-
CB-162	1.1.1	++	-	++++	+	+	-	-	-	-
CB-163	1.1.1	++	-	++++	+	+	-	-	-	-
CB-167	1.3.3	++	-	+++	+++	+	-	-	-	-
CB-168	1.3.3	++	-	+++	+++	+	-	-	-	-
CB-173	1.2.2	++	-	+++	+++	+	-	-	-	-
CB-179	1.3.1	+	-	++++	+++	+	-	-	-	-
CB-227	1.3.3	++	-	+++	++++	+	-	-	-	-
CB-231	1.2.3	++	-	+++	++++	+	-	-	-	-
CB-260	1.3.2	++	-	+++	+++	+	-	-	-	-
CB-511	3	+++	-	+++	++++	+	-	-	-	-
CB-1257	1.2.1	++	-	++++	+++	+	-	-	-	-
CB-508	2	+	-	++	++++	+	-	-	-	-
CB-170	1.3.2	++	-	+++	+++	+	-	-	-	-
AS1	Quaternary clay	++	-	+	+++	+	+	+++	-	-
CS1	Tertiary clay	+	-	++	++++	-	+	-	+	-
CB2	Quaternary clay	++	+	++	++++	+	-	-	+	-
CB1	Quaternary clay	+++	+	++++	+	+	-	-	+	-
EP1	Quaternary clay	+	-	++	++++	+	+	+	+	+

All of the sediments are fine grained (silt and fine sand) and lack gravel or pebbles (except for clay sample CS1). However, their textural (Table 5, Figure 9) and mineralogical (Table 4, Figure 10) compositions differ significantly. In turn, these compositions determine the degree of plasticity of the raw materials and their suitability for pottery production.

The experimental test and analyses conducted show that the very pale brown sample CS1, which is associated with Miocene deposits found between Cala Saona and CBII, lacks the plasticity necessary to shape a vessel because it is impossible to make a coil with this soil. This sample is rich in carbonates (calcite=82%, Figure 10a) and has the highest proportion of medium-coarse sand (32%; Figure 9a) and the coarsest particles (average=113.6 μ m) among the natural clays analyzed. Therefore, the mineralogical and textural composition of this sample allows us to classify this Tertiary deposit as a soft marly limestone that consists of a mixture of clay, mud and particularly sand and is related to abundant calcareous material.

The light brownish gray (10YR 6/2) or pale brown

(10YR 6/3) clay samples (AS1 and EP1) collected from Holocene deposits associated with the salty lagoon environments located on the northwest side of the island have a higher degree of plasticity. These samples are suitable for pottery production because a coil can be easily molded from them, and fractures do not occur in the coils during the drying phase. These calcareous marls (which have calcite contents that range from 30 to 60%) have the finest texture of all of the samples analyzed from the study area. They are dominated by fine sands-coarse silts (67.4-83.5%) and average particle sizes of 57 and 67 μ m. Sample AS1 has the finest texture because 43% of the clay is composed of particles up to 63 μ m in diameter. Illite-muscovite and smaller amounts of kaolinite are the clay minerals identified in these samples. Both samples are also characterized by the presence of gypsum and halite and small amounts of quartz and feldspar in the diffractograms. In addition, sample EP1 (collected in S'Estany Pudent) also shows the presence of dolomite and aragonite as accessory phases (Table 4). The presence of halite (rock salt), which is particularly abundant (38%)

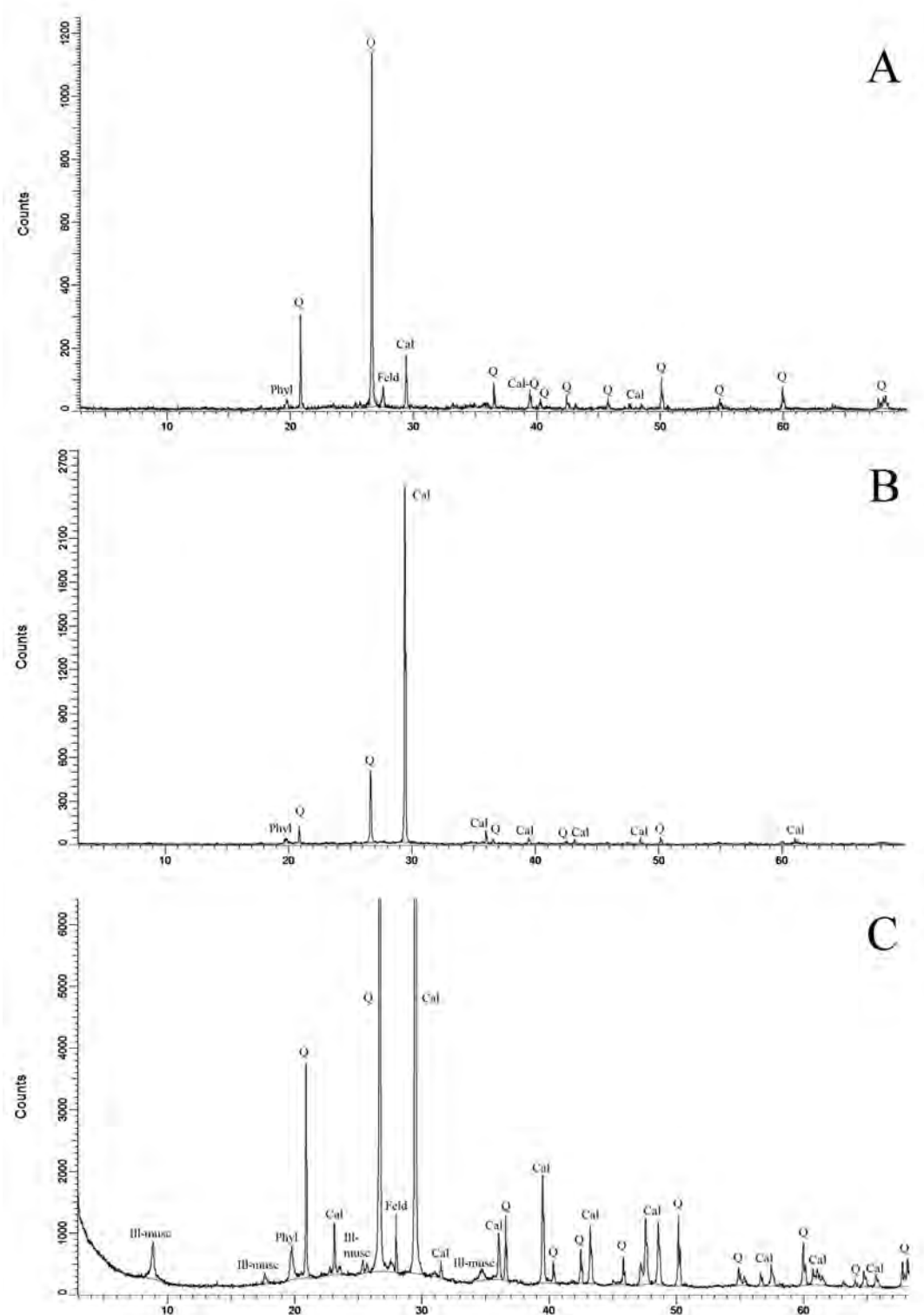


Figure 8. XRPD diffractograms showing the main mineralogical phases documented in samples assigned to Fabric 1. A) Sample CB-162 displays a high quartz content and low-intensity calcite peaks. B) Sample CB-227 displays high calcite peaks related to the addition of spathic calcite temper. C) Sample CB-1257. Note the absence of high-temperature minerals and the presence of well-preserved secondary peaks related to illite-muscovite.

Table 5. Laser diffraction particle-size analysis (LDPSA) showing the textural distribution of the clay samples recovered in the prospecting.

	Clay samples				
	CS1	CB1	CB2	EP1	AS1
% Coarse sand (2000-500 μm)	14.0%	0.7%	8.8%	0.8%	2%
% Medium sand (500-250 μm)	18.0%	14.4%	16.3%	4.2%	10.9%
% Fine sand (250-63 μm)	39.6%	51.7%	45.2%	55.3%	44%
% Coarse silt (63-16 μm)	15.8%	21.1%	16.2%	28.2%	23.4%
% Medium silt (16-8 μm)	4.5%	4.6%	4.5%	4.3%	6.4%
% Fine silt (8-2 μm)	5.9%	5.1%	6.1%	4.8%	9.4%
% Clay (< 2 μm)	2.1%	2.4%	2.8%	2.3%	4.0%
Mean (Folk and Ward method)	113.6	83.59	97.75	66.99	57.30

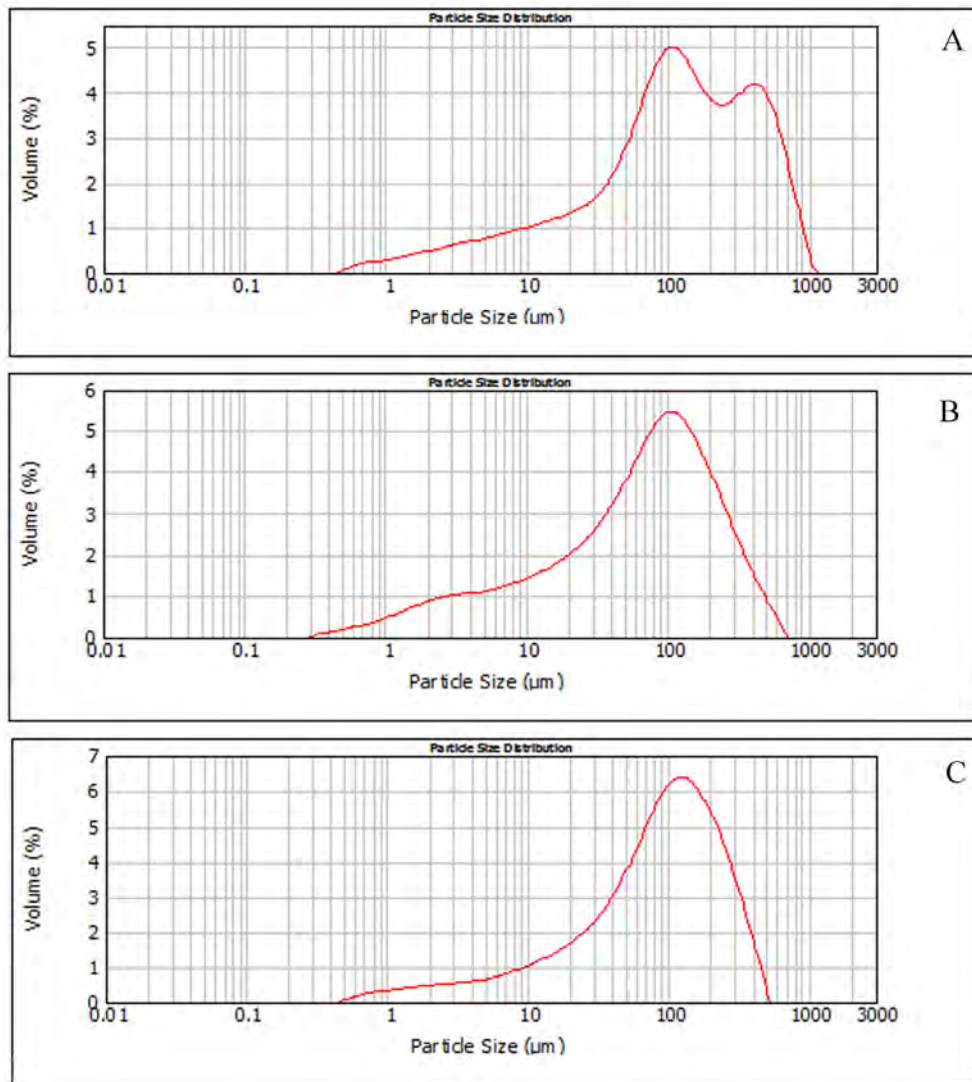


Figure 9. Graphs showing the particle size distribution achieved by laser diffraction grain-size textural analysis (LDGSA) of the clay samples analyzed from the study area. A) Samples CS1; B) Sample CB1; C) Sample AS1.

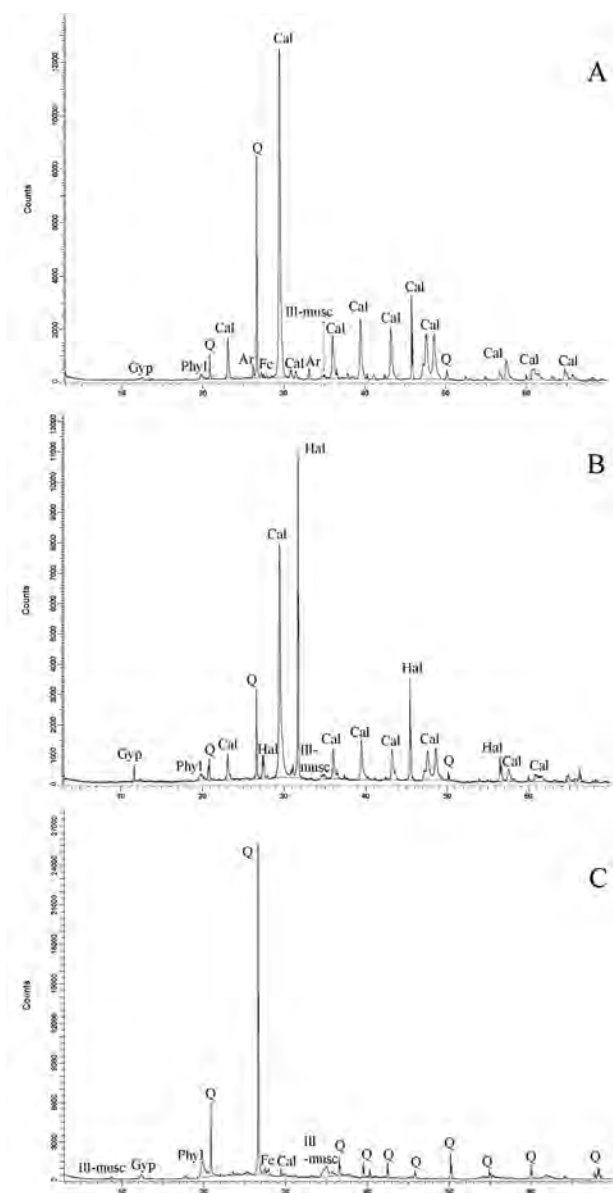


Figure 10. XRPD diffractograms showing the main mineralogical phases documented in the clay sources analyzed in this study (Ill-Musc: illite-muscovite; Phyl: phyllosilicates; Q: quartz; Cal: calcite; Fels: feldspars; Ar = aragonite; Hal = halite; Gyp = gypsum; Dol = dolomite). A) Sample CS1. B) Sample AS1. C) Sample CB1.

in sample AS1 (Figure 10b) that was collected from a salt lake, may partly explain some of the physical properties of this raw material because clays formed in salty environments are much easier to moisten and require less mechanical preparation (Linares et al., 1983).

Finally, it is necessary to determine the features of the reddish-brown clays associated with the Pleistocene and Holocene deposits located in the archaeological area

of Cap de Barbaria (Figure 2). Outcrops of these raw materials are present in the surroundings of the Cap de Barbaria II and Cap de Barbaria I archaeological sites. Both samples (CB1 and CB2) contain the same crystalline phases, which consist of illite-muscovite, kaolinite, quartz, calcite, feldspar and aragonite. Nevertheless, the clay sample collected 100 m from CBII contains a relatively large amount of calcite (51.6%), whereas the sample collected adjacent to Cap de Barbaria I (Figure 10c) must be related to a border calcareous (calcite=3.7%) refractory clay with high contents of quartz (57%) and phyllosilicates (32.4%). The texture of these samples also differ slightly (Table 5); sample CB1 is finer-textured because 72.8% of the particles are ordered in the fine sand-coarse silt fraction (Figure 8b), and the average particle size is 83 μm . Therefore, the degree of decalcification and the particle size of these raw materials are variable, and these characteristics influence the physical properties and the degree of plasticity of the clays. Although these samples are coarser-textured than the clays collected in the lagoon area of S'Estanty Pudent, the plasticity tests carried out demonstrate that they are very plastic and suitable for pottery production, especially sample CB1.

TECHNOLOGICAL CHOICES

Raw material procurement

The results of the petrographical and, to some extent, XRPD analyses provide evidence that Fabric 1 is associated with the preferential use at CBII of a secondary decalcified clay with abundant silt that consists of rounded quartz and occasional siliciclastic rock fragments (e.g., sandstone, siltstone, and chalcedony), clay nodules and terrestrial gastropods. The composition of this clay agrees well with the features of the Quaternary raw materials that are scattered throughout the Cap de Barbaria area and are currently used for cultivation. However, LDPSA and XRPD analyses show that the mineralogical and textural characteristics of the clay outcrop located adjacent to the Cap de Barbaria I site (i.e., a quartz-rich non-calcareous clay with abundant silts and fine sand) agree well with the features observed in the vast majority of the pottery samples classified as Fabric 1. These data suggest that the vessels may have been shaped from sediment such as this (if not this precise sediment). In addition, the plasticity tests carried out with this raw material demonstrate that this clay is suitable for pottery production. This clay has the highest degree of plasticity within the territory where prospecting was conducted, a property that must be related to its higher quantity of clay minerals (Table 4). Last but not least, these clays are situated only 750 m away from the CBII site, which is in agreement with the preferential range of exploitation observed in many ethnographic studies of communities of potters (Arnold, 2006).

The variations observed between the samples classified as Fabric 1 may be related to the intradeposit variability and the exploitation of the same raw material over a long period of time, an aspect that would have determined the differences recorded in the abundance of silt contained in the clay. However, the use of other outcrops of this geological formation can be proposed for samples CB-1268 and CB-1257. This interpretation is based on the different color of the groundmasses and the higher abundance of mudstone and chalcedony rock fragments of detrital origin, respectively. In addition, Fabric 2 must be related to a non-calcareous clay with very little silt that is finer in texture than Fabric 1.

In contrast, Fabric 3 is related to the use of a raw material that is completely different from that observed in Fabric 1 and Fabric 2. In this case, the potters exploited a secondary clay with abundant calcareous rock fragments associated with eolianites originating from the Miocene calcarenite deposits. These rock fragments were heavily reworked as a result of erosion and grain movement. In short, this raw material is associated with clays that agree well with the local geology. The presence of this fabric at CBII may reflect pottery produced at other archaeological sites on the island that was eventually used and deposited at CBII. It should be noted that, although petrographical studies are not available, the use of quartz-poor clays associated with karst environments has been proposed for the production of the vessels found at the Cova des Riuets site, an archaeological site located on the other side of the island approximately 20 km away from CBII (Marlasca et al., 2013).

Paste recipes

Despite the differences in the raw materials used to make the vessels, we observed that crushed spathic calcite crystals were added in all cases to temper the clay (although in different amounts), regardless of the origin and the type of clay used.

As occurs at the archaeological site of Cova des Carritx located on Menorca (Gómez-Gras and Risch, 1999), the presence of spathic calcite in the vessels must be related to the addition of crushed speleothems to the paste. This material can be found in the karstic formations located along the coastline of Formentera. We have undertaken the identification of caves situated close to the site to confirm the existence of stalactites or stalagmite formations in the Cap de Barbaria area that were potentially available to the prehistoric inhabitants of this territory. The prospecting carried out in the catchment area of the site confirmed that the closest cave (i.e., Cova de Sant Valero) is located only 2.5 km away from CBII (Figure 2). This cave contains several galleries with abundant stalactites and stalagmites, together with natural water deposits that could also have

been used in prehistoric times (Marlasca and Garí, 2014). In addition, the exploitation of this type of mineral resource by the inhabitants of CBII is attested by the presence of stalagmite fragments at the archaeological site (Sureda et al., 2013).

The petrographical analysis that we conducted permits us to roughly distinguish two trends in the ceramic assemblage regarding the amount of spathic calcite added to the samples and the chronology of the vessels (Figure 11). Unfortunately, these trends could not be further refined due to the difficulties existing at the site (i.e., poor sedimentation processes) that make it impossible to relate some of the samples to specific and narrower chronological periods. This limitation has forced us, as noted above, to assign some ceramics to very broad temporal ranges.

On the one hand, there is a tendency related to the vessels that are not only and exclusively associated with Phase 2, thus including pottery dated to the preconstruction phase or the first phase of use of the structures. Pottery related to the preconstruction phase or first use of the structures (i.e., before c. 1500 BC) tends to have a moderate spathic calcite content (15-25%) or, less frequently, a small amount (<10%) of this temper. Furthermore, the amount of calcite temper is very low in those vessels related to types characteristic of the Early Bronze Age (e.g., CB-161, CB-162, CB-170, CB-202, CB-203, CB-225, CB-502, CB-511, and CB-1150). The vast majority of these samples contain only up to 10% of this temper, and in only two cases (CB-170 and CB-202) do the vessels contain moderate amounts of calcite (<25%). In short, many samples classified as Fabric 1 and Fabric 2 contain only a very few coarse calcite crystals (e.g., CB-1331, CB-161, CB-1333), usually poorly ordered, thereby generating a bimodal distribution in the paste (Figure 5b). We must consider that the limited amounts of spathic calcite seen in these samples would not have had a significant effect on the physical properties of the paste. Thus, we can state that this technological choice would not have been related to the functional aspects of these samples (those associated with the processes of production and use) but to social, identity and (perhaps) symbolic phenomena (Albero Santacreu, 2011, 2017a).

On the other hand, almost all of the samples associated with Phase 2 (i.e., those assigned an age younger than c. 1000 BC), and some vessels of Phase 1 (e.g., CB-231) contain very large amounts of this temper. Thus, samples that contain low or medium amounts of calcite crystals (<25%) are only marginally present in Phase 2. In these cases, the samples show abundant well-sorted calcite crystals in the submillimeter fraction and with a polymodal distribution (Figures 5f and 6c). In these cases, the addition of a considerable quantity of spathic calcite to

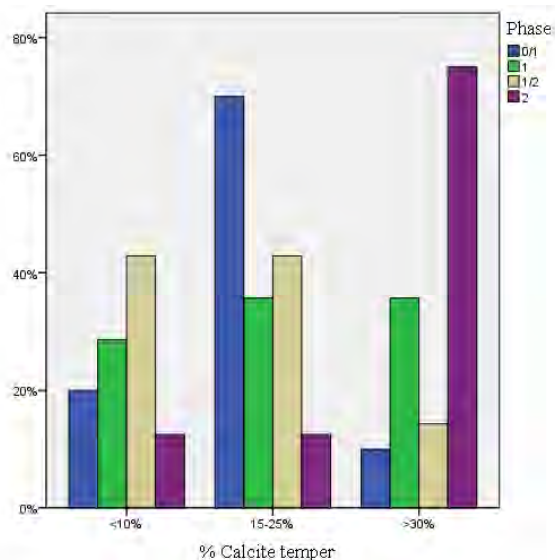


Figure 11. Graph showing the amounts of calcite temper added to the ceramics according to the phases established at the archaeological site. Note the difference between phase 0/1 and phase 2.

the paste would have promoted significant changes in the physical properties of the ceramics.

There is greater variability in the samples unequivocally related to Phase 1. In this period, we observe vessels with low amounts of temper, as well as others with large amounts of spathic calcite. However, we must consider the possibility that, due to the wide temporal range covered by Phase I (1586-958 cal BC), many of the vessels with high calcite contents assigned to this phase may have been manufactured in the Late Bronze Age and not at the beginning of the Naviform period (i.e., the Middle Bronze Age).

These trends are in agreement with previous research conducted at other sites on Mallorca and Menorca, such as Closos de Can Gaià (Albero Santacreu, 2011) and Cova des Carritx (Gómez-Gras and Risch, 1999), where the inclusion of a small amount of calcite has been confirmed in Early and Middle Bronze Age ceramics. It is in the Late Bronze Age when greater amounts of spathic calcite crystals are detected at multiple archaeological sites on these islands (Albero Santacreu, 2017a). The use of this temper has also been observed at other archaeological sites on Formentera, such as Cova des Riuets (Marlasca et al., 2013). However, these authors propose the addition of significant amounts of calcite temper to ceramics from the Early Bronze Age and the beginning of the Naviform period. Moreover, they suggest that the relatively high contents of calcite temper observed in Early and Middle Bronze Age ceramics from Formentera may indicate that

this tradition was first developed on this island within the archipelago. In our case, even though there are samples that contain significant amounts of crushed calcite (20-25%) dated to the preconstruction phase and the first phase of use of the naviform structures, the calcite contents are clearly much higher in the Late Bronze Age vessels. In any case, just as occurs in the oldest phases of Cap de Barbaria II, the coexistence of vessels with abundant calcite crystals and pottery that contains small amounts of this temper has also been noted at Cova des Riuets.

Firing strategy

The petrographical and XRPD analyses show that the estimated firing temperature was below 800 °C in all cases. On the one hand, the spathic calcite crystals do not show thermal alteration, and microscopic investigation shows that these crystals retain their natural optical characteristics (i.e., colorless crystals, good cleavage planes, twinning and well-marked polarization colors) in virtually all of the samples. We detected incipient thermal alteration of the calcite crystals only in some unusual cases (e.g., CB-225). The XRPD data are in agreement with this interpretation because the calcite peaks are well preserved in the diffractograms (thus indicating that this mineral has not begun to decompose) and high-temperature phases (e.g., gehlenite, wollastonite, and anorthite) are totally absent (Figure 8).

On the other hand, the presence of well-preserved peaks of clay minerals in the XRPD diffractograms provides further evidence of low firing temperatures for these ceramics (García Orellana et al., 2001). As occurs with calcite, clay minerals can be neoformed when the vessels are fired at low temperatures. Therefore, these clay minerals can reach their initial structure after long periods of time, thus producing peaks and areas very similar to the original ones in the XRPD diffractograms. The presence of well-preserved illite-muscovite peaks in many samples at 10 Å (e.g., CB-260, CB-1257) and especially at 5 Å provides information regarding this aspect (Figure 8c). From 650 °C, the diagnostic peak of illite-muscovite begins to be altered; this alteration continues if the temperature is increased until the peak almost totally disappears at 800 °C (Drebushchak et al., 2005). Therefore, firing temperatures of up to 700 °C must be considered for most of these vessels. This interpretation is consistent with the anisotropic and birefringent nature of the groundmass when it is observed under the petrographic microscope, which indicates the absence of a vitreous phase in the ceramics.

The estimated firing temperature (<800 °C) is the most appropriate to prevent the decomposition of calcite and to avoid the vitrification of the clay matrix. Under conditions in which calcium carbonate is subjected to heat until

decomposition, a very unstable phase known as calcium oxide appears. This phase change produces significant stresses in the pottery and may consequently generate fractures. In addition, calcium oxide is hygroscopic, so it absorbs moisture from the atmosphere, resulting in its hydrated form $[\text{Ca}(\text{OH})_2]$. This hydration occurs immediately and increases the volume of the crystals, usually causing the collapse of the ceramic (Rye, 1976; Gibson and Woods, 1990). This process involves the generation of cracks in the pottery as a result of high tensional stresses and leads to its total pulverization in less than 24 hours after being exposed to humidity (Albero Santacreu, 2011). The extent of the damage depends on several factors, such as the temperature achieved, the time of exposure to the highest temperature and the amount and size of the carbonates present in the paste. Some scholars (Gibson and Woods, 1990) have stated that the dilatometric changes that the paste suffers are of little importance in firings below 800°C . In addition, calcite has a low coefficient of thermal expansion, which is virtually identical to those of low-fired clays (Rye, 1976; Hoard et al., 1995). This coefficient minimizes the generation and propagation of fractures during the firing process. Thus, the micro-structures of the calcareous pastes remain relatively unchanged over a wide temperature range ($600\text{--}750^\circ\text{C}$) during the firing process. Thus, the firing temperatures estimated for the CBII pottery were high enough to fire the vessels but were also less critical in achieving suitable ceramics.

Regarding the firing atmosphere, we observe (Figure 12) that most of the ceramics were fired under oxidizing conditions. However, total or partial reduction is also well attested within the ceramic record (40% of the samples). This trend is observed regardless of the chronology of the samples and the amount of calcite added to the paste. Nevertheless, the samples with smaller amounts of calcite usually display a greater tendency to present totally oxidized cross sections (75% of the samples with up to 10% calcite were fired in this kind of atmosphere, whereas this percentage drops to 50% in the samples with more than 30% calcite).

Since the amount of organic matter present in the samples is very low, and organic matter occurs naturally in the clays, the reduction observed in the cores and the margins of most vessels must be associated with the use of reducing firing atmospheres, at least at the beginning of the firing process (Albero Santacreu, 2014). Potters often build specific types of features to encourage the absence of oxygen within the firing structure. Moreover, they can saturate the firing atmosphere with smoke originating from the combustion of fuel, especially if green or wet wood is used. In short, reducing atmospheres are attained by using closed firings and continuously adding fuel

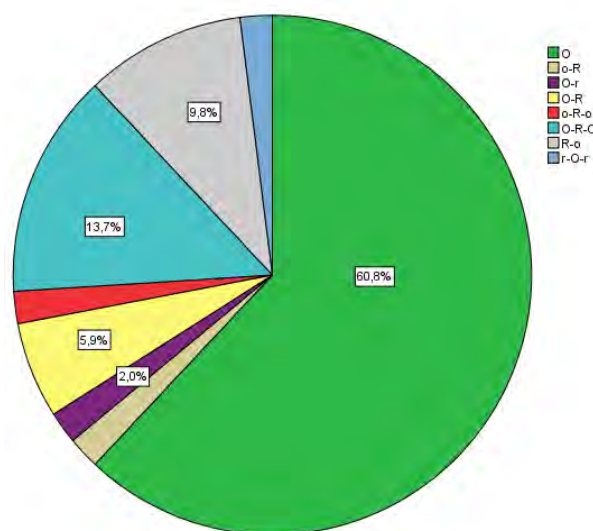


Figure 12. Graph showing the chromatic transitions recorded in ceramic cross sections related to the use of different atmospheres in the firing process (O = oxidizing atmosphere; R = reduced atmosphere).

because, in this way, the circulation of air within the structure is impeded (Barley, 1994; García Rosselló and Calvo, 2006).

The significant evidence of firing under reducing conditions seen in the pottery from CBII has been noted in previous research (Sureda et al., 2013). However, thorough observations of the oxidation/reduction processes that took place in the cores and the margins of the ceramics demonstrate that the degree of oxidation observed in the vessels is highly variable (Table 1). As explained above, fully oxidized sections (O) are found within the ceramics analyzed here; however, vessels with reduced cores and oxidized (O-R-O) or slightly oxidized (o-R-o) margins and sections with only slightly oxidized external margins (R-o) are also present. In addition, the vast majority of the vessels analyzed show heterogeneous colors on their surfaces (e.g. Figures 3f and 4b), indicating that the firing was carried out in structures in which the air circulation and heat distribution were not uniform. Moreover, the existence of black patches on the surfaces of the vessels points to the use of structures in which the fire and fuel were in contact with the pottery (García Rosselló and Calvo, 2006). In a reducing atmosphere, the gas released during firing tends to bond with the oxygen atoms of some ceramic components. This process explains the substantial variability in color, which is usually observed on the surfaces of the pottery but not in the cores.

The great chromatic variety observed in the sections and on the surfaces of the vessels, together with the low firing

temperatures used, point to the use of firing structures in which the flow of oxygen was irregular and the ceramics did not usually surpass 800 °C. Pottery firings like these, which usually do not reach 900 °C and in which completely reduced or oxidized atmospheres are very difficult to achieve, are the products of both bonfires and pit firings (Van As, 1984; Reid, 2001; Livingstone-Smith, 2007). In these structures, the firing conditions are not entirely uniform throughout the process, especially when most of the fuel has been consumed and oxygen invades the firing structure. Experimental firings carried out in both pits and bonfires sealed with mud (Waldren, 1991) demonstrate that oxygen enters these structures during the last stage of the firing process (once the fuel has been consumed) and especially during the cooling period. Thus, the presence of air inside the firing structures oxidizes the ceramic surfaces and, in some cases, the vessel margins, which develop the thin red layer that we noted in the cross sections.

The use of heterogeneous reduced atmospheres to fire the vessels has also been observed in archaeological sites from Menorca. However, this variability was explained by considering the arrangement of the vessels within the structure (García Orellana et al., 2001), rather than the physicochemical changes that took place inside the structure during the firing process. Furthermore, the presence of pottery fired using both reduced and oxidized atmospheres has also been observed in many sites from Mallorca, such as Closos de Can Gaià (Albero Santacreu, 2011). Although reduction firings are very difficult to achieve, even using modern laboratory techniques (Dawson and Kent, 1984, 1985), they have some technical benefits. In comparison to an oxidizing atmosphere, the use of a reducing environment increases the reaction temperature of the components of the paste by 50 °C (Maritan et al., 2006). Therefore, the use of this firing atmosphere allows for an increase in the temperature at which calcite decomposes to 850 °C and thus yields a harder and more consistent final product. However, as we have already pointed out above, many of the vessels from CBII were fired in predominantly oxidizing environments. These observations suggest that the potters may not have realized that reduced atmospheres would increase the hardness of their products.

Skills of potters

Several features observed in many vessels from CBII can be related to potters who were relatively experienced and were relatively specialized in pottery production. The elevated skill levels of these potters can be glimpsed in several phases of the *chaîne opératoire*. First, the specialization, solid expertise and technical skill of the potters are evident in the long-term exploitation and use

of Quaternary decalcified clays in this territory. Second, the paste recipes identified in this study indicate the dominance of the use of spathic calcite temper. This recipe is consistent with thorough preparation of the paste; thus, in most cases, the temper size was homogenized and the grains were well sorted and well mixed with the clay, thus generating bimodal or polymodal grain size distributions and uniform and slightly porous pastes.

Third, the orientation of the spathic calcite crystals and fractures observed in several of the cross sections (e.g., CB-167, CB-231, and CB-1249) allows us to suggest the use of coiling techniques to shape the vessels (Figure 13a); the internal overlapping of coils is evident in some cases. Moreover, the orientation of the pores, inclusions and temper with respect to the pottery surfaces observed in the thin sections indicate that considerable pressure was applied by the potters when the coils were modeled and joined. They exerted considerable effort in carrying out the coiling and strongly pressed the walls, thus promoting the orientation of the temper parallel to the surface (Figure 13b). In addition to the effort expended in terms of energy, the proper working of the clay reflected by the orientation of pores and the temper implies a relatively complex organization of the activity; the time required may have been as important as the skill of the individual. The use of coarse-textured pastes, such as those observed in many of the fabrics (e.g., Subfabrics 1.2.3 and 1.3.3), significantly increases the time required to process the paste and produce a vessel, even if the temper has a small particle size (Schiffer and Skibo, 1987; Hoard et al., 1995; Sillar and Tite, 2000).

Last but not least, the successful production of calcite-tempered ceramics requires a certain amount of technical knowledge of the temperature, duration and atmosphere used in firing. Thus, firing this type of calcareous paste requires considerable practice to establish the thermometric behavior of the material to achieve a useful end product that can be used. Evidence of the thorough control of this stage is provided by the absence of thermal alteration of the spathic calcite crystals, and the XRPD analyses point to a low firing temperature of <750 °C. This implies that the potters developed knowledge that allowed them to fire their vessels while avoiding the risks involved in crystal decomposition. Thus, at least some of the potters would have developed considerable expertise and a thorough understanding of this stage of the *chaîne opératoire*, which allowed them to reach an optimum temperature below that of calcite decomposition. Another technological choice that can also be associated with experienced potters is the use of reducing firing atmospheres. As explained before, firing pottery in this type of atmosphere is complex and requires deep knowledge of the process. Moreover, the use of a

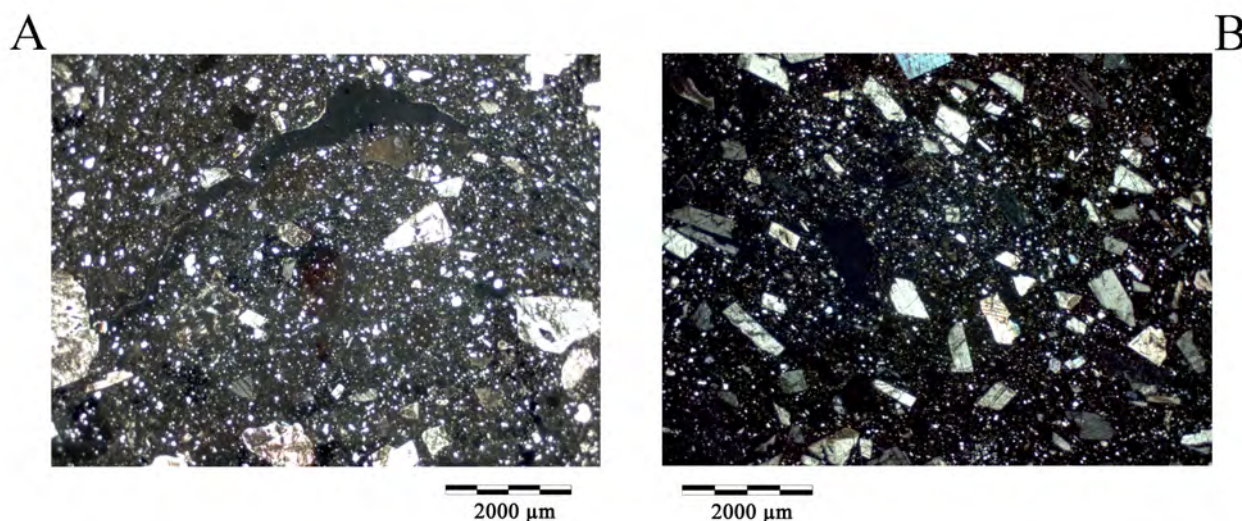


Figure 13. A) Photomicrograph of a ceramic thin section showing a fracture related to the use of the coiling technique to shape the vessel (CB-1249, XPL). B) Photomicrograph of a ceramic thin section showing the orientation of calcite temper parallel to the surface of the vessel (CB-231, XPL).

reducing environment increases the reaction temperature of the components of the paste by 50 °C. In any case, we have already mentioned that the high variability observed in the ceramic assemblage regarding the firing atmosphere may be related in many cases to the difficulties associated with achieving a totally reducing environment throughout the entire firing process.

In short, the paste composition indicates that the potters were highly skilled and devoted effort, time and resources to standardizing the technical process. The knowledge related to all of these stages of pottery production was crucial in developing the practical and social dimension of the material culture associated with the site. Moreover, such knowledge would have been embedded in the community of practice of the potters of CBII, who transmitted it from generation to generation.

Comparison with other archaeological sites

The petrographical and mineralogical analyses carried out indicate that the ceramic assemblage recovered from the CBII site is relatively homogeneous with respect to features (i.e., the use of decalcified clays, the addition of spathic calcite temper and the use of low firing temperatures). Two technological choices were made in the production process that involved the whole community of potters and persisted over a long period (between 1624 and 730 cal BC). Here, we refer to the preferential exploitation of a decalcified clay and the use of the spathic calcite recipe to prepare the paste. As we have stated previously, the selection of decalcified clay and spathic calcite would have been greatly influenced

by ecological factors related to the accessibility and availability of these raw materials in the environment (Albero Santacreu, 2014, 2017a). Nevertheless, the persistent use of these materials over several centuries also points to a shared use of the mineral resources involved in pottery production, both among different generations and among contemporary individuals. In addition, the scarcity of raw materials observed in the study area suggests that the resources would have been shared among all of the potters. Therefore, such technological choices were fully embedded in the development of certain social practices that were strongly related to the definition of certain places that played a key role in the construction of the landscape and taskspace of the community (Albero Santacreu, 2017a).

The use of the same materials and recipes must be associated with the transfer of knowledge among contemporary artisans. Furthermore, the perpetuation of these technological choices would have required the intergenerational transmission of the knowledge associated with this particular *savoir faire*. Such communication may have been facilitated by the existence of well-defined learning contexts and by situating some phases of the production process (e.g., clay procurement, paste preparation, and the firing process) in the public domain, where information could easily be shared. In this sense, the presence of negative imprints left by seeds and other organic materials in some pottery cross sections and surfaces (Sureda et al., 2017a) suggest that the vessels were probably produced near spaces that were used to process these types of biotic materials. Finally, the maintenance

of this long-term technological tradition over several centuries has to be explained by a shared *habitus* among the potter's community of practice and the existence of well-established learning contexts (Albero Santacreu, 2017b). The incorporation of these technological choices into the unconscious realm would have prevented any deviation from tradition. In short, all of these collective strategies and the acquisition of a shared technological *habitus* would have reinforced the social cohesiveness of the community that inhabited the Cap de Barbaria II site.

Some technological choices observed in the ceramic assemblage from CBII are also present in the pottery recovered from Cova des Riuets (Marlasca et al., 2013). We refer to the use of the same paste recipe and the low number of vessels that fall outside the norm. The use of spathic calcite temper has also been identified at this site, and the two trends observed at CBII are also present (i.e., samples with a polymodal distribution and a large amount of well-crushed temper and samples with a bimodal distribution, a low quantity of temper and larger calcite crystals). In addition to these similarities, there are also some differences between the pottery recovered from both sites. The ceramics found at Cova des Riuets were made using clays with low quartz contents obtained from a karst environment, a technological choice that differs greatly from that inferred for CBII. These different types of raw materials used in pottery production indicate that prehistoric communities settled in distant areas of Formentera (e.g., La Mola, Cap de Barbaria) exploited different clay sources according to proximity, among other factors. Unfortunately, the pottery samples from these archaeological sites cannot presently be compared because thin sections are not available from Cova des Riuets.

The technological choices identified at CBII are also observed at other archaeological sites on the Balearic Islands. The utilization of decalcified clays in pottery production was very unusual on the other islands of the archipelago during the Bronze Age (Albero Santacreu, 2011, 2017b), although this kind of clay was used as a construction material (Albero Santacreu and García, 2010). However, the wide use of spathic calcite temper has been attested in most of the archaeological sites from Menorca and Mallorca (see Albero Santacreu, 2011, 2017b). Furthermore, the observed diachronic change in the amount of temper added to the paste between the Early and Late Bronze Ages has also been detected at several archaeological sites on Mallorca and Menorca, such as Cova des Carritx (Gómez-Gras and Risch, 1999), Son Mercer de Baix (Plantalamor and Rita, 1984) and Closos de Can Gaià (Albero Santacreu, 2011). Very small amounts of calcite crystals were added to the Early Bronze Age ceramics from these sites.

Other connections involve certain visual aspects of the pottery, such as the types manufactured and some decorative motifs. On the one hand, decorative motifs made up of finger imprints are present on the rims of some large storage pots found at CBII (Figure 3), and similar motifs are also attested from other naviform sites on Mallorca, such as Illot des Porros, Naveta Alemany (Albero Santacreu et al., 2013) and Canyamel (Pons, 1999). On the other hand, we can see how the pottery produced at CBII resembles types that are also present at other Bronze Age sites on Formentera, such as Ca na Costa (Fernández et al., 1979), Cova des Riuets (Trias and Roca, 1975), and Sa Cala o Cova des Fum (Ramon and Colomar, 2010). Furthermore, these types are also present on Mallorca and Menorca, including naviform sites such as Closos de Can Gaià, Naveta Alemany (Guerrero et al., 2007) and the Naveta Ponent of Hospitalet (Pons, 1999). Here, we refer to the presence of bowls and globular vessels (some with perforated handles), both of which are characteristic of the Bronze Age.

However, it should be clarified that some of the pottery recovered from Closos de Can Gaià or Naveta Alemany, including vessels related to the types mentioned above, seems to be related to the preconstruction phase of the naviform structures (Javaloyas et al., 2007; Albero Santacreu et al., 2013). Therefore, several types present in the pottery assemblage from CBII show certain archaizing features when compared with the shapes that are typically found at other naviform sites on Mallorca and Menorca. For instance, certain types that are characteristic of the Naviform period, such as the large storage pots called “*tonells*” and vessels with everted flattened rims, are absent at CBII. In addition, flat bases are scarce at this site, and they are represented by a few fragments ($n=12$). Therefore, it must be elucidated that, even though there are certain typological connections with the archaeological record found on other islands in the archipelago, the ceramic assemblage from CBII is characterized by the presence of conservative morphologies. This aspect points to a potter community with deep-rooted traditions and great resistance to technological change.

CONCLUSIONS

The archaeometric characterization of the archaeological pottery recovered from the Bronze Age of CBII allows us to identify certain technological choices developed by the potter's community of practice who inhabited this site. The analysis conducted on both natural clays and pottery samples demonstrates that the vessels recovered from the site have a local origin, and none of them can be related to imported wares. Moreover, such analyses point to the long-term exploitation and use of Quaternary decalcified clays in pottery production and

the use of a recipe including spathic calcite to prepare the whole ceramic assemblage. Moreover, this study provides evidence that, even though pastes with abundant calcite temper were more common in the Late Bronze Age, its presence has also been confirmed in all phases at the site. In any case, the amount of calcite crystals added to the paste is more variable in comparison with other ceramic assemblages recorded on other islands of the archipelago. Despite some degree of variability regarding the firing atmospheres used throughout the firing process, the use of low firing temperatures has also been confirmed in all cases; these temperatures never exceeded 750 °C. The knowledge related to the exploitation of the raw materials, the preparation of the paste and the firing of calcite-tempered vessels points to solid expertise and technical skill on the part of the potters.

Technological choices, such as clay and temper acquisition, can be interpreted from ecological viewpoints, such as the scarcity and proximity of the materials selected. However, the homogeneity of these practices also suggests that such technological choices may also be related to collective production strategies, especially regarding the procurement of raw materials (clay and temper) and the preparation of the paste. In this sense, knowledge was clearly transmitted among the potters who inhabited the site from generation to generation that promoted a higher degree of social cohesion among these individuals and the shared construction of landscape landmarks. The long-lasting nature of the technological choices recorded, together with the presence of conservative pottery shapes during the Bronze Age, points to a potter community with deep-rooted traditions and great resistance to technological change.

Finally, it is important to highlight that some of the technological choices (e.g., the addition of spathic calcite temper) recorded in the pottery have also been observed at other archaeological sites on Formentera, such as Cova des Riuets and Mallorca and Menorca. Therefore, these data suggest that the craftspeople from CBII established links to and shared knowledge with other communities on the island, as well as people from the other Balearic islands.

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