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RESEARCH

Exploring handmade pottery traditions and Early Iron Age Iberian networks through the site of La Fonteta (Alicante, Spain)

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Abstract

The Phoenician colony of La Fonteta in southeastern Iberia holds significant importance for understanding Phoenician settlement patterns in the region. While previous research has primarily focused on wheel-thrown ceramics indicative of the new technological advancements and trade networks implemented after the Phoenician arrival, handmade ceramics have been somewhat overlooked despite their prevalence in the Early Iron Age (EIA) contexts. Our study, based on the analysis of 36 individuals from recent excavations at La Fonteta, sheds light on the technological aspects (temper choice and estimated firing temperature) and mobility patterns associated with handmade ceramics in this context. Contrary to previous assumptions, our findings indicate that handmade ceramics played a crucial role in regional and broader exchange systems, possibly with limited ties to wheel-thrown ceramics. Moreover, regional mobility seems to have been prominent, likely stemming from local networks and technological frameworks established during the preceding Late Bronze Age (LBA) period.

Keywords Early Iron Age · Iberia · Phoenician · Optical petrography · WD-XRF · PXRD · SEM-EDS · Handmade ceramics

Introduction

The Phoenician colony of La Fonteta (38° 06' 5" N, 0° 39' 2" W) stands out as one of the main protohistoric sites in southeastern Iberia, and its study has played a pivotal role in elucidating the circumstances surrounding the establishment of the early Phoenician settlement in the region (González Prats 2014, 2011; Lorrio Alvarado et al. 2022; Rouillard et al. 2007). This site represents a newly built architectural complex, dating approximately from the late 8th to the late 6th century BCE. It conforms to a well-established settlement pattern employed by Phoenician communities in the western Mediterranean, as it was strategically situated at the mouth of a river and close to the local site of Peña Negra (38° 16' 26" N, 0° 49' 42" W), located at the eastern border of Tartessos (González Prats 1993; Lorrio Alvarado 2023;

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Lorrio Alvarado and Torres Ortiz 2022). Both textual and archaeological evidence attests to the profound influence of the latter site on settlements placed in the vicinity, including those situated along the two primary river basins in the region, namely the Segura and the Vinalopó (Figure 1).

Archaeological excavations have revealed that La Fonteta underwent two distinct phases. The initial phase, Fonteta Arcaica (Early Fonteta), was characterised by a thriving craft and metallurgical industry. It witnessed the emergence of multi-room dwellings built with cob walls atop stone foundations, constituting the earliest architectural remains at the site. This period is believed to have ended around 600 BCE. Shortly after, the settlement underwent a significant transformation by constructing a defensive wall with towers. This transformation marked the beginning of the Fonteta Reciente (Late Fonteta) phase. During this second phase, the primary occupation of the settlement consisted of residential activities, although traces of a metallurgical furnace have been identified. The site was eventually abandoned during the third quarter of the 6th century BCE.

Fig. 1 **A**: Location map. **B**: Detailed view of Early Fonteta levels beneath the defensive wall foundations. **C**: Detailed view of Late Fonteta levels, showcasing the distribution of domestic structures along the defensive wall

The ceramic assemblage unearthed at the site comprises an extensive collection of wheel-made pottery, which is characteristic of Early Iron Age and Phoenician contexts in southern Iberia. This pottery assemblage encompasses various types, including storage and transport amphorae (types T.10.1.1.1, 10.1.2.1, and 10.2.1.1) (Ramon Torres 1995). Additionally, it includes tableware featuring Grey Ware, Red Slip pottery, and Bichrome ware bowls, along with storage containers in Bichrome ware, such as the well-known *pithoi* and Cruz del Negro urns (González Prats 2014, 2011; Lorrio Alvarado et al. 2023b; Rouillard et al. 2007). The assortment also incorporates forms originating from other Mediterranean regions, comprising vessels attributed to Levantine, Phoenician central Mediterranean, Eastern Greek, Corinthian, and Attic traditions. A limited selection of Etruscan storage and transport amphorae and tableware is also present (Lorrio Alvarado et al. 2023a).

Based on the material recorded during the last excavation season (2018-2019), handmade pottery exhibits unusually high proportions, averaging approximately 29.5 % throughout the entire occupation period. Regardless of the construction phase, the most prevalent handmade ceramics are coarse vessels characterised by their high walls, primarily intended for storage and cooking purposes (mostly type A1, A2 and A3 from Ortiz Temprado (2014), recently updated by Vinader Antón (2022)) (see Figures 2 and 3, Table 1). These vessels, when decorated, typically feature appliqué, impressions, and incisions. Open vessels used for food processing, known as *lebrillos*, are also present to a lesser extent. Finely finished vessels constitute a minimal percentage (< 1 %) and are mainly limited to tableware, especially carinated bowls. In terms of typology, these ceramics closely resemble those found at other regional sites, such as Peña Negra (González Prats 1983; Vinader Antón 2022), Los Saladares (Arteaga and Serna 1979), or Castellar de Librilla (Cutillas Victoria and Ros Sala 2020; Ros Sala 1989). Additionally, albeit to varying degrees, similarities have been observed with southern and northeastern Iberia ceramic types, highlighting the connections between the local population and neighbouring areas.

Despite their relatively high abundance, handmade ceramics have played a marginal role in shaping exchange networks or contributing to the technological framework within which the inhabitants of La Fonteta existed. This situation is a trend that extends to most Early Iron Age colonial sites in southeastern Iberia.

Up to this point, ceramic characterisation at La Fonteta has primarily involved petrographic analyses focused on wheel-thrown pottery, with only a limited set of nine handmade pieces included in such studies (González Prats 2011). Among these handmade pieces, two distinct groups have been identified. Five of nine individuals exhibited a light surface colouration and were petrographically assigned to a potentially local sedimentary geological environment (group ES). The remaining four pieces have darker colours and contain inclusions of metamorphic origin, which could be linked to sedimentary and igneous materials (classified as group EM). These latter ceramics likely originated from the Málaga-Guadalhorce area, suggesting an importation from that region. This picture differs from the broader range of potential origins proposed for wheel-thrown ceramics.

According to the interpretation proposed by the authors, ceramic products rich in sedimentary material would resemble those identified at the neighbouring site of Peña Negra (González Prats and Pina Gosálbez 1983). Extensive evidence of craft activities, generally attributed to the late phases of the Bronze Age, has been discovered in this local settlement. This evidence includes handmade ceramics, loom weights, and areas for metallurgical and ivory work. Local wheel-made ceramic production from the 7th-6th centuries BCE at Peña Negra is associated with creating a new area in the eastern part of the settlement. This area featured buildings with an orthogonal layout and abundant evidence of craft activities, such as spindle whorls, copper and bronze ingots, and even a goldsmith's die. However, direct evidence of dual-chamber kilns is lacking. The excavation team identified this area as a "Phoenician quarter" (González Prats 1993), likely the result of an agreement with the local elite and a sign of closer ties with foreign communities, a phenomenon like those documented in the Near East and replicated in some regions of the Iberian Peninsula, such as the Huelva region (Aubet Semmler 2012; Mederos Martín 2006).

Our research expands upon prior studies by incorporating a more extensive sample of handmade pottery that includes materials from the last fieldwork season at La Fonteta. We have integrated petrographic observations into a multi-technique program, as the resulting complementary data provide a more comprehensive understanding of the origin and technology of those ceramics. Compositional data are also compared with pottery recovered in Iberia, with a particular focus on a small Peña Negra set. Our goal is to investigate the role of handmade ceramics in local and regional exchange networks, particularly in their interactions with other local communities. Additionally, the resulting data helps address uncertainties related to provenance issues documented along the eastern coast of Iberia (Madrid i Fernández and Buxeda i Garrigós 2021; Montenat 2007).

Materials and methods

The individuals included in this study were unearthed during excavation works at La Fonteta (2018-2019). These pieces were analysed using X-ray fluorescence (WD-XRF) and X-ray powder diffraction (PXRD) for chemical and mineralogical characterisation, scanning electron microscopy (SEM-EDS) for microstructure analysis and optical petrography (OP) for textural and compositional

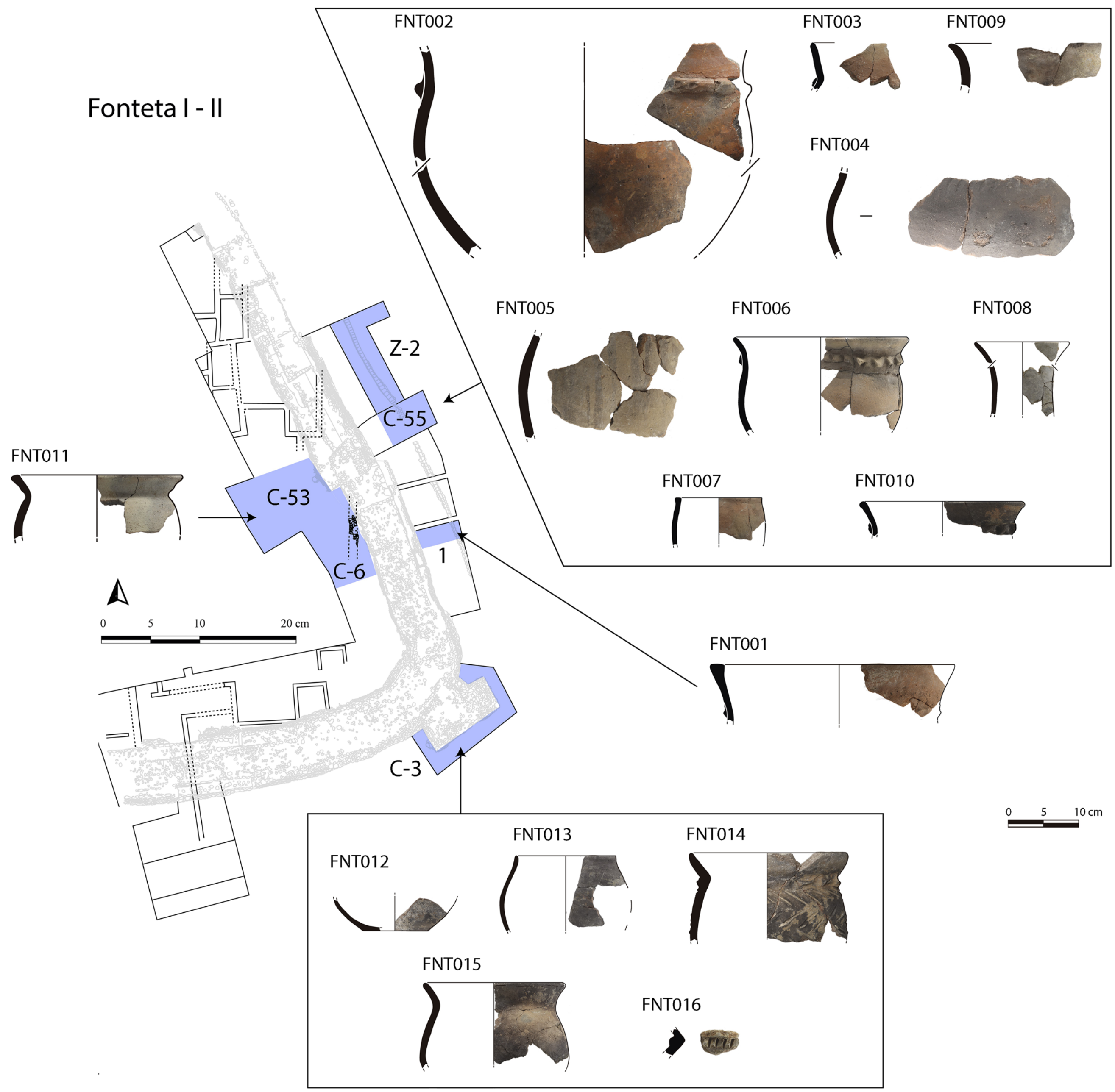

Fig. 2 Analised materials from Early Fonteta and recovery areas

observation. When sampling the individuals, three criteria were considered: chronological and formal classification and macroscopic inspection of the fracture. The archaeological context of the pieces was based on their assignment to the constructive phases identified. Additionally, 10 individuals from the nearby local site of Peña Negra (9th-6th centuries BCE) were also included for comparison (Supplementary material, Table 1). For the ceramics from Peña Negra, only their chemical composition was available at the time of this study, as their comprehensive analysis is currently in progress. The sample primarily consists of fragments with light-coloured calcareous pastes, which, based on previous research, can generally be classified as local (group B, after González Prats and Pina Gosálbez 1983).

Regarding formal and functional variability, a bulk of coarse cooking ware, bowls, storage vessels, and a few examples of burnished tableware ceramics, including a finely crafted carinated bowl, were analysed. The low representation of this latter ware mirrors the reality of the settlement. Finally, based on the observation of the pieces, we attempted to select a good number of pastes considered to be local due to their abundance in the archaeological record and the exhibition of characteristic

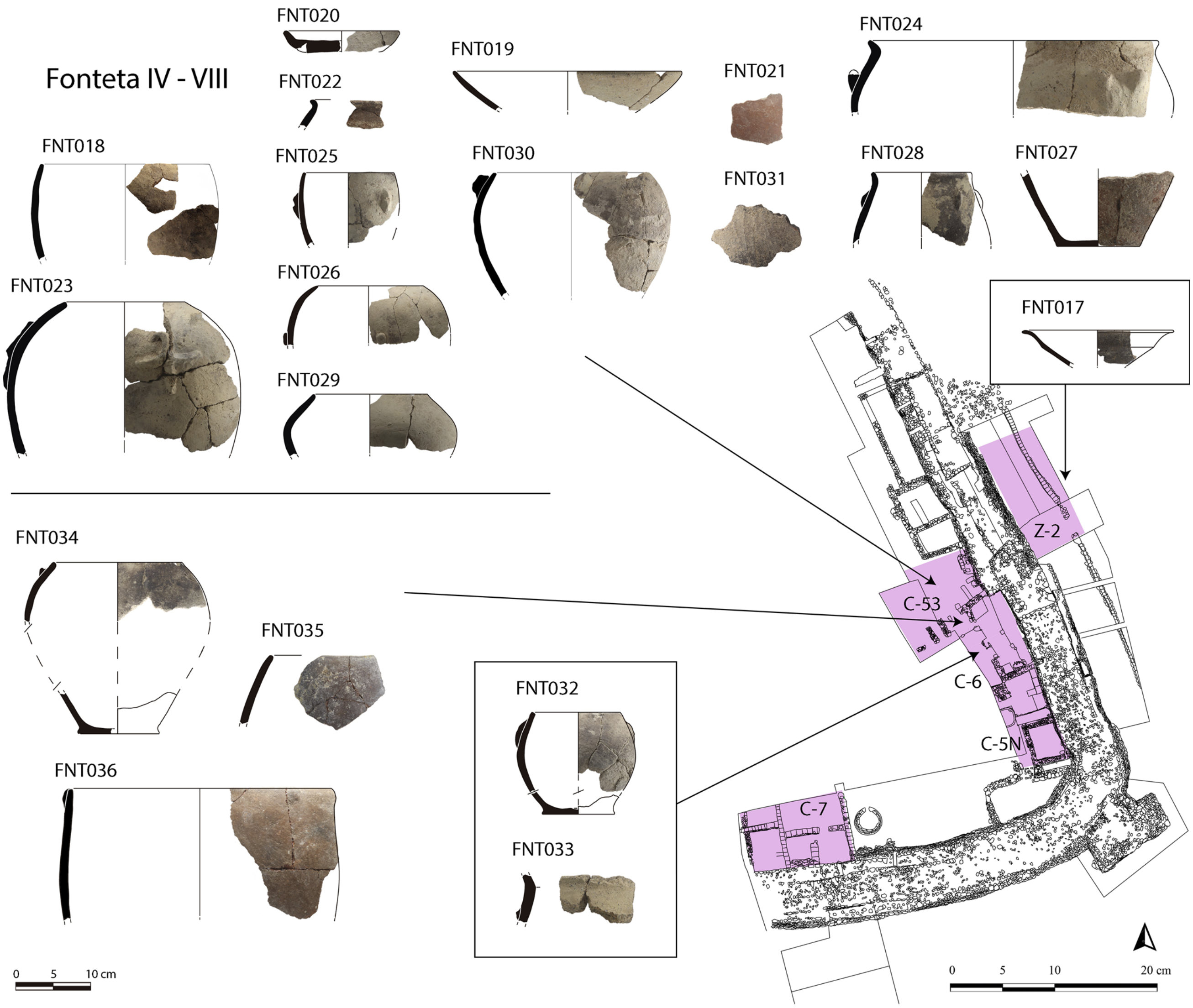

Fig. 3 Analised materials from Late Fonteta and recovery areas

traits such as buff-coloured pastes and coarse calcareous inclusions (González Prats 2011; Ortiz Temprado 2014), as well as other individuals considered imported (characterised by mica-rich red to dark coloured pastes) or underrepresented in the research carried out at the site so far. A summary of the samples and the techniques employed in each case can be found in Table 1, along with macroscopic assignments. Details on sample preparation and statistical methods are provided in the supplementary materials (Analytical and statistical methods).

Compositional grouping

The variation matrix was calculated based on all possible variances of the retained subcomposition with all possible alr transformations. This matrix measures the variability of the geochemical data, known as the total variability (*tv*) (Buxeda i Garrigós and Kilikoglou 2003). This matrix also provides information on the contribution of each determined element to the overall variability of the dataset (Figure 4). The elements that contribute the most to the variability are MnO ($tv/\tau_{.j} = 0.38$), Sr ($tv/\tau_{.j} = 0.37$), and especially CaO ($tv/\tau_{.j} = 0.09$). Conversely, the element with the lowest contribution to the variability is Nb ($tv/\tau_{.j} = 0.94$). The total variability obtained is very high ($tv = 4.51$), indicating the coexistence of multiple paste compositional reference units and, thus, a probable polygenic nature of the dataset (Buxeda i Garrigós and Kilikoglou 2003).

A hierarchical cluster analysis (HCA) was conducted using the clr transformation on the retained subcomposition (Figure 5). The dendrogram, created based on the squared Euclidean distance and the centroid agglomerative

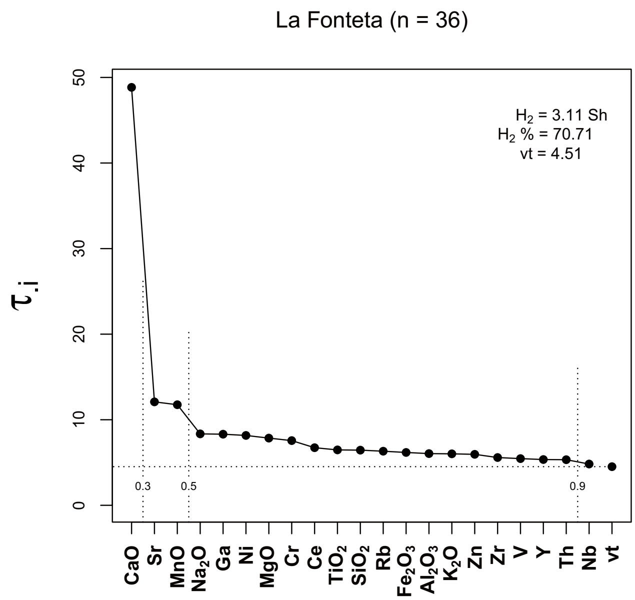

Fig. 4 Compositional evenness graph of the 36 individuals sampled. H_2: information entropy (in shanons, Sh); H_2%: percentage of the maximum possible attainable; *vt*: total variation; $\tau_{.j}$: sum of the variances following the alr transformation using element *j* as the divisor. Vertical dotted lines express different $tv/\tau_{.j}$ values

algorithm, reveals a complex structure that aligns with the high total variability observed. The fusion points predominantly occur at high ultrametric distances, resulting in clusters with few individuals.

The dendrogram's structure is heavily influenced by the significant role of CaO, with most individuals displaying compositions characteristic of calcareous and highly calcareous pastes situated in the left branch (5-6 % < CaO < 15-20 % and CaO > 15-20 %, respectively). However, only one individual from the second branch (FNT009, CaO = 7.61 %) exhibits normalised values exceeding 6 %, while the rest fall below 5 % and, in some cases, even lower than 1 %, corresponding to low calcareous ceramics (CaO < 5-6 %). Six groups were identified (Table 2). Additionally, six individuals were classified as outliers. Notably, the dispersion observed within the dataset is more prominent among samples with lower CaO concentrations.

The distribution of the samples and their relationship to the transformed values can be observed through the covariance and form biplots, which account for 80.97 % of the set's variability (Figure 6). These biplots are generated by applying singular value decomposition to the data with clr transformation and double centring, which involves subtracting the mean of each column from its respective values (Aitchison and Greenacre 2002; Greenacre 2010; van den Boogaart and Tolosana-Delgado 2013). In these graphical representations, it is evident that most samples exhibiting calcareous pastes display a positive trend along the first component, while those with lower CaO values are in negative positions. The biplots also reveal a substantial dispersion among calcareous and low-calcareous samples. There is a significant agreement between the chemical and petrographic groups, with ceramic pastes characterised by either carbonatic or siliceous components being distinctly separated.

The chemical group CGFNTG1 consists of five ceramic individuals, all from the earliest occupational phase of the site. Chemically, these samples are characterised by low concentrations of MgO and Na_2O (means of 1.02 % and 0.46 %, respectively) and very low concentrations of MnO (mean of 0.01 %) (Table 2). Petrographically (Supplementary material, petrographic descriptions) (Figure 7), these individuals display a yellowish to dark brown groundmass under plane-polarised light and a reddish-brown colour in FNT003 and FNT007. Voids in these samples are mainly planar, with some vesicles displaying dark rims, a sign of carbon diffusion. The coarse fraction primarily entails very coarse to medium sand-sized angular spathic calcite crystals. Typologically, the samples in this group consist of three cooking pots and two storage jars.

The largest group in the dataset, CGFNTG2, is characterised by high Sr values and can be further divided into three smaller clusters labelled CGFNTG2a (*n* = 2), CGFNTG2b (*n* = 7), and CGFNTG2c (*n* = 5), forming a gradient along the first component of the biplots (Table 2). The concentrations of several elements suggest that the chemical similarities are more apparent than real. Thus, an inverse trend between concentrations of Sr and CaO might suggest significant differences in the raw materials. The CGFNTG2 samples cover almost every typological category defined in the study.

CGFNTG2a is the most distinct subgroup and includes two individuals from the most recent occupation of the site. When corrected from the significant differences in CaO, these individuals exhibit higher Na_2O, Ga and Cr concentrations than the other subclusters. CGFNTG2b consists of seven individuals, most of whom date back to the most recent occupation phase, except for one sample (FNT008) from the earlier one, which shows a lower degree of similarity. Generally, high MgO values characterise these samples. CGFNTG2c displays higher CaO values than the other two subclusters and, once corrected from CaO differences, by higher Nb, Y and Th values.

The ceramic individuals assigned to Group CGFNTG2 correspond to different petrographic fabrics. The correlation between petrographic and chemical composition is clearer within the proposed subgroups, but some overlap is still observed.

According to petrography, FNT018, FNT024, and FNT028 (CGFNTG2b), as well as FNT033 (CGFNTG2c), form a group of samples characterised by the presence of angular spathic calcite crystals as the primary component of

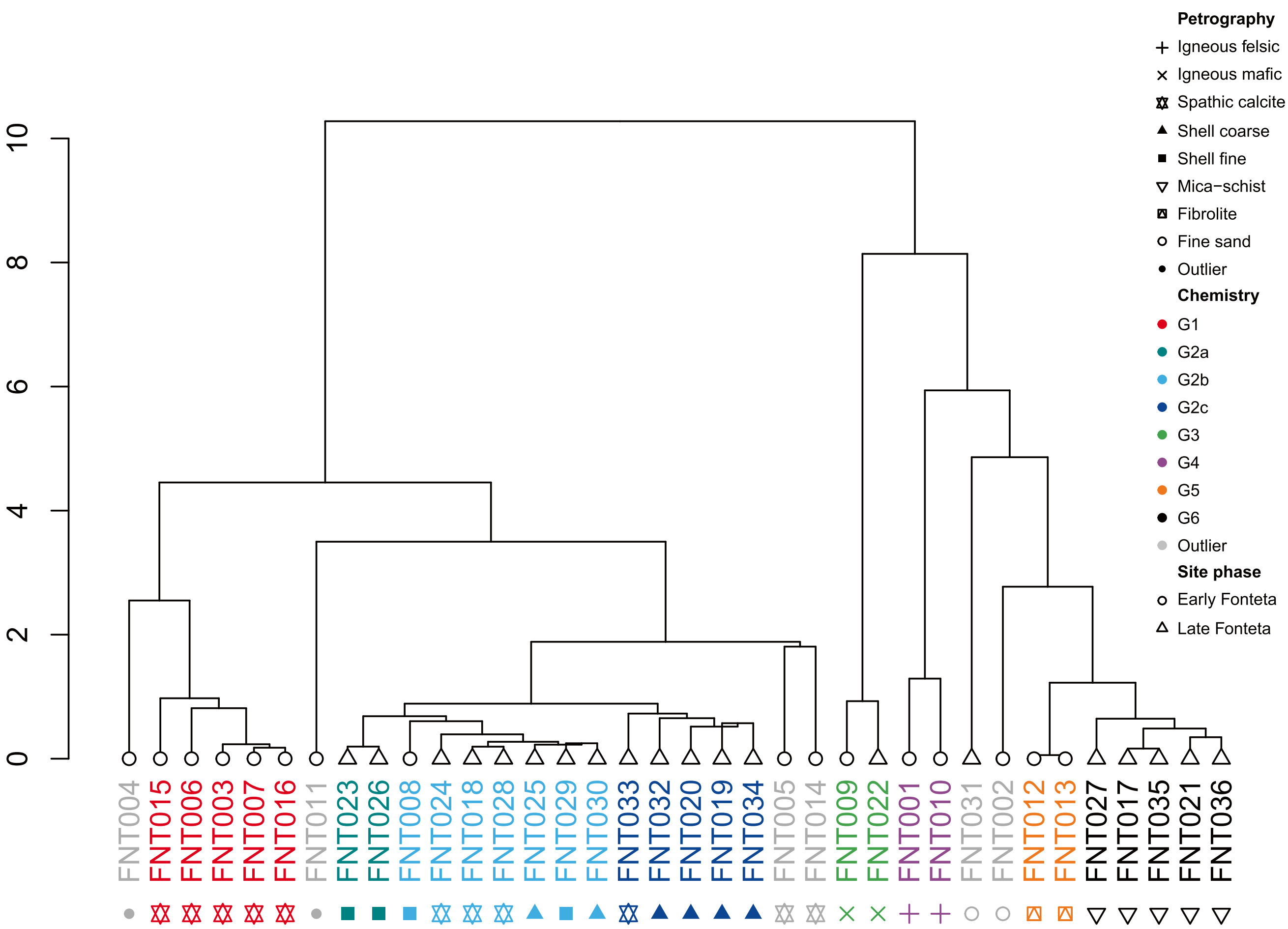

Fig. 5 Dendrogram resulting from the HCA on the clr-transformed subcomposition Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, V, Cr, MnO, Fe_2O_3, Ni, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ce, and Th. Symbols represent petrographic groups described in the text and Table 1

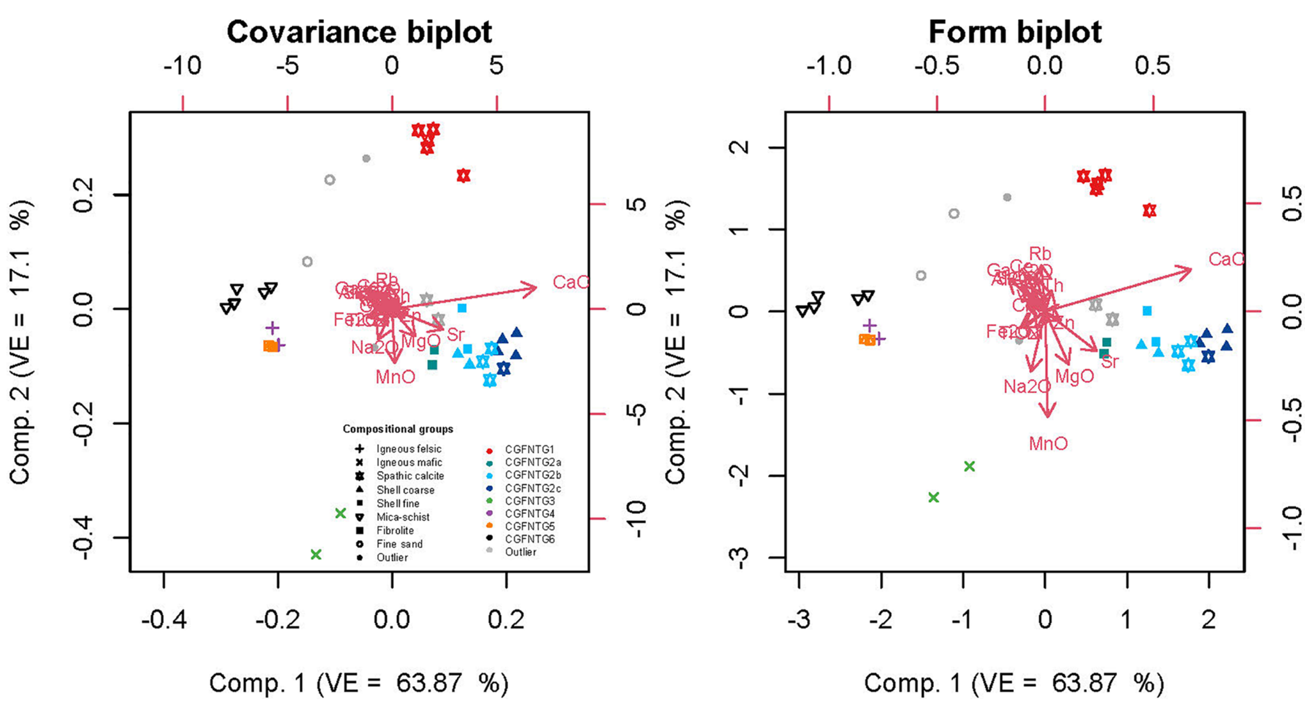

Fig. 6 Covariance and form biplots. Symbols correspond to petrographic fabrics described in the text and Table 1. VE: explained variability

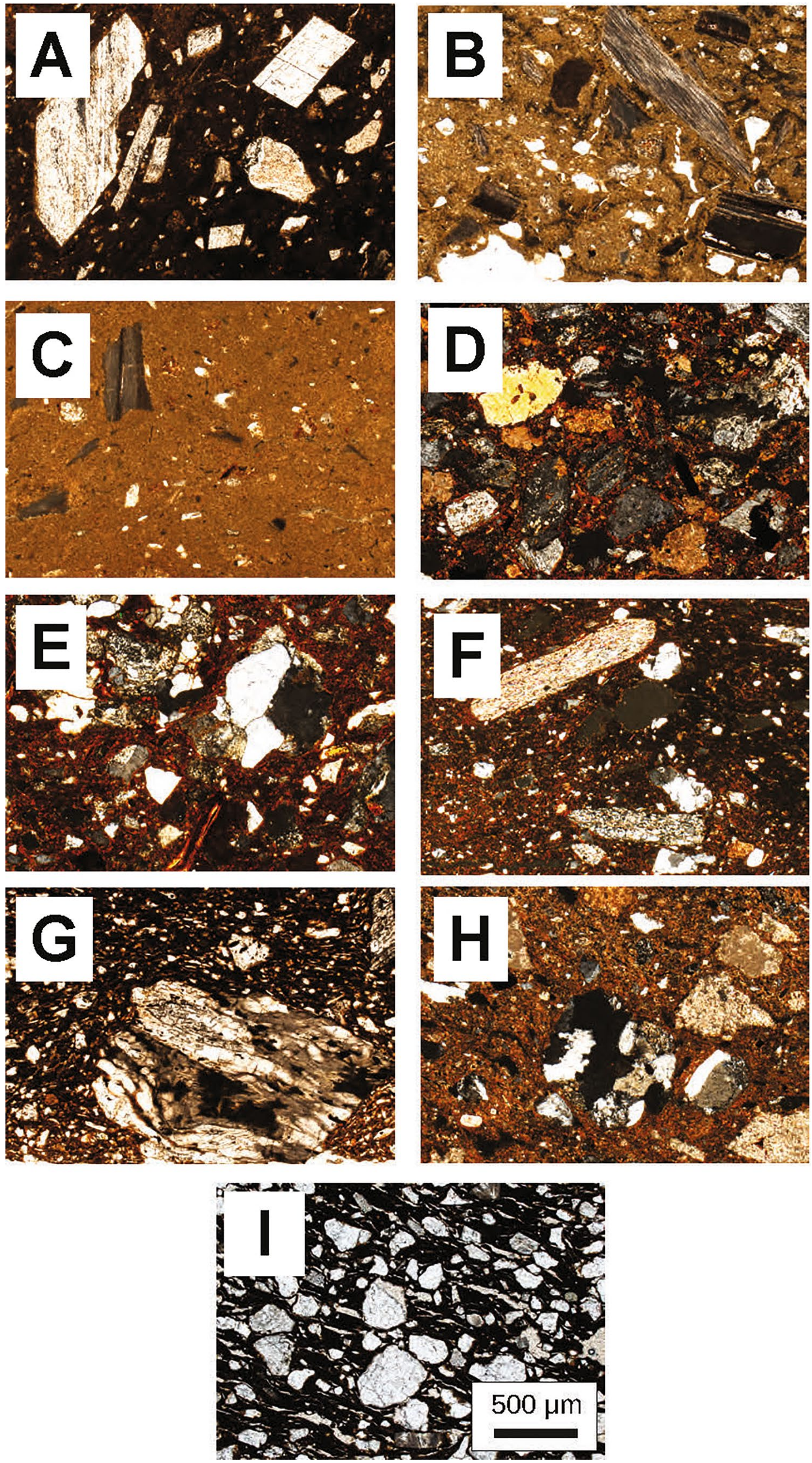

Fig. 7 Main petrographic fabrics. **A**: Calcareous (spathic calcite) (PPL). **B**: Calcareous (shell fragments), coarse (PPL). **C**: Calcareous (shell fragments), fine (PPL). **D**: Igneous (mafic) (XP). **E**: Igneous (felsic) (XP). **F**: Metamorphic (Phyllite and mica-schist) (XP). **G**: Metamorphic (fibrolite) (PPL). **H**: Calcareous (fossiliferous limestone) (XP). **I**: Low calcareous (sand quartz) (PPL)

the coarse fraction. Notably, a very fine to silty detrital fraction consisting mainly of quartz and white mica is present and differentiates these individuals from those included in CGFNTG1. This fine fraction includes rare opaque materials, which may be stained fragments of bioclasts. Another distinctive feature of these samples is their heterogeneous matrix, which is yellowish-brown with reddish patches and stripes of iron-rich material. Crystal depletion features are also observed. Typologically, this fabric includes two cooking pots and two storage jars.

CGFNTG2 includes another petrographic group consisting of FNT023, FNT026 (CGFNTG2a) and FNT008 and FNT029 (CGFNTG2b). The ceramic pastes of these individuals contain a coarse fraction composed of medium to fine sand-sized grains, with quartz and argillaceous inclusions as the main components. The argillaceous inclusions exhibit higher optical density than the surrounding matrix, formed by reddish, iron-rich fine material along with fragments of metamorphic rock and related mineral inclusions. The amount and size of these argillaceous inclusions are notably higher in FNT023. As with the remaining samples assigned to CGFNTG2, the groundmass of these ceramics is fine and associated with a carbonatic fine fraction consisting of shell fragments and characteristic crystal depletion features that resemble the one described for the previous four individuals. Samples from this fabric include two cooking pots, one storage jar and characteristic *à chardon* vessel.

Samples FNT025, FNT030 (CGFNTG2b), FNT0019, FNT020, FNT032 and FNT034 (CGFNTG2c) belong to the same petrographic group characterised by a similar groundmass and fine fraction. In this case, the coarse fraction primarily comprises shell fragments that fall within the coarse and very coarse sand grain size categories. However, the amount of coarse fraction varies significantly between samples, representing about 30 % of the thin section surface in individuals assigned to CGFNTG2c, while it is reduced to around 5 % in individuals assigned to the chemical subcluster CGFNTG2b. Other components of the coarse fraction include variable amounts of quartz, epidote, white mica, and argillaceous inclusions. All the individuals included in this fabric are cooking pots.

CGFNTG3 consists of two individuals from different occupational phases (FNT009 and 022, from Early and Late Fonteta, respectively). These individuals exhibit a relatively uniform chemical pattern, with elevated Fe_2O_3, MgO, Nb, V, Ni, and Cr values, and especially MnO (mean 0.17 %), TiO_2 (mean 2.29 %) and Na_2O (mean 3.61 %), explaining their position at the far negative side of principal component 2 (Figure 6). The last two values are highly atypical in ceramic compositions and must be related to special raw materials. Conversely, Rb concentrations are the lowest in the dataset, along with low levels of Th and CaO. The latter element shows significant variations between the two individuals. The chemical characteristics of samples in CGFNTG3 can be readily attributed to the prevalence of basic igneous rocks and associated minerals within a low-calcareous reddish-brown to dark-brown silty groundmass.

The main inclusions within the samples can be quite coarse, often reaching sand-sized or even coarser dimensions. These inclusions encompass feldspar crystals with varying degrees of alteration, commonly plagioclase, and fragments of basic igneous rocks. These igneous rock fragments exhibit a holocrystalline texture and are composed of feldspar, serpentinite, clinopyroxene, and opaque minerals. Quartz and variable amounts of serpentinite and clinopyroxene aggregates are also discrete inclusions. Additionally, subordinate percentages of opaque minerals, brown mica, and olivine were detected—the latter, mainly in FNT022.

It is worth noting that ferromagnesian minerals appear fresher in FNT022, while FNT009 exhibits a higher abundance of serpentinite aggregates and opaque particles, likely indicating differences in the level of alteration of the parent rock. FNT009 also contains a few micritic lumps, which are absent in FNT022. Petrographic observations could be linked to the notable difference in CaO content and explain the relatively high percentage of CaO detected in FNT009, which is the highest among the low-calcareous samples. SEM-EDS mapping of the polished thin section showed that Na_2O (3.76 % - 3.86 %) and MgO (4.00 % - 4.46 %) levels are connected to the presence of feldspar and serpentinite, respectively (Figure 8). Typologically, the sherds correspond to one storage jar and one cooking pot.

CGFNTG4 contains two individuals from the first occupation (Early Fonteta). CGFNTG4 entails a substantial chemical variability as reflected by the largest total variation (tv = 0.67), though high Ce and Na_2O, relatively high SiO_2, and very low Ni and Cr values are distinctive against the rest of the set (Table 2). Chemical affinity is probably connected to their common geological nature. Thin sections show a reddish silty groundmass where elongated planar and connected vughs are the most common voids. The coarse fraction is formed mainly by medium to very coarse sand particles formed by common to dominant granitoid lithic fragments, including quartz, altered feldspars (sericite), biotite, amphibole, opaques and epidote. Mineral inclusions are compatible with the lithics, mainly quartz, heavily altered feldspar (alkali feldspar and less commonly plagioclase), epidote, brown and white mica and amphibole. Although rare, iron-rich argillaceous inclusions exhibiting higher optical density than the groundmass with clear boundaries have been detected. Typologically, the group is formed by ceramic types related to culinary preparations, a "*lebrillo*" and a cooking pot.

CGFNTG5 entails two other cooking pots from the earlier occupation (Fonteta Arcaica). From the chemical point of view, it is important to highlight the high Al_2O_3, Y and Ga concentrations, containing some of the higher for those

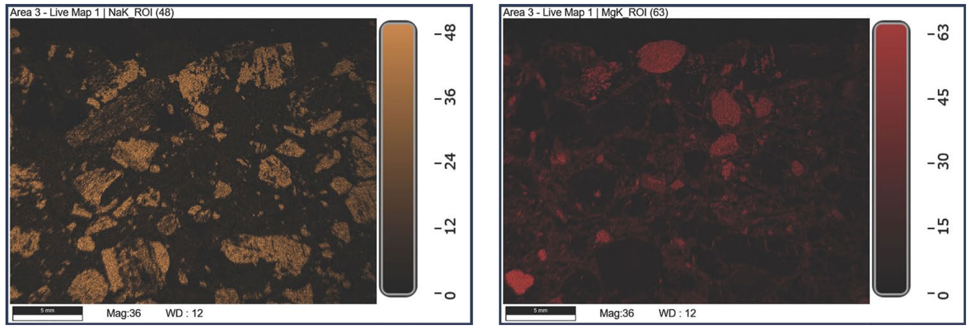

Fig. 8 Representative SEM-EDS images of CGFNTG3 and basic igneous fabric. Bright crystals in yellow correspond to felspars. Brighter particles in reddish hues are fibrous alteration products identified as serpentinite

elements, but also the significant high Sr content (Sr mean 402 mg/kg) for low calcareous materials (CaO mean 1.86 %). Under the optical microscope, these samples are formed by a red-brown to dark-brown groundmass with pores that show dark rims due to carbon diffusion in a limited number of cases. Grain size distribution is slightly bimodal and predominates fine to very fine sand, but lithic inclusions commonly fall in the very coarse sand and larger categories. Regarding the composition, the presence of metamorphic rock fragments with sillimanite is characteristic; other components of the rock fragments are quartz, white mica, opaques and, less commonly, kyanite and andalusite. Mineral inclusions are possibly connected to the mineralogy of lithic fragments, with frequent quartz and white mica and subordinate quantities of feldspar (including crystals with plagioclase twinning), opaques and andalusite. Scarce remnants of carbonatic material are also observable.

The last defined group, CGFNTG6, comprises five individuals from the most recent phase. This group stands out due to its high concentrations of V, which are the highest in the set (Table 2). All the samples in CGFNTG6 share a homogeneous petrographic composition, displaying low-grade metamorphic rocks. Under the microscope, they exhibit a reddish-brown groundmass. Some individuals have a relatively massive structure, with up to 2 % porosity levels. The coarse fraction primarily consists of abundant quartz and variable amounts of rock fragments such as phyllite, quartzite, and schist, exhibiting lepidoblastic and crenulated textures. These rock fragments contain quartz, white and brown mica, and opaque minerals. Although a few micrite lumps were observed in FNT010, FNT027, and FNT029, their presence does not have a clear correlation with differences in CaO content. The samples in this group include an unclassified sherd and three fragments representing different functional categories: a cooking pot, two storage jars, and one bowl likely used for food consumption.

Six individuals were identified as outliers, most from the earliest occupation phase (Fonteta Arcaica). Only one sample (FNT031) was recovered from levels formed after the construction of the city wall (Late Fonteta). These outliers exhibit significant differences in their composition, as indicated by their positions in both the cluster and biplot analyses. Petrographically, these samples display marked variations in the proportion of carbonatic material.

Among the carbonate-rich individuals, one sample (FNT004) is composed of metamorphic rocks and fragments of fossiliferous limestone. FNT011 is another chemical and petrographic outlier, with its coarse fraction mainly composed of quartz, mica-schist, calcite and bioclasts. The limestone fragments and spathic calcite crystals in FNT011 appear cloudy, possibly due to firing. FNT005 and FNT014 were clustered together as part of the same fabric (spathic calcite), although they are classified as chemical outliers. From the chemical point of view, even if they share a similar general trend, significant differences also exist. In both highly calcareous ceramics (CaO 26.18 % and 21.58 %, respectively), the Sr content shows a surprising inverse trend (Sr 289 mg/kg and 673 mg/kg, respectively). The low-calcareous outliers (FNT002 and FNT031) exhibit good sorting, with a quartz-rich coarse fraction predominantly ranging from fine to medium sand size, as expected from well-developed sediments or grain-size control strategies. In terms of typology, most of the outlier samples are cooking pots. One of the samples, FNT005, is a storage jar.

XRD results

Mineralogy was further examined using X-ray diffraction (XRD) techniques. This method offers valuable insights into the technology employed, particularly the firing process, and potential signs of alteration. Estimating the firing temperature is crucial for understanding the transformation of mineral phases in the original ceramic body. This transformation depends on various factors, including the composition of the ceramic paste (especially carbonate content), the temperature reached, soaking time, oxidation regime, and heating rate (Livingstone Smith 2001; Thér 2014). Due to the lack of complete information, these estimates are made by comparing experimental programs and available ethnoarchaeological data. Moreover, the many factors influencing the firing that cannot be assessed oblige to estimate the equivalent firing temperature (EFT) and not the firing temperature, *i.e.*, the firing temperature at which the observed characteristics will happen in some controlled conditions (Roberts 1963).

The data obtained from these observations are also relevant for discussing the technical properties of ceramic wares during their lifespan. Physical attributes such as the hardness and toughness of the pottery walls depend on the matrix's texture and degree of sintering (Müller et al. 2010, 2015). These properties play a crucial role in using ceramics as cooking or transport vessels, as they determine thermal and mechanical stress resistance. Other characteristics influenced by firing include the surfaces' final colour and weight, which impact how the vessels are perceived and handled (Walker and Schiffer 2006).

Chemical data provides initial insights into mineralogy and technology. The ternary phase diagram (Figure 9A) illustrates the differentiation between calcareous and highly calcareous ceramics against low calcareous samples. Individuals labelled with chemical associations CGFNTG4, CGFNTG5 and CGFNTG6 are low calcareous ceramics around the limit between the Qz-An-Mul and Qz-An-Wo thermodynamic equilibrium triangles (abbreviations according to Warr 2021). In contrast, samples in CGFNTG3 and four ungrouped individuals are depicted within the latter's limits, corresponding to calcareous ceramics. The remaining samples are distributed across different subsystems along the increasing (Fe_2O_3 + MgO + CaO) axis. There is a compositional gradient between coarse shell-tempered samples (most of CGFNTG2c), closer to the (Fe_2O_3 + MgO + CaO) tip, partially overlapping with calcite-tempered individuals (CGFNTG2b) in the upper range. Other samples from CGFNTG2 and CGFNTG1 that straddle between two subsystems contain typically finer shell fragments, quartz, limestone, and argillaceous inclusions as the main components of the coarse fraction, for CGFNTG2a, and spathic calcite, for CGFNTG1.

As expected, none of the samples are in a state of thermodynamic equilibrium since ceramics are complex systems where equilibrium is only locally achieved (Heimann and Maggetti 2014). The presence of mineral phases within specific fields on the plot would increase with firing

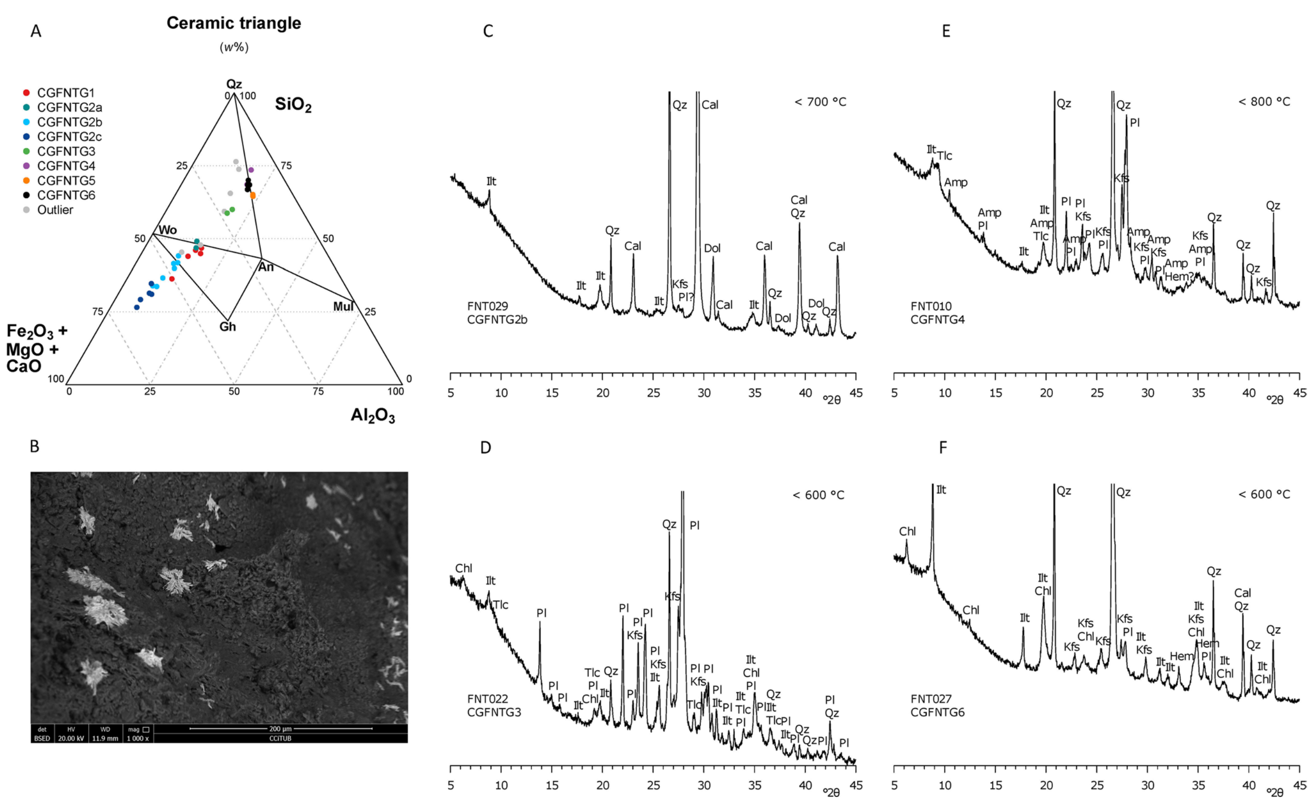

Fig. 9 **A**: Phase diagram of the ternary system (Fe_2O_3 + MgO + CaO)-Al_2O_3-SiO_2 (ceramic triangle) showing the situation of the individuals analysed. **B**: Photomicrograph by SEM of the individual FNT023 (group CGFNTG2a) using the backscattered detector showing authigenic crystals of baryte. C to F: XRD patterns for the categories of association of crystalline phases as detected by XRD. **C**: individual FNT029 XRD pattern CGFNTG2b-1. **D**: individual FNT022 XRD pattern CGFNTG3-1. **E**: individual FNT010 XRD pattern CGFNTG4-1. **F**: individual FNT027 XRD pattern CGFNTG6-1. Amp: Amphibole; An: anorthite; Chl: chlorite; Dol: dolomite; Gh: gehlenite; Hem: hematite; Ilt: illite (illite-muscovite); Kfs: K-feldspar; Mul: mullite; Pl: plagioclase; Qz: quartz; Tlc: talc; Wo: wollastonite (abbreviations, according to Warr 2021)

Table 1 Table of studied individuals, applied techniques, compositional groups, macroscopic groups, archaeological classification and site phase. (In petrographic fabric) *: outlier. (In macroscopic group) ES: sedimentary inclusions-rich ceramic paste; EM: metamorphic inclusions-rich ceramic paste. Ceramic types according to Ortiz Temprado (2014) and Vinader Antón (2022)

	XRF	OP	XRD	SEM	Chemical group	Petrographic fabric	Macroscopic group	Ceramic type	Phase
FNT001	x	x	x	x	CGFNTG4	Igneous felsic	OTHER	A5a2	Early
FNT002	x	x	x		Outlier	Sand quartz*	ES	B3	Early
FNT003	x	x	x		CGFNTG1	Spathic calcite	ES	A7a2	Early
FNT004	x	x	x		Outlier	Fossiliferous limestone*	ES	A3/A6	Early
FNT005	x	x	x		Outlier	Spathic calcite	ES	A7	Early
FNT006	x	x	x		CGFNTG1	Spathic calcite	ES	A3b2b	Early
FNT007	x	x	x		CGFNTG1	Spathic calcite	ES	A1e	Early
FNT008	x	x	x		CGFNTG2b	Shell fragments	ES	A10	Early
FNT009	x	x	x	x	CGFNTG3	Igneous mafic	OTHER	A7b2	Early
FNT010	x	x	x		CGFNTG4	Igneous felsic	OTHER	A3/A6	Early
FNT011	x	x	x		Outlier	Bioclasts*	ES	A6b2c	Early
FNT012	x	x	x		CGFNTG5	Fibrolite	EM	A	Early
FNT013	x	x	x		CGFNTG5	Fibrolite	EM	A3b1b	Early
FNT014	x	x	x		Outlier	Spathic calcite	ES	A6a2b	Early
FNT015	x	x	x		CGFNTG1	Spathic calcite	ES	A3a2b	Early
FNT016	x	x	x		CGFNTG1	Spathic calcite	ES	A7	Early
FNT017	x	x	x		CGFNTG6	Phyllite	EM	B5b	Late
FNT018	x	x	x		CGFNTG2b	Spathic calcite	ES	A2a	Late
FNT019	x	x	x		CGFNTG2c	Shells fragments	ES	A4a3	Late
FNT020	x	x	x		CGFNTG2c	Shells fragments	ES	A4b1	Late
FNT021	x	x	x		CGFNTG6	Phyllite	EM	A	Late
FNT022	x	x	x		CGFNTG3	Igneous mafic	OTHER	A3b1e	Late
FNT023	x	x	x	x	CGFNTG2a	Shell fragments	ES	A7c3	Late
FNT024	x	x	x		CGFNTG2b	Spathic calcite	ES	A7d2	Late
FNT025	x	x	x		CGFNTG2b	Shell fragments	ES	A1a	Late
FNT026	x	x	x		CGFNTG2a	Shell fragments	ES	A2b	Late
FNT027	x	x	x	x	CGFNTG6	Phyllite	EM	A	Late
FNT028	x	x	x		CGFNTG2b	Spathic calcite	ES	A3a1b	Late
FNT029	x	x	x		CGFNTG2b	Shell fragments	ES	A2c	Late
FNT030	x	x	x		CGFNTG2b	Shell fragments	ES	A2a	Late
FNT031	x	x	x		Outlier	Sand quartz*	ES	A	Late
FNT032	x	x	x		CGFNTG2c	Shell fragments	ES	A2a	Late
FNT033	x	x	x		CGFNTG2c	Spathic calcite	ES	A7a	Late
FNT034	x	x	x		CGFNTG2c	Shell fragments	ES	A2b	Late
FNT035	x	x	x		CGFNTG6	Phyllite	EM	A7c2	Late
FNT036	x	x	x		CGFNTG6	Phyllite	EM	A7c2	Late

temperature, limited by short diffusion distances and soaking times. However, there is a clear distinction between calcareous and low calcareous samples, with a compositional gradient to highly calcareous observed mainly in CGFNTG1 and CGFNTG2. The identification of primary phases and firing phases enables the establishment of mineralogical scales to estimate equivalent firing temperatures (EFT).

Group CGFNTG1 includes five individuals in two XRD patterns, *i.e.*, in two different associations of crystalline phases by XRD (Table 3). The difference between both patterns is the presence or absence of chlorite. XRD pattern 1, with one individual, exhibits chlorite, together with calcite, illite-muscovite, K-feldspar and quartz. The estimated EFT is below 600 °C since chlorite destabilisation typically begins at 550 °C-580 °C, although, in some cases, the complete or near-complete decomposition occurs at 700 °C-750 °C (Jornet 1983; Gliozzo 2020). XRD pattern 2, with four individuals, exhibits the same association except for chlorite, and therefore, the EFT must be estimated to be over 600 °C. The upper limit of this estimation must be 800/850 °C,

Table 2 Mean ($\overline{X}$) and standard deviation (s) of the defined groups on normalised data. LOI: loss on ignition. *tv*: total variation (LOI was not considered when calculating *tv*). Major and minor elements are expressed as oxides in *w*%. Trace elements are expressed in *w* mg/kg. LOI is expressed in *w*%

	CGFNTG1 (*n* = 5) (*tv* = 0.41)		CGFNTG2a (*n* = 2) (*tv* = 0.10)		CGFNTG2b (*n* = 7) (*tv* = 0.26)		CGFNTG2c (*n* = 5) (*tv* = 0.45)		CGFNTG3 (*n* = 2) (*tv* = 0.45)		CGFNTG4 (*n* = 2) (*tv* = 0.67)		CGFNTG5 (*n* = 2) (*tv* = 0.03)		CGFNTG6 (*n* = 5) (*tv* = 0.31)	
	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s	$\overline{X}$	s
Na_2O	0.46	0.05	1.24	0.03	0.76	0.08	0.45	0.08	3.61	0.14	1.91	0.39	1.67	0.02	0.83	0.16
MgO	1.02	0.20	2.67	0.09	2.62	0.27	1.97	0.11	4.02	0.40	1.63	0.37	2.12	0.04	1.71	0.08
Al_2O_3	11.46	1.50	11.29	0.34	7.71	1.03	5.69	0.76	16.44	0.91	17.03	0.59	20.74	0.28	17.82	0.57
SiO_2	32.17	3.88	36.57	1.68	27.24	3.55	20.45	2.37	51.36	1.95	64.05	4.06	58.05	0.27	61.27	0.90
K_2O	2.30	0.44	2.38	0.23	1.81	0.28	1.28	0.18	2.12	0.14	3.29	1.08	2.46	0.15	3.18	0.16
CaO	26.50	3.66	21.45	0.23	29.54	3.05	36.39	1.93	5.85	1.77	1.75	0.50	1.86	0.11	1.46	0.59
TiO_2	0.43	0.04	0.50	0.06	0.37	0.05	0.28	0.04	2.29	0.10	0.70	0.16	0.85	0.00	0.71	0.01
V	70	13	84	5	55	7	43	10	131	6	95	37	110	1	127	4
Cr	47	6	58	6	37	5	28	5	165	17	23	6	86	1	96	2
MnO	0.01	0.00	0.06	0.01	0.04	0.01	0.04	0.01	0.17	0.04	0.06	0.00	0.04	0.00	0.04	0.00
Fe_2O_3	2.49	0.55	4.21	0.50	3.00	0.37	2.32	0.55	8.81	0.47	5.65	1.38	6.78	0.03	7.15	0.31
Ni	18	6	33	4	23	4	14	4	60	4	7	1	44	1	44	1
Zn	62	15	80	15	61	6	46	4	122	49	60	15	78	6	49	6
Ga	12	3	12	0	7	1	4	1	17	1	20	1	24	1	20	1
Rb	91	14	88	8	68	8	52	4	51	1	104	10	111	4	116	3
Sr	284	69	782	16	645	95	649	224	553	151	251	40	402	10	231	57
Y	15	1	20	1	14	2	11	1	17	1	22	5	29	1	24	1
Zr	102	14	124	6	89	10	83	16	183	2	136	7	164	3	192	9
Nb	15	1	16	1	14	1	12	1	37	1	18	2	20	0	19	1
Ce	45	6	49	1	31	9	22	3	49	6	87	7	62	5	64	6
Th	14	1	16	0	13	1	12	2	13	1	20	2	16	1	17	1
LOI	23.08	2.48	19.49	0.71	26.80	2.06	31.04	1.69	5.19	2.10	3.84	1.75	5.31	0.08	5.73	0.62

in which, for CaO-rich ceramics, calcite is usually decomposed, and calcium oxide acts as a flux to promote phase reactions and the appearance of firing phases. According to experimental data, the effects of calcite transformation into lime become evident at 700 °C, with generally lower intensity peaks. Complete decomposition typically occurs around 800 °C (Maggetti 1982). However, coarse and well-crystallised spathic calcite, as identified in some samples, especially in groups CGFNTG1 and CGFNTG2b, can withstand firing temperatures up to 900 °C (Cultrone et al. 2001). In these cases, the coarse crystals start exhibiting cracks and reaction rims visible through optical microscopy at temperatures around 700 °C - 780 °C. The absence of typical firing calcium and calcium-aluminium silicates in calcareous ceramics enables us to infer an EFT between 600 °C and 800/850 °C.

Group CGFNTG2a, with only two individuals, also exhibits two different patterns (Table 3). Compared with the previous group, CGFNTG2a is characterised by the same phases as previously, with the addition of plagioclase and dolomite. XRD pattern 1 exhibits the presence of chlorite, and the estimated EFT is below 600 °C. It also exhibits the presence of hematite. In the presence of carbonatic material, hematite reflections can be detected from 500 °C onwards, becoming more apparent in XRD at higher temperatures, especially if dolomitic material is also present in the ceramic body (Trindade et al. 2009). Following chlorite decomposition, the released iron from this phase contributes to the formation of hematite between 750 °C-850 °C (Nodari et al. 2007). Nevertheless, hematite, as a firing phase, is typically observed at temperatures above 800 °C, and it is challenging to infer whether it is a primary phase in this pattern. XRD pattern 2 lacks hematite and chlorite. The absence of the latter suggests an EFT over 600 °C. Moreover, the presence of dolomite also indicates an EFT below 700 °C when thermal decomposition is believed to conclude (Gliozzo 2020).

The seven individuals of group CGFNTG2b exhibit the same pattern (1), which is characterised by the presence of dolomite, calcite, illite-muscovite, K-feldspar, quartz and, possibly, plagioclase, suggesting an EFT below 700 °C (Table 3). This is consistent with the NV (non-vitrification) stage observed by SEM for the individual FNT023,

Table 3 Summary of the mineralogical patterns defined by PXRD analysis for each of the six chemical groups and loners. Mineral phase names abbreviations: Amp: amphibole; Cal: calcite, Chl: Chlorite; Dol: dolomite; Kfs: F-feldspar, Hem: hematite, Ilt: illite (illite-muscovite), Pl: plagioclase, Qz: quartz (according to Warr 2021). SEM: individual studied by SEM

Chemical group	XRD pattern	Mineral phases	Individuals	EFT (°C)
CGFNTG1	1	Chl, Cal, Ilt, Kfs, Qz	FNT016	< 600
	2	Cal, Ilt, Kfs, Qz	FNT003, 006, 007, 015	600–800/850
CGFNTG2a	1	Chl, Dol, Cal, Hem, Ilt, Kfs, Pl, Qz	FNT026	< 600
	2	Dol, Cal, Ilt, Kfs, Pl, Qz	FNT023^{SEM}	< 700
CGFNTG2b	1	Dol, Cal, Ilt, Kfs, Pl (?), Qz	FNT008, 018, 024, 025, 028, 029, 030	< 700
CGFNTG2c	1	Dol, Cal, Ilt, Kfs, Pl, Qz	FNT019, 020, 032, 033, 034	< 700
CGFNTG3	1	Chl, Tlc, Ilt, Kfs, Pl, Qz	FNT022	< 600
	2	Tlc, Cal, Hem, Ilt, Kfs, Pl, Qz	FNT009^{SEM}	600–800
CGFNTG4	1	Amp, Tlc, Hem (?), Ilt, Kfs, Pl, Qz	FNT010	< 800
	2	Amp (?), Tlc (?), Hem, Ilt, Kfs, Pl, Qz	FNT001^{SEM}	800/850–900/950
CGFNTG5	1	Hem, Ilt, Kfs, Pl, Qz	FNT012, 013	< 900/950
CGFNTG6	1	Chl, Hem, Ilt, Kfs, Pl, Qz	FNT027^{SEM}	< 600
	2	Chl, Cal, Hem, Ilt, Kfs, Pl, Qz	FNT021, 035, 036	< 600
	3	Cal, Ilt, Kfs, Pl, Qz	FNT017	600–800/850
Outliers	1	Chl, Dol, Cal, Ilt, Kfs, Qz	FNT004	< 600
	1	Cal, Ilt, Kfs, Pl, Qz	FNT011	< 800/850
	1	Dol, Cal, Ilt, Kfs, Qz	FNT005	< 700
	1	Tlc, Cal, Hem, Ilt, Kfs, Pl, Qz	FNT014	< 800
	1	Cal, Ilt, Qz	FNT031	< 900/950
	1	Cal, Ilt, Kfs, Pl, Qz	FNT002	< 900/950

which points to an EFT < 750 °C (Maniatis and Tite 1981). Moreover, the study of this individual by SEM has enabled the identification of crystals of authigenic secondary baryte (Figure 9B). It must be highlighted that FNT023 has the highest concentration of Ba (1540 mg/kg, Supplementary material, Table 2), which is the result, in part, of the enrichment of allochthonous barium. The high concentrations of Ba determined in many individuals are possibly due to an extensive crystallisation of secondary barite as observed in other case studies (see, for example, Miguel Gascón and Buxeda i Garrigós 2013).

The five individuals in group CGFNTG2c are also classed in the only observed pattern (1), which has an association of crystalline phases similar to the previous group (Table 3). The EFT is estimated at < 700 °C after the presence of well-developed peaks of dolomite (Figure 9C).

In the previous calcareous groups, the presence of primary phases that decompose at low firing temperatures and the absence of firing phases in calcareous pottery have demonstrated a clear trend in using low firing temperatures. In the remaining groups of low-calcareous ceramics, the presence of calcite, if present, is always witnessed with very weak peaks.

Group CGFNTG3 comprises two individuals defining two different XRD patterns (Table 3). The first one (1) exhibits chlorite, talc, illite-muscovite, K-feldspar, plagioclase and quartz (Figure 9D). The peaks of talc are weak, and its identification is not easy. Talc is thermally decomposed at 800 °C when transformed into enstatite (Liu et al. 2014; Maritan et al. 2018). The estimated EFT is at < 600 °C after the presence of chlorite. XRD pattern 2 does not exhibit the presence of chlorite, and the EFT must be over 600 °C. Moreover, it exhibits calcite and hematite. The absence of clear firing phases might suggest an EFT below 800 °C, but this individual shows, by SEM, an NV stage pointing to an EFT < 750 °C.

Group CGFNTG4 is also composed of two individuals classed in two different patterns (Table 3). XRD pattern 1 is characterised by amphibole and talc, together with illite-muscovite, K-feldspar, plagioclase, quartz and possibly hematite (Figure 9E). The EFT must be estimated at < 800 °C because of talc. In the case of XRD pattern 2, the EFT could be estimated at a slightly higher temperature because the presence of talc and amphibole is not sure, while the presence of hematite is clear. However, the EFT can be estimated at < 750 °C because the study of individual FNT001 by SEM shows an NV stage.

The two individuals in group CGFNTG5 do not show primary phases that decompose at low firing temperatures but do not exhibit clear firing phases (Table 3). Thus, the EFT estimated for this pattern must be at < 900/950 °C, when we could expect spinel formation after its chemical composition (Table 3). The intensity of illite-muscovite peaks is acknowledged in all the samples but is particularly high in these individuals, possibly due to the metamorphic geology of the group and the abundance of mica observed during petrographic analysis.

The last defined group, CGFNTG6, comprises five individuals classed in three patterns (Table 3). XRD patterns 1 (with one individual) and 2 (with three individuals) exhibit the presence of chlorite, hematite, illite-muscovite, K-feldspar, plagioclase and quartz (Figure 9F), and, in pattern 2, also calcite. After the presence of chlorite, the estimated EFT is at < 600 °C in good agreement with the NV stage observed in individual FNT027 (pattern 1). The last individual is classed in XRD pattern 3, which differs from pattern 2 by the absence of calcite and hematite. Without clear firing phases, the EFT must be estimated above 600 °C and below 900/950 °C.

The previous results clearly show that low-calcareous ceramics can also be associated with low firing temperatures. The study of the outliers also revealed the use of low firing temperatures for calcareous and low-calcareous ceramics because of the absence of firing phases reinforced by the presence of chlorite (FNT004), dolomite (FNT004 and FNT005) and talc (FNT014) (Table 3). In the case of individual FNT011, the petrographic observation revealed the cloudy appearance of spathic calcite that can be related to cracks and reaction rims developed in coarse calcite crystals at temperatures around 700 °C - 780 °C (Gliozzo 2020).

Provenance

The chemical and petrographic composition of the ceramics from La Fonteta does not always align with the geological environment of the site. The settlement is positioned within a coastal Holocene dune massif, which largely overlays the Pliocene bedrock of sandstone and calcarenite that can be observed along the southern bank of the Segura River, with some presence north of its course. These materials coexist with marl, silt, and clay accumulated during the Tertiary period, as well as slope deposits and extensive areas covered by undifferentiated sedimentary bodies formed during the Quaternary period (Montenat et al. 1972). This geology is generally compatible with some of the calcareous and highly calcareous pastes described, leaving out the low-calcareous individuals. However, those broad compositional categories (calcareous and highly calcareous) entail several paste traditions and probably different origins.

The identification of strictly local products from La Fonteta is a complex matter, being sometimes difficult to differentiate from neighbouring settlements as the local site of Peña Negra (González Prats and Pina Gosálbez 1983). In addition, although La Fonteta could have been a pottery production centre, the reality is that no remains of workshops or other evidence of ceramic production have been found yet. This absence could be partly due to the excavated areas: houses and mostly in-wall areas (Late Fonteta). Most visible evidence of ceramic workshops, such as firing structures, could be most likely placed outside the settlement to avoid annoyances related to craft activity, as it happens in workshops located in southern Iberia, for example, the production centre of La Pancha, in Málaga (Martín Córdoba et al. 2006), or in an industrial belt in the periphery of the site, such as in Cerro del Villar (Aubet Semmler 2018). Consequently, local productions have only been hypothesised from the viewpoint of compatibility with the geological environment of the site. According to previous descriptions, *local* products mostly contain quartz, calcite, limestone fragments and bioclasts. However, previous work has also pinpointed significant uncertainties in the definition of origins across the area stretching from Alicante to present-day Catalonia (Montenat 2007), or even when compared with southwestern Iberia products (Seva Román et al. 2011).

To delve into the circulation patterns of handmade pottery, considering the abundance of possible origins posed for both handmade and wheel-thrown ceramics, a comparison was carried out with archaeological materials from the settlement of Peña Negra and other sites analysed by compatible means (Supplementary material, Comparison). Apart from the case of Peña Negra, still unpublished, the comparison data have been previously published elsewhere (Barrachina et al. 2014; Fantuzzi et al. 2020; Cutillas-Victoria et al. 2021; Miguel Gascón et al. 2023). Combining chemical and petrographic data could also help address the provenance uncertainty detected in previous works. The comparison reveals that a closer resemblance occurs with pieces from the Alicante-Murcia region. Fusion points between samples from La Fonteta and other origins generally occur at distinctively high ultrametric distances (Supplementary material, Comparison, Fig. 1).

One of the closest chemical resemblances detected is between pieces from Castellar de Librilla (CLI) group CLI-C2 and the components of CGFNTG6 from La Fonteta. Macroscopically, individuals in CGFNTG6 can be classified as part of the macroscopic group EM assigned to the area of Málaga in previous research and, more specifically, to the Guadalhorce basin. Interestingly, CLI individuals are cooking pots attributed to levels dating from the end of the 8th century and the 6th century BCE. Moreover, there is also an important petrographic affinity with samples from La Fonteta, as all the samples from Castellar de Librilla exhibit characteristic fragments of low-grade metamorphic rock (quartzite and phyllite) forming their coarse fraction. Technologically, all the CLI individuals are characterised by low EFT (< 700-750 °C). They also exhibit signs of grog addition. Regarding provenance, CLI-C2 components are clearly local, including kiln disposals (CLI046).

In our comparison, the same association also includes the individual MOS038, a plate recovered at the site of St. Jaume, in northeastern Iberia. However, the connection of the latter sample with individuals from La Fonteta and Castellar de Librilla seems uncertain due to its high Sn content, which has not been considered during the statistical analysis. In addition, some individuals from Peña Negra also show similarities with samples in group CLI-A1 and especially CLI-A2 of Castellar de Librilla, another local group. The clearest example is probably PN-117, a wheel-thrown *pithos* from Peña Negra, which fits the CLI-A group's heterogeneous nature.

Similarly, important affinity is shown by individuals from Peña Negra (PN-103, PN-148 and PN-159, all handmade) and ceramics within the CGFNTG2b/CGFNTG2c groups, which, as indicated, is a complex cluster including individuals with shell fragments, spathic calcite and a range of finer pastes formed by quartz and different types of carbonatic material and argillaceous inclusions. Massive calcareous bodies are common in the region, including important karst systems at Callosa del Segura and Montepinar in the Segura Valley (20 km) (Ayala Carcedo et al. 1986). Similarly, massive Mg-rich calcareous bodies form the Crevillente Mountain Range, where the site of Peña Negra is located. The inclusion of spathic calcite-rich pastes (FNT018, FNT024, FNT028, FNT033) is noteworthy, as calcite addition has been previously associated with paste traditions detected since the Late Bronze Age in the area, also found at Peña Negra. This association reinforces the notion of a regional origin. However, the compositional variability shown by calcite-tempered ceramics at La Fonteta indicates more than one source. As our initial exploratory analysis noted, CGFNTG1 samples appear unrelated to any other group in this comparative round. This fact could be reflecting compositional variability of available raw materials in the region (Pignatelli García et al. 1972), although extra-regional origins could not be completely ruled out.

To explore this possibility further, we compared the chemical results from La Fonteta with materials from the Imperial and Late Roman periods in the València area (Valentia), and ceramics from the island of Ibiza with different chronologies. These materials were analysed in the same facilities at the University of Barcelona by the research groups ERAAUB and GRACPE (Buxeda i Garrigós and Cau Ontiveros 1997, 1998; Cau Ontiveros 2003; Cau Ontiveros et al. 2019a, b; Madrid i Fernández and Buxeda i Garrigós 2021).

While this new comparative round had a limited impact on the provenance determination for most of the samples from La Fonteta, it significantly contributed to elucidating the potential relationship between the chemical and petrographic outlier FNT004 with the Ebusitan ceramic MOS050, a jar recovered at St. Jaume with an origin in Ibiza (Supplementary material, Comparison, Fig. 1).

In the subsequent comparison (Supplementary material, Comparison, Fig. 2), FNT004 was found to be associated with chemical groups that include individuals from various sites on Ibiza, including the Punic FE-13 workshop (Buxeda i Garrigós and Cau Ontiveros 1997). These individuals are linked to ceramics from the necropolis of Puig des Molins (Ibiza), materials from Turó de Ses Beies (Mallorca), Puig Vermell (Mallorca), and Valentia, all likely originating from Ibiza, as well as one individual from Peña Negra (PN-167, handmade). Petrographic information is also available for samples recovered at Valentia, describing pastes consisting of a calcareous matrix containing quartz, limestone, microfossils, white mica, and variable amounts of other materials, including quartzite. Additionally, samples from the FE-13 workshop exhibit quartz, bioclasts, and white mica. Overall, these Ebusitan petrographic fabrics are consistent with FNT004.

From a typological perspective, distinctive shapes similar to those found in Peña Negra and La Fonteta have been identified at the Sa Caleta site on Ibiza, dating back to the late 8th to 7th centuries BC (Ramon Torres 2007). Notably, form A6 at Sa Caleta closely matches the type attributed to individual FNT004 at La Fonteta. Such typological connections appear to continue in later contexts, as exemplified by type PNI-B4 from Peña Negra and artifacts recovered from grave ALS-12 at Puig des Molins (Ramon Torres 1996). In light of this evidence, the Ebusitan origin of vessels from La Fonteta and Peña Negra suggests an early phase of ongoing exchange between ceramic traditions developed on Ibiza and the coastal region spanning from the Vinalopó to the Segura valleys.

The comparison of chemical data does not indicate potential origins for other individuals included in this work. This involves ceramics with a coarse fraction predominantly composed of igneous material (groups CGFNTG3 and CGFNTG4), which do not align with the geological environment of La Fonteta. In addition, they cannot be categorised into the previously defined ES or EM macroscopic groups, referring to sedimentary and metamorphic geological environments, respectively. As for CGFNTG3, the closest resemblance reported appears to be some Late Bronze Age ceramics from the settlement of Cobatillas La Vieja (located in the Segura basin), rich in basic igneous material (Cutillas-Victoria and Day 2022). In this case, raw materials seem to be connected to outcrops located at various points in the territory between the Segura and Vinalopó valleys and adjacent spaces. These formations have been generally classified as metabasites, originating from diabase that show varying degrees of alteration, particularly accentuated at the eastern and southeastern limits of the formation (Montenat et al. 1972). However, the classification of various outcrops near the coast varies between diabase/ophite and microgabbro, revealing differences in their texture and mineralogy. The lack of olivine and serpentinite in Cobatillas La Vieja, which are characteristic elements in CGFNTG3 thin sections, as well as the lack of other reference group (RG, after Buxeda i Garrigós and Madrid i Fernández 2016) in the area, make it impossible to dismiss other and more distant origins. Along the same lines, the exceptional MnO, TiO_2 and Na_2O values seem compatible with reworked materials originating from the igneous bodies belonging to the alkaline series located in the area of València, such as the ones present in the areas of Cofrentes and Picassent, especially Cofrentes, where holocrystalline materials including Mg-rich olivine and clinopyroxene have been described (Ancochea et al. 1984; García-Rodríguez et al. 2022). The variability detected between FNT009 and FNT022, assigned to different occupational phases, could echo a shift in the exploitation of regional sources over time.

CGFNTG4 composition is equally incompatible with the geological environment of La Fonteta, with granitoid formations being uncommon along the Southeastern Iberian coast. Interestingly, based on information from the analysis of archaeological pieces, Cau Ontiveros et al. (2019a) defined the petrographic group PF9 for Late Antique ceramics characterised by the abundance of holocrystalline rock fragments of intermediate-acid composition. Chemically, this group is characterised by relatively high values of Al_2O_3 (16.8% - 19.5%) and Na_2O (1.5% - 2.4%), and it is associated with the abundance of plagioclase in the pastes. Various possible origins have been suggested for this group: Murcia and the southern part of the current province of Alicante, without ruling out a possible northeastern origin, although there is no archaeological evidence of such workshops. Consequently, a regional origin, or even a northeastern Iberian one, can be hypothesised for the components of our CGFNTG4, which should be tested in the future.

Finally, the provenance of CGFNTG5 remains unclear. Macroscopically, it can be classified as part of the EM group as the components of CGFNTG6, but it differs from CGFNTG6 regarding chemical and petrographic composition. Handmade ceramics with sillimanite have been described among the presumably indigenous materials recovered in the Cathedral Square of Ceuta, considered either local or originating from an undetermined point along the Andalusian coast (Cau Ontiveros et al. 2010), where handmade pottery showing affinity with A3 type from La Fonteta has been recovered (Villada Paredes et al. 2010 type B). In terms of their composition, these pieces depart from CGFNTG5 due to the inclusion of fragments of altered ultrabasic rocks and abundant garnet. Concerning a potential Andalusian origin, metamorphic rock fragments and related discrete mineral inclusions are the main components of archaeological and clay samples from the Málaga area analysed by Fantuzzi et al. (2020). These latter individuals include samples related to Eastern Málaga (FG5), which contain staurolite and garnet and are characterised by very high levels of Zn (in sample 18/124: Zn = 181 mg/kg) and Al_2O_3 percentages of up to 19.42 %. The same applies to other values such as Cr and Ni (370 and 209 mg/kg, respectively, for sample 18/151), which are associated with the presence of alteration material from ultrabasic rocks. It is worth noting that CGFNTG5, which has the most similar petrographic composition to the samples from the South, presents different chemical patterns (e.g., Al_2O_3 ~ 21-22%; Zn ~ 80-90 ppm). However, it is important to underscore that this discrepancy in chemical composition does not preclude an Eastern Málaga origin. Comparable materials like PF4 (Fantuzzi et al. 2020) may also originate from Eastern Málaga. Albeit lacking certain index minerals found in FG5, the latter set of samples still contain rare garnet inclusions.

As a result, although the Málaga region is the origin hypothesised for the EM macroscopic group, no RG completely matches CGFNTG5. This group might show affinity with products from the eastern Andalusian coast or North Africa. Connections with Eastern Andalusia could be supported by typological and chemical affinity with key sites from Eastern Málaga (Velez-Málaga) (Behrendt and Mielke 2019; Vinader Antón 2022, pp. 522–539). In this Andalusian area, the establishment of pottery production centres seems related to introducing new crops and utilising local resources (grape and olive cultivation, fishing, and early signs of metalworking, among other activities), which were later distributed along the Mediterranean coast. It is challenging to determine whether handmade ceramics were also included in these circuits or in others that could have emerged in parallel. This challenge is partially due to the dearth of data about handmade productions in Iberia. While limited information exists regarding certain handmade pottery samples discovered in the colonies, our understanding of their composition remains remarkably limited (e. g. Puch Monge 2017). Handmade pottery-making imposes unique requirements regarding clay workability and firing techniques, leading to specific preferences in raw material selection and processing that are not always compatible with wheel-thrown production. These factors can significantly impact the final composition of the ceramic body, particularly when incorporating tempering agents that alter the original clayey material's compositional signature (Hein and Kilikoglou 2020). As a result, compositional and textural differences are expected in handmade pottery and need to be carefully analysed from the perspective of ceramic paste analysis.

Technological choices in pottery production

One of the main technological traits observed in our research is firing, specifically equivalent firing temperatures or EFT. According to our results, the estimates for the entire sample set did not exceed 850 °C. Chlorite, dolomite, and talc peaks in several specimens suggest even lower firing temperatures. Their presence is compatible with the absent or incipient signs of alteration in the spathic calcite crystals of some individuals, which, along with the intensity of the peaks, indicates EFT not higher than 700 °C in most cases. Mineralogical and microstructural data suggest, then, a chiefly low-fired assemblage with the resulting vessels characterised by low strength and high toughness, likely in contrast to wheel-thrown wares simultaneously used on the site. This result agrees with the use assigned to most of the assemblage, which is supposed to be involved in cooking activities. However, there is no clear distribution of EFT based on compositional or typological-functional groups, reflecting the previous lack of correlation with chemical and petrographic observations. As with compositional comparisons, low EFT values for samples from La Fonteta resemble those obtained from nearby settlements along the Segura and Vinalopó valleys.

The other main technological trait covered in this paper is the use of temper. Tempering is another strategy commonly connected to pottery use, especially strength and toughness. It could be connected to the majoritarian use of handmade ceramic for cooking on-site, although there is no clear correlation between functional groups and chemical/petrographic composition. One temper category identified at La Fonteta is angular calcite. It is also possible that argillaceous inclusions in fabrics connected to CGFNTG2 and outliers such as FNT002, FNT031 were intentionally added. Similar materials have been identified as grog in local ceramics in Iberia. As with grog and added argillaceous materials, the inclusions identified in La Fonteta are variable in colour, exhibit internal structure, are discordant with the surrounding matrix, and have clear limits (Whitbread 1986). Another potential added inclusion is bivalve shells, as pottery containing high amounts of shells is better interpreted as tempered (Quinn 2013). It seems interesting that temper categories normally appear to be applied solely on La Fonteta, which differs from what happens in levels from LBA and EIA settlements along the Segura valley. However, more work will be necessary to address technological choices in the area and their utility as provenance markers. In addition, the use of temper does not only affect pottery performance but also enhances clay workability. Indeed, temper use could be connected to the need to improve the behaviour of raw materials during the production process. Temper choice has also been connected to identity and maintaining local indigenous traditions on other sites. In Castillo de Doña Blanca (Cádiz), for instance, igneous material and grog are characteristic of handmade products and a limited amount of wheel-thrown vessels (Johnston 2015).

Along the same lines, the choice of raw materials could relate to the area's previous LBA and even earlier local ceramic traditions. Although different in their composition, local communities in the area must have been familiar with the characteristics of raw materials generated by the alteration of igneous rocks for several millennia, at least in the Vinalopó Valley (del Pino Curbelo et al. 2021). This use may be associated with exploring lithic resources for stone tool production (Orozco Köhler 2000). The use of grog and calcite has also been common along the Eastern Iberian coast since the Early Neolithic. Tempering practice, thus, reinforces the idea of some connection between EIA handmade pottery in La Fonteta and local/indigenous traditions developed in the area throughout Late Prehistory.

However, it does not seem that there is an exclusive relationship between the production process and raw material selection. Similar paste recipes, including temper addition, appear applied in both handmade and wheel-thrown ceramics in colonial contexts along the Iberian coast, such as the mentioned cases of Cádiz and Castellar the Librilla, and it might also be the case of St. Jaume, in NE Iberia, although in this case crushed calcite addition can be originating in different workshops (Barrachina et al. 2014; Miguel Gascón et al. 2015). Similarities in paste composition between handmade and wheel-thrown individuals have equally been detected in the case of Ceuta (Cau Ontiveros et al. 2010). Considering these examples, there are clear regional limits in such resemblances, which could be the effect of the interaction between a heterogeneous local/indigenous technological substratum and local processes of technological transfer.

Our current results could be testifying to the characteristic conditions in which processes of resilience and change could occur in southeastern Iberia, parting from specific identities and local traditions and the relationship developed between the dwellers of La Fonteta and nearby local settlements. The compositional, technological and typological connection among Peña Negra, La Fonteta and Castellar de Librilla (among others) would be in agreement with the pivotal role posed for Peña Negra as the main settlement in the area, as well as with the maintenance of overland exchange networks with an important regional dimension, normally eclipsed by maritime and long-distance routes implemented during the EIA. The link between Peña Negra and La Fonteta, more specifically, would also be aligned with the construction of the so-called Phoenician quarter in the local settlement. A clearer picture of such a relationship could only be obtained when more research is carried out on the area.

Conclusions

Although trade, technological transfer and resilience of local populations are some of the main traits defended for cultural encounters and Phoenician colonisation in the Western

Mediterranean, those have rarely been addressed from the point of view of local craft traditions and their products. Our results show that handmade pottery had its own mobility patterns in southeastern Iberia during the EIA, which probably took part in complementary or the same exchange networks as those observed mainly from wheel-thrown ceramics but also as part of the movement of people (e. g. López Pardo and Suárez Padilla 2002). The site of La Fonteta also shows an alternative view on regional exchange networks built on the results obtained from other sites in the area (Cutillas Victoria 2021), implying that provenance analysis of those vessels does not necessarily point towards local/regional origins, it also draws attention on the potential volume of handmade ceramics involved in regional or even wider commercial exchange networks.

Handmade pottery from La Fonteta had diverse origins, more than posed by initial characterisation works. The largest part of the potential imports is recovered in levels assigned to Early Fonteta, including a limited number of individuals from farther territories, including the island of Ibiza. Though problematic, it is then possible that handmade ceramics took part in long-distance mobility patterns. The compositional grouping has a clear chronological component, with most groups including samples from only one of the main occupational phases. The distribution of potential regional origins along the chronological series, with most of the outliers and groups with unknown/non-regional origin concentrated in the earlier occupations, could respond to a general pattern of economic regionalisation observed in the transition between the 8th and 7th century BCE (Johnston 2015).

However, the provenance of many samples recovered in La Fonteta can only be hypothesised given the lack of RG for handmade production in Iberia and the rest of the Mediterranean. Temper choice seems quite varied among sites, which can also be useful to address uncertainty areas affecting calcareous and highly calcareous fabrics. A sharper image can only be obtained when more work is done.

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Author contributions MPC and JBG data analysis and main text preparation. IVA sample selection and preparation. ALA, MTO and ELR provided archaeological information and discussed results. All authors reviewed the manuscript.

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Data availability The WD-XRF and PXRD raw data presented in this study are openly available in the CORA.RDR, Research Data Repository (https://dataverse.csuc.cat/) (Buxeda i Garrigós et al. 2024): https://doi.org/10.34810/data1096.

Declarations

Competing interests The authors declare no competing interests.

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