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REVIEW

Archaeometric analysis of the pottery from the Chalcolithic site of El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén, Spain)

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Abstract
This paper presents the findings gleaned from a series of macroscopic, colourimetric, mineralogical, geochemical and microstructural analyses of a pottery assemblage brought to light during the archaeological excavation (2012–2013) of the settlement of El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén, Spain). The different analyses aim at identifying the mineralogical composition and manufacturing processes of the Chalcolithic vessels. The typological and stratigraphic analysis of the different structural complexes, combined with a radiocarbon dating, place the site in the last third of the 3rd millennium BC. The study sheds light on the phases of transition characteristic of Eastern Andalusia's Copper Age and the wide range of analytical techniques confirms both the uniformity of the raw materials (evidencing a local provenance) and that the pottery production process was well integrated into the technological traditions of the south of the Iberian Peninsula.

Keywords Upper Guadalquivir Valley · Copper Age · Pottery · Production · Bell Beaker

Introduction

Research from the end of twentieth and the outset of the twenty-first century has led to a considerable increase in the understanding of the Chalcolithic period of southern Iberia's Upper Guadalquivir Valley. This stems in part from systematic surface surveys (Pérez et al. 1992; Pérez 1994) and a few excavations in the framework of research projects (Arteaga et al. 1993; Nocete et al. 2010). Knowledge of this period is likewise bolstered by an exponential increase in preventive interventions linked to urban development, agricultural intensification and investment in infrastructures (Ruiz et al. 1986; Nocete 1994; Zafra 2011; Afonso et al. 2014; Lechuga et al. 2014; Milesi et al. 2020). However, specific examinations of Chalcolithic pottery has been limited almost exclusively to typological classifications (Nocete 1994; Lizcano 1999). Moreover, technological ceramological analyses in this sector of Iberia are practically absent. Exceptions are the investigations carried out on assemblages from the sites of Las Eras del Alcázar (Úbeda, Jaén) (Inácio 2009), El Cerro de la Virgen (Orce, Granada) (Molina et al. 2017) and Los Castillejos (Las Peñas de los Gitanos, Montefrío, Granada) (Vico et al. 2018). Thus, the focus of the present study is to shed light on the operational sequence of the production of pottery at the Chalcolithic site of El Cortijo de Montiel Bajo (Jaén). The intention is to contribute to characterise the potential differences between vessels with Bell Beaker decor and other contemporary productions and to begin to determine whether social identities can be defined based on formal and technical similarities or differences (Odriozola et al. 2007, 2012; Garrido et al., 2000) between the productions of the Recent Copper Age of the southeast of Iberia and the features identified among the ceramic ware of the present site and other sites of the Upper Guadalquivir area. This study likewise intends to contribute to broadening the

Geographical coordinates 38°1′44.78304″. -3°8′22.27668″.
Source of the DMS coordinates of the archaeological site of El Cortijo de Montiel Bajo: Google Maps.

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debate regarding the various interpretations as to the persistence and extinction of the Bell Beaker sequence in the Iberian Peninsula and its potential link with the continuity of occupation in certain settlements such as Cerro de la Virgen compared to the abandonment of others such as Los Millares. In fact, the Bell Beaker phase in other areas such as Catalonia and the Pyrenees persisted until the Middle Bronze Age (Garrido 1999).

It must be noted that the site of El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén), the object of the current study, has yet to benefit from a systematic global analysis and is only referenced in passing in the articles by Sánchez (1984) and Ruiz et al. (1986). The materials studied here stem from a rescue operation carried out between 2012 and 2013 during construction of an irrigation channel near the De la Vega River (Pérez et al. 2013, unpublished report). Furthermore, this sector of the Upper Guadalquivir Valley's southern sub-plateau has seen little research despite its key role in connecting the Guadalquivir Valley, Granada's Orce-Huéscar High Plains, the Levant and the eastern passes of the Sierra Morena.

El Cortijo de Montiel Bajo and the end of the Chalcolithic

Archaeological context

The site straddles the Municipalities of Cazorla and Santo Tomé in the NE of the Province of Jaén (Fig. 1a). It is set on the first fluvial terrace at an altitude of c. 410 masl. The terrace corresponds to the De la Vega River, a stream that flows into the nearby Guadalquivir River (Sánchez 1984; Ruiz et al. 1986; Pérez et al. 2013, unpublished). Referred to in the first publications as Puente del Río de la Vega (Ruiz et al. 1986), the site now takes its name from the Cortijo

Fig. 1 **a** View of the Iberian Peninsula with the position of the Copper Age sites cited in the text. 1, El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén); 2, El Cerro de la Virgen (Orce, Granada); 3, El Malagón (Cúllar-Baza, Granada); 4, Las Angosturas (Gor, Granada); 5. Los Castillejos (Montefrío, Granada); 6, El Manzanil (Loja, Granada); 7, Cerro de la Encina (Monachil, Granada); 8, Terrera Ventura (Tabernas, Almería); 9, Los Millares (Santa Fe de Mondújar, Almería); 10, Almizaraque (Cuevas de Almanzora, Almería); **b** detail of El Cortijo de Montiel Bajo and its proximity to the Guadalquivir River and De la Vega River; **c** vertical views of the foundation of a cabin (Structural Complex 1), **a d** funerary feature (Structural Complex 6) and **e** a ditch (from Pérez et al. 2013, unpublished)

de Montiel Bajo (Santo Tomé) (Fig. 1b). A series of trial trenches in 1983 linked to modern road work confirmed a Chalcolithic occupation marked by numerous Bell Beaker ware finds. The initial publications were succinct, only making reference to the artefacts suggesting a continuity of occupation between an advanced phase of the Copper Age to the Bronze Age (Sánchez 1984; Ruiz et al. 1986). Subsequently, rescue operations throughout 2012–2013 in the framework of the construction of irrigation infrastructure unearthed Chalcolithic features in the site's lower area and later historical features, especially Roman, in other areas (Pérez et al. 2013, unpublished). The combination of data from the two campaigns now suggests the extension of the Chalcolithic settlement to correspond to about 5 ha and that of the later occupation linked to the Roman period in the upper sectors to up to 15 ha. The strategic nature of the Chalcolithic occupation is bolstered not only by its vast extension, but also by its position at the confluence of the Río de la Vega and the Guadalquivir River.

The agrarian intensification characteristic of the Upper Guadalquivir's transition to the Copper Age in (Nocete 1994; Nocete et al. 2010) is confirmed at this site by the presence of numerous spaces linked to grinding and combustion. These are marked by abundant remains of fauna, cereals, carbonised legumes and pottery types linked to storage and food processing (area CE-1) (Fig. 1c). The notion is bolstered by the fact that certain pits could have originally served as storage features as is the case of other sites of the Upper Guadalquivir (Afonso et al. 2014). Apart from the group of pyriform pits, the excavation revealed the presence of a funerary complex (Fig. 1d), a longitudinal structure (ditch) (Fig. 1e), and in the upper sectors, circular cabins dating from the more recent prehistoric phases.

The chronology of Cortijo de Montiel Bajo and its place in the framework of the end of the Chalcolithic

The study of the relationships between the structural complexes (ditch, pits and cabins) suggests the existence of two large Chalcolithic phases. A third prehistoric phase is deduced exclusively from surface finds mixed with later elements from the Roman occupation.

The earliest phase is marked by a stone and adobe foundation of a dwelling, a segment of an enclosure ditch in the lower sector (following the contour lines) and the group of pyriform sunken features. These pits, for the most part outside the ditch, usually range between 1.30 and 2 m in diameter and are preserved at a depth of between 0.84 and 2.60 m. They contained a variety of fills, notably abundant layers of ash, which suggest they originally served as silos and/or ovens before being filled with debris (Supplement I.1). The fill of pit UEN 7, on the other hand, is characterised by gravel and a reddish hue suggesting it was filled naturally by erosion.

The second Chalcolithic phase presents a greater variety of structural complexes. The pits are smaller with diameters ranging between 1.10 and 1.80 m and depths between 0.22 and 0.90 m. Their fills of gravel and ash suggest more erosive or intentional fillings (Supplement I.2). The ditch with a V-section is likewise linked to this phase. This feature with a depth of up to 2.80 m and a width of 10.70 m contained notably potsherds with Bell Beaker decors (Supplement I.3). The seocnd phase is also marked by a rectilinear channel with a 'U' section, presumably to facilitate drainage, 1.50 m in width and 1.45 m deep likewise containing Bell Beaker ware (Supplement I.4). This phase also features a funerary structures (Structure Complex 6) (Supplement I.5) containing both human and animal bones. The phase also reveals circular dwellings circa 6.30 m in diameter charcaterised by stone foundations and postholes (Supplement I.6 and I.7). These contained materials related to food processing (roasting) and consumption as well as textile working.

Finally, the upper area of the site is capped by altered levels, including the remains of foundations of dwellings attributed to the more recent prehistoric phases capped by later Roman remains (Supplement I.8) (Pérez et al. unpublished; Ruiz et al. 1986).

The different finds point to a timeframe in the second half of the 3rd millennium BC linked specifically to the last phases of the Copper Age. This range has been corroborated by a radiocarbon dating of a pig metatarsus from stratigraphic unit 9 of UEC 25.2, a feature attached to phase II. The bone is from the edge of the V-shaped ditch, the point with the greatest percentage of decorated Bell Beaker ware. It is noteworthy that the fill of this ditch consists of homogeneous layers of small-sized river pebbles and gravel suggesting an intentional anthropic fill, without excluding periodic level processes of flooding. In either case, these layers presumably took place at a time when there was no longer any interest in maintaining the enclosure. Its abandonment and filling are in fact evidenced by the superposition an arc-shaped structure of stones held together by earth (UEC 26.1) corresponding to the base of a dwelling (Pérez et al., unpublished). Thus, despite the problems entailing the dating of materials from ditch fills, the pig metatarsus does yield a *terminus post quem* for the end of phase 2 given that a cabin was raised over the ditch after it was sealed.

The sample (Ua-70262) analysed by the Tandem laboratory (Uppsala University, Sweden) yielded 3727 ± 32 BP. Its calibration by means of the IntCal 20 curve (Reimer et al. 2020) of the Calib programme (Rev 8.1.0.) offers a 1σ range of 2198–2041 cal BC and at 2σ range of 2273–2029 cal BC. In any case, its 2σ range (97% probability) sets the interval at between 2205 and 2029 cal BC. All this suggests the end of phase 2 to be around 2100 cal BC and that the occupation, as proposed, continued throughout the transition between the 3rd and 2nd millennium BC. Moreover, this range falls in line with the socioeconomic transformations or abandonments identified at numerous Chalcolithic sites in the southeast of the Iberian Peninsula (Molina and Cámara 2005; Lull et al. 2010; Juan-Cabanilles 2005; López Padilla 2006).

Individualised arrangements of grave goods in collective burials at neighbouring sites such as Haza de Trillo (Toya, Jaén) together with the appearance of individual burials at certain other nearby sites such as the roughly contemporary Puente Mazuecos (Baeza, Jaén) (Ua-40062: 1σ cal BC 2194–2037; 2σ cal BC 2203–1982) suggest regional changes were also taking place marked by a transition towards new social systems represented by new burial forms (Pérez 1994). Transformations of this type have also been observed at Marroquíes (Jaén), in particular in its urban system and its funerary rituals. This is also confirmed by the decrease in availability of datings aligned with the last centuries of the 3rd millennium BC for artificial pits and caves burials outside the settlement, as well as the finds of burials with Late Bell Beaker goods inside fortified areas such as that of García Triviño (Cámara et al. 2012). Furthermore, there are changes within urban systems with the appearance of large oval dwellings and later, in the Bronze Age, shortly before the abandonment of the town, a settlement marked by streets between rectangular buildings (Zafra et al. 1999; Cámara and Molina 2016). Finally, although it is difficult to reconcile the end of the ditches prior to the abandonment of the fortifications (Zafra et al. 2010), it is true that the defensive layout underwent modifications in certain areas and that even sections of abandoned ditches served for burials during the late 3rd millennium BC (Beck et al. 2016; Nicás and Cámara 2017; Milesi et al. 2020).

Finally, one must note the establishment of new settlements in elevated areas. An example is Cerro del Alcázar (Baeza) whose sequence of occupation began towards 2300 BC (Pérez Bareas 2010; Molina et al. 2019: Table 1). Although this date is near the end of the end of the Bell Beaker phase and the Copper Age at certain sites of southeastern Iberia (Lull et al. 2010, 2020; Castro et al. 1996), there is a marked continuity at Cerro del Alcázar where the main transformations include the appearance of Argaric features towards 1950 BC (Molina et al. 2019). Key transformations also took place at Eras del Alcázar (Úbeda) towards the end of the 3rd millennium and early 2nd millennium BC evidenced by the construction of rectangular houses with differentiated internal rooms and with the appearance of the Argaric funerary rite denoted by individual burials under dwellings and new types of grave goods (Nocete et al. 2010; Molina et al. 2019).

Therefore, the dating of El Cortijo de Montiel Bajo coincides with numerous socioeconomic transformations of the time. These are linked, in the first place, to environmental variations marked by an increase in aridity coinciding with the beginning of the climatic event of 4.2 ka cal BP (Bond Event 3) (Burjachs et al. 1997; Bini et al. 2019; Zielhofer et al. 2019), and, secondly, by transformations in territorial occupation stemming from modifications in the social structure that led to an increase in conflicts and to a more open display of social differences that need not be masked by the rite of collective burial (Molina et al. 2016; Nocete 1994; Jover et al. 2019, 2020; Lull et al. 2010, 2016).

Objectives, materials and methods

Objectives

The objective of the current study is to determine the mineralogical composition of the clay fabrics serving to produce the pottery as well as to identify the manufacturing processes. As noted, both the technical process itself and the raw materials are relevant in terms of evaluating, at a small scale, the processes of social transformation and mobility that have been identified for this period. This can only be carried out by taking into account the differences between certain classes of pottery. Hence, the samples selected for the current analysis consist of a combination of ware of Bell Beaker tradition and undecorated cooking and deep bowls (Table 1).

The pottery samples

Fifty-two samples were selected among the sherds of El Cortijo de Montiel Bajo based on their spatial and stratigraphic proximity to Bell Beaker vessels. These criteria allow to evaluate the similarities of production processes between the different classes of vessels and attempt to identify potential procedures of procurement of raw materials and products. The samples include hemispherical bowls (Fig. 2) and cooking ware consisting of either straight walled or ovoid or globular pots, platters with bevelled rims and carinated profiles, large simple platters at times with thickened rims and, to a lesser extent, cups and deep bowls with spherical and semi-ellipsoidal form (Fig. 3; Table 1).

Methodology

The study began by delving into the question of petrofabrics by means of macroscopic observations (external surfaces and matrices) (Capel and Delgado 1978; Velde and Druc 1999; Gámiz et al. 2013). This was followed by colourimetric analyses in order to determine the variations in hues stemming from the specific firings of local types of clays. This required grinding both the potsherds and the geological sediments into a powder for PCE-CSM 2 colourimeter

Table 1 Listing of the different types of plain common pottery of the site of El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén) and their respective analytical techniques. Macroscopic (M), X-ray fluorescence (XRF), X-ray diffraction (DRX), thin section (TS), scanning electron microscopy (SEM), colourimetry (C), Fourier transform infrared spectroscopy (FTIR)

Sample	Form	Morphological description	Functional category	Analytic type	Figure ID
3	Simple large platter	Flattish open vessel	Serving plate	M, FRX, DRX, TS, C	Figure 3x
4	Cup	Small open vessel	Serving (drinking)	M, FRX, DRX, C	Figure 2b
5	Platter	Flattish open vessel	Serving plate	M, FRX, DRX, C	Figure 3r
6	Deep bowl	Closed globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3h
7	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3d
8	Simple large platter	Flattish open vessel	Serving plate	M, FRX, DRX, C	Figure 3y
9	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2p
10	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3e
13	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3p
14	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3t
15	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2n
16	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 2x
17	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 2y
18	Cup	Small straight walled vessel	Serving (drinking)	M, FRX, DRX, C	Figure 2a
19	Platter	Flattish open vessel (with carinated profile)	Serving plate	M, FRX, DRX, C	Figure 3k
20	Deep bowl	Closed globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3i
21	Pot	Closed globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3c
22	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3u
23	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2m
24	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, TS, C	Figure 3g
25	Simple large platter	Flattish open vessel	Serving plate	M, FRX, DRX, C	Figure 3s
26	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C,	Figure 2e
27	Deep bowl	Flattish open vessel (with carinated profile)	Cooking vessel	M, FRX, DRX, TS, C	Figure 3z
28	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3w
29	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2o
30	Simple large platter	Flattish open vessel	Serving plate	M, FRX, DRX, C	Figure 3l
31	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2l
32	Simple large platter	Flattish open vessel	Serving plate	M, FRX, DRX, C	Figure 3j
33	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3q
34	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2j
35	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, TS, C	Figure 2f
36	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, C	Figure 3o
37	Platter	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, TS, C	Figure 3n
38	Pot	Closed globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 2z

Table 1 (continued)

Sample	Form	Morphological description	Functional category	Analytic type	Figure ID
39	Pot	Straight walled vessel	Domestic basin	M, FRX, DRX, TS, C	Figure 2u
40	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, TS, C	Figure 2g
41	Pot	Straight walled vessel	Domestic basin	M, FRX, DRX, C	Figure 2v
42	Deep bowl	Straight walled vessel	Cooking vessel	M, FRX, DRX, C	Figure 3f
43	Platter	Flattish open vessel (with thickened rim)	Serving plate	M, FRX, DRX, C	Figure 3m
44	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2c
45	Pot	Straight walled vessel	Domestic basin	M, FRX, DRX, C	Figure 2w
46	Pot	Closed globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3b
47	Pot	Open globular vessel	Cooking vessel	M, FRX, DRX, C	Figure 3a
48	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2d
49	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C	Figure 2h
50	Bowl	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, SEM, C	Figure 2k
51	Bowl (incised decor)	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, DRX, FRX, C,	Figure 2s
52	Platter (incised decor and white paste)	Flattish open vessel (with bevelled rim)	Serving plate	M, FRX, DRX, TS, SEM, C, FTIR	Figure 3v
53	Bowl (incised/impressed decor and white paste)	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, C, FTIR	Figure 2q
54	Bowl (incised/impressed decor and white paste)	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, C, DRX, TS, SEM, C, FTIR	Figure 2r
55	Bowl (incised/impressed decor and white paste)	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, TS, SEM, C, FTIR	Figure 2t
56	Bowl (incised/impressed decor)	Hemispherical and semi-ellipsoidal vessel	Serving bowl	M, FRX, DRX, TS, C	Figure 2i

tests by means of a silicon photodiode sensor, a 8/d capture geometry, a blue-excited LED source and a CIE L*a*b*C*h range of colours with an error of ≤ 0.80 ΔE*ab. The colourimetric data were then statistically processed through a principal component analysis (Aitchison 1983). The next phase consisted of characterising the decorative white paste inlays of certain vessels by means of Fourier transform infrared spectrometry (FTIR). This applied a Jasco model 4700 spectrometer with an attenuated total reflectance (ATR) module to attain a total of 25 measurements per sample.

The next phase consisted of XRD mineralogical characterisations of all the samples. This consisted of analysing the sherds and sediments in powdered form with a Bruker D8 Advance diffractometer with a high stability copper anode X-ray source, a source detector and a fast detector (Lynxeye) applying the Bragg–Brentano geometry and the CuKα radiation. The analyses were set at θ–2θ, $\Delta\theta = 0.04°$ with 1-s intervals, $2\theta = 5$–$70°$ at room temperature (25 °C) applying the traditional dust method (Moore and Reynolds 1989). The samples were then ground in a mortar until obtaining an optimal granulometry (60µ) before subjecting them to a working power of 40 kV and 40 mA. The diffractograms were analysed by XPower software (Martín-Ramos et al. 2012) which required resorting to the PDF2 database of the International Diffraction Data Centre and the application of the quartz pattern (Chisholm 2005) (PDF2 database, 85–0796: Quartz) quantified with the Reference Intensity Ratios (RIR) method (Chung 1974; Martin 2008: 47–52).

This step was followed by mineralogical analyses of 10 thin sections intended to expand on the question of the ceramic fabric textures. This was carried out by means of a petrographic microscope with planar polarised light under crossed nicols and described along the lines of a modification of the Whitbread system. This system consists of grouping the samples according to their main characteristics, inclusions, matrix and porosity (expressed as c:f:v), with 10 µm serving as the limit between large and fine grains (Whitbread 1995). Grain size distribution and component orientation, in turn, were estimated visually following the Bullock et al. (1985) guidelines and applying the same

Fig. 2 Pottery forms: cups (**a**–**b**); bowls (**c**–**t**); pots (**u**–**z**)

frequency category identification technique described by Matthew et al. (1997). The choices of the thin sections were based on the desire to delve deeper into the results of the other techniques, allowing an examination of features such as the origin of the calcium carbonate (primary or secondary) and the organisation of the minerals/rocks in the matrix according to the different textural, colourimetric and technological groupings.

The subsequent analysis to characterise the microstructure of the fabrics required making fresh breaks without coating of four samples in order to observe the level of sintering or vitrification of their matrix. The four samples were selected from among the most numerous assemblage of the site and bear both decors and white paste. This thus renders the four samples as representative of both the technological and decorative aspects. This analysis ultimately yielded data serving to estimate firing temperatures by means of X-ray diffraction (XRD). The study thus resorted to a Coxem scanning electron microscope (EM-30AXP) in a low vacuum atmosphere with SE, BSE and EDS detectors.

The final step was the geochemical characterisation (pXRF) of all the powder samples of both the vessels and sediments. This consisted of applying a PANATEC Niton XL3t equipped with a 50 kV and 100 microampere X-ray tube and a filter that corresponds to the Soils model, one analysis per sample, which is made up of two 60″ beams per beam for a total

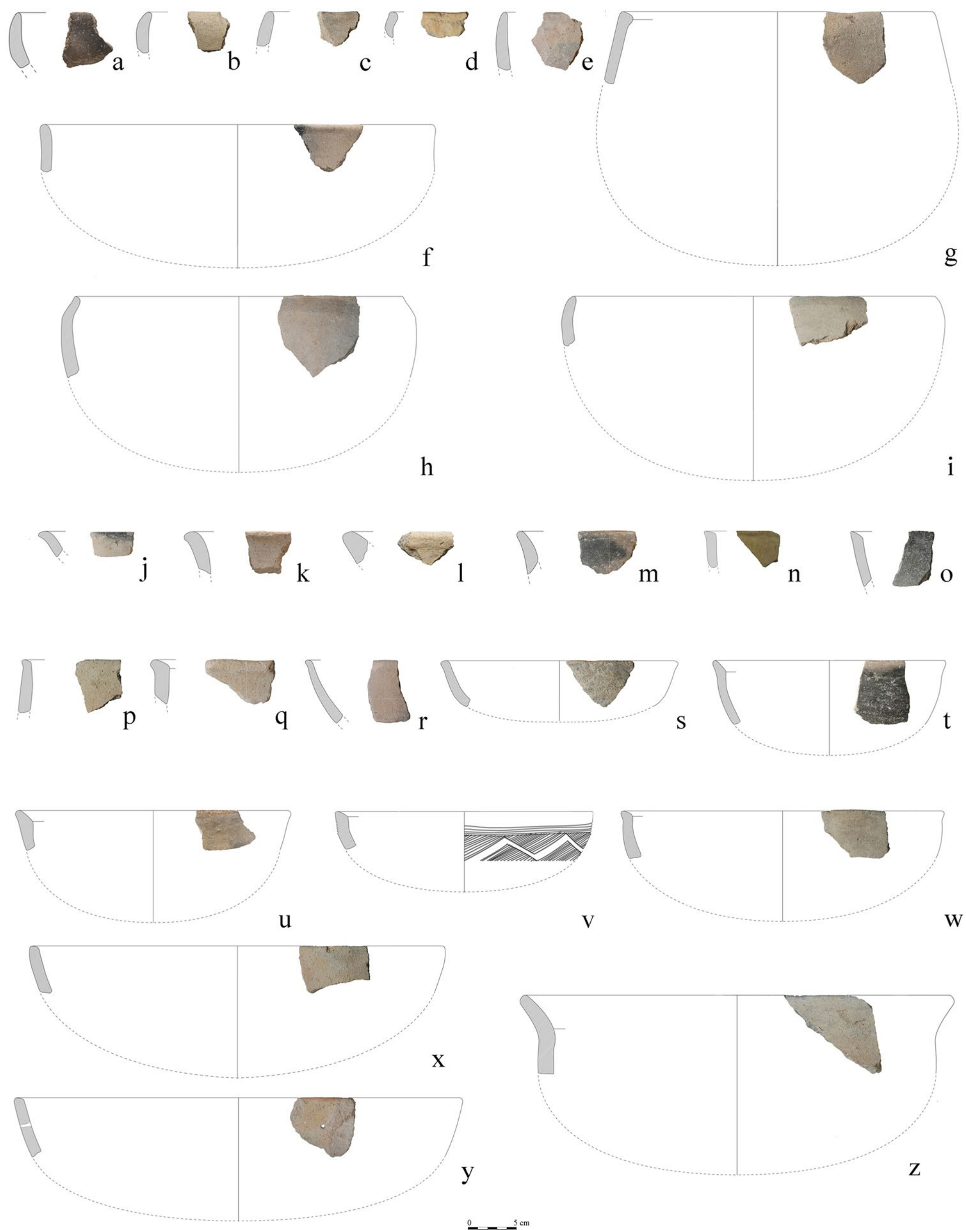

Fig. 3 Pottery forms: pots (**a**–**d**); deep bowls (**f**, **g**, **h**, **i**, **y**), platters (**j**–**x**)

of 120″. As each mode operates at a different voltage, it is possible to enhance the fluorescence of a set of elements and select different filters to optimise peak/background ratios. Thus, this technique quantified the values of a number of elements (Mo, Zr, Sr, Rb, U, Rb, Th, Pb, As, Zn, W, Cu, Co, Fe2O3, MnO, Cr, V, TiO2, Sc, CaO, K2O and S) expressed in ppm. Finally, the data garnered from the quantification process was subjected to a statistical process of reduction of dimensions by means of the principal component analysis (PCA) and then compared through a dendrogram with intergroup linkage (Aitchison 1983, 1984; Whallon 1990; Glasckoc 1992; Baxter 1994, 2003; Padilla et al. 2006). The pXRF technique suffers from certain limitations when attempting to identify provenance. However, the technique has been compared with other higher resolution techniques and there is a high degree of correlation between each of the groups (Padilla et al. 2006; Craig et al. 2007; Speakman et al. 2011; Liritzis & Zacharias 2011; Goodale et al. 2012; Bonizzoni et al. 2013; Hunt and Speakman 2015). This renders it a technique that is generally accepted in our discipline and suitable for the study of archaeological pottery provenance. Although we acknowledge that the pXRF is not highly precise, we believe that its contribution is always greater than qualitative characterisations as it allows observing general compositional trends of the samples.

Geological analyses

Data as to the geological sequences of the surroundings of the site were gleaned from Map 907 (Villacarrillo) and its corresponding report by the Spanish Geological Survey (Instituto Geológico y Minero de España, IGME 1980). The Hornos-Siles (Tg^2-Tg^3) unit, the oldest geological unit in the area, is Triassic and characterised by fine limestone (micrites) outcrops with intercalations of loam, dolomite and pyrite and ferruginous elements (Muschelkalk Tg^2), as well as layers of gypsum, clay, sand and sandstone (Keuper facies Tg^3). The Beas de Segura (J_{1}), Chorro (J_1-$_2$—JC_1-$_2$) and Upper Oxfordian ($J31^3$) units are Jurassic. The first mainly consists of dolomites, loams, crystals, gypsum, calcite and episodes of fine calcarenitic, intrasparitic and micritic bases. The second is dominated by calcarenitic and micritic units. Microcrystalline limestone, sandy episodes with numerous ferruginous oolites (oomicritite and bio-oomicritite), in turn, is common at the base of the third. The Sierra de Segura (Kimmeridgian-Valanginian) (J_{32}-C_{15}) unit, dated to the Cretaceous, is represented by three different episodes generally marked by limestone, loam, calcarenite, quartz, ferruginous pisoliths, sandstone and detritic elements. Highlighted among the materials of the Lower Cretaceous of the Sierra de Cazorla are detritic materials (infra-Cretaceous) and carbonate Jurassic sequences. The detritic sedimentation extending from the SE to the NW corresponds to the Upper Oxfordian comprising limestones in the form of oolites, thick rhombohedral dolomites and elements of the Beas formation. This is followed by the Neogene period which in the Guadalquivir and the Sierra de Cazorla is represented by two formations. The first is the Tortonian ($T^{BC}{}_{11}$) comprising clasts, sandstones with pebbles, conglomerates and loams, whereas the second, the Andalusian ($T^{BC}{}_{12}$), is formed by loam with abundant planktonic microfauna, schists, bioclastic limestones, sparite and microsparite cements. Lastly, the Quaternary corresponds to an initial Pleistocene episode marked by red silt, dolomitic pebbles and pebbles with Cretaceous, Eocene and Palaeozoic materials followed by second level, assigned to the Holocene, made up of monogenic gravels, grey silts, decomposed clays and loam solifluction (Fig. 4).

Analyses and results

Macroscopic analyses

The results of the stereoscopic analysis reveal different handbuilding techniques, notably pinching, moulding and coiling. Platters, pots and deep bowls were generally fashioned by the basketry technique, at times combined with coiling. This is deduced by the presence of oblique traces in the matrix, imprints and burrs on the edges of the vessels, as well as surface undulations (Gámiz et al. 2013). The remaining vessels, fundamentally bowls, were built by pinching or hollowing, techniques confirmed by traces on their bodies and orderly arranged tempers (Dorado et al. 2017).

Surface treatments (Calvo et al. 2004) of pots and bowls generally consist of the burnishing of the interiors and smoothing or applying a spatula to the exterior. The spatula technique contrasts with that applied to platters, which most often reveal burnishing followed by smoothing that, on occasions, was combined with spatula work. One of the cups bears a smoothed interior and traces of spatula on its exterior, while the others only reveal burnishing of their exteriors. Finally, the walls of the deep bowls are generally regularised by smoothing combined at times with the spatula technique (Fig. 5a–c). The analyses of the vessel surfaces likewise identified certain technological features such as a small and fragmentary dermatoglyph (Fig. 5d) potentially linked to the fashioning of the vessel and a perforation (Fig. 5e) subsequent to the original firing related to repair or a change of use of the vessel (Míguez et al. 2016; Martin 2021).

Characterisation of the pottery decors and white paste

Among the pieces selected for the different analyses are six decorated vessels. These consist of impressed zig-zags, oblique incisions at times forming horizontally grids, bands of horizontal incisions, spatula impressions, 'sun-shaped' motifs (Fig. 5k) and white paste inlays (Fig. 5m) (Martín and Camalich 1982). FTIR spectroscopic analyses of the white paste revealed a series of absorption bands with ranges approximately at 1415.49 cm^{-1}, 1012.45 cm^{-1}, 712.57 cm^{-1} and 419.44 cm^{-1} linked to $CaCO_3$ and SiO2 (Fig. 6a) (Mihailova et al. 2015). The mineralogical X-ray diffraction analysis, in turn, reveals peaks mainly linked to quartz, calcite and dolomite also shed light on this material (Fig. 6b).

Colourimetric analyses

Evidence of the original firing processes stems from observations of both their surfaces and matrices. The prevalence of brown, grey or black hues points to a predominance of reducing atmospheres. There are nonetheless chromatic variations (beige and orange) indicative of oxidising conditions. Certain samples also reveal networks of thermal cracks, distortions in the lip and vertical fractures (García and Calvo 2006) (Fig. 5f–h). The colourimetric analyses of the samples of sediments allow to distinguish three main groups (Fig. 7).

The first (total 21) consists of five sediment samples, two deep bowls, eight platters and six pots. The lot reveals a great homogeneity as most were subjected to an oxidising firing. In this case, the highest values are among the spectrum H (41.12),

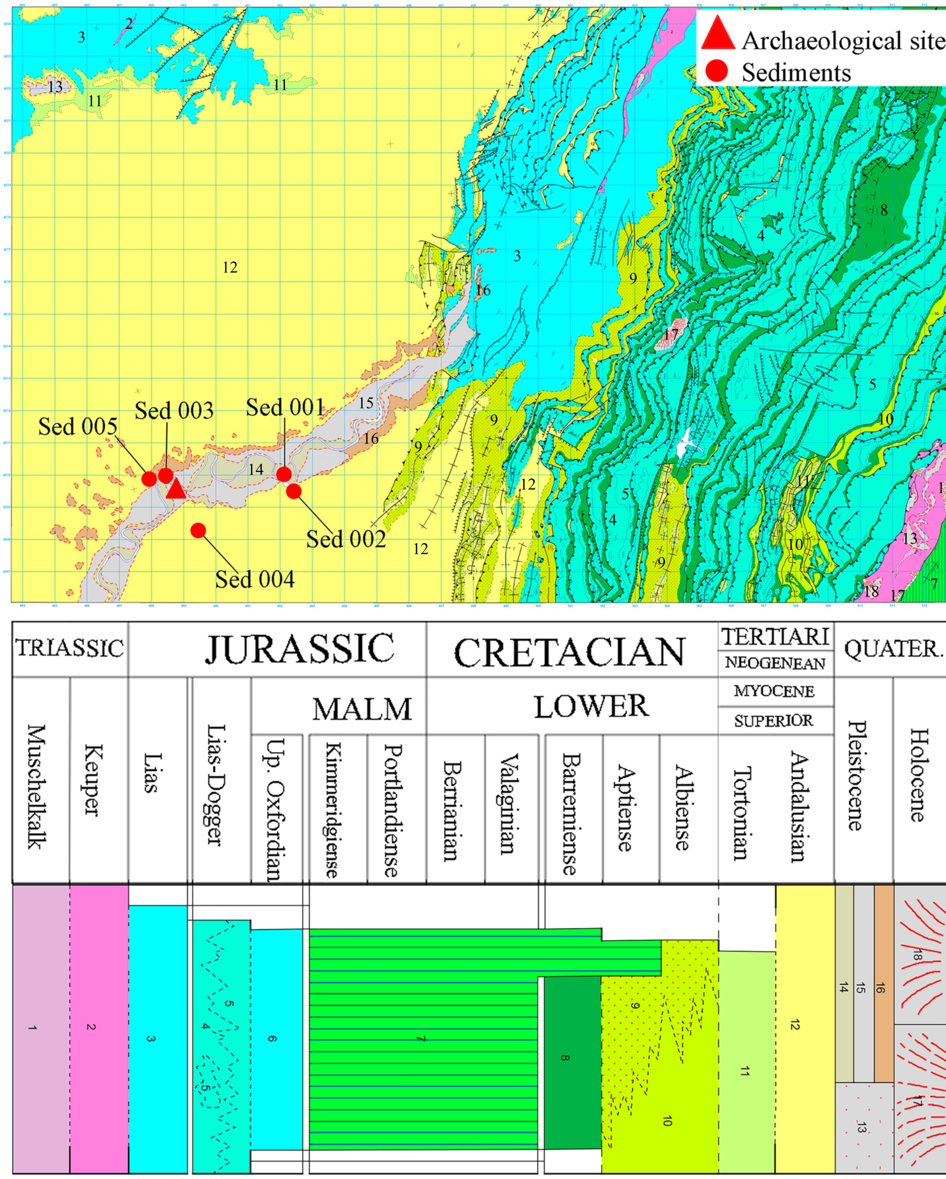

Fig. 4 Geological map of the area of Santo Tomé de la Vega (Jaén): 1, dark grey limestone in platelets with fauna and yellowish marlstones; 2, clays, gypsum and sands; 3, fine dolomites, clays, marls on a white limestone ceiling with pentacrinites; 4, grey massive dolomite with large rhombohedrons; 5, white oolitic limestone; 6, white to pink nodular limestone with ammonites; 7, thick banks of beige to dark grey nodular biomicrites; 8, green clays with ferruginous pisolites and very sparse sands and dolomites; 9, sands, clays and tableted dolomites of intense and varied colouring; 10, beige, table-like marly dolomites with quartz grains and orbitolinid phantoms; 11, conglomerates and calcareous sandstones with marl and rare intercalations of algae limestones; 12, grey loams and calcareous sandstones in Iznatoraf; 13, undifferentiated terrace; 14, cemented gravels and red silts; 15, grey gravels and silts; 16, fine gravels and silts; 17, slope deposits; 18, dejection cones. (IGME 1980: extract from the map 907)

surpassing those of spectra L (24.39), A (19.67), B (11.7657) and C (25.43). The second group (total 28) consists of two deep bowls, 13 bowls, eight platters, five pots and two cups for the most part fired in reducing conditions (especially the bowls). The means of their values reflect, as in the previous case, a greater intensity among the H spectrum (342.73), much lower values among the L spectrum (4.17) and averages of A 69.59, B – 20.62 and C 75.3927 among the remaining spectra. Finally, the results for group 3 (total 6) made up of five bowls and one pot, reveal the lowest values among the L (2.84) and B (– 94.37) spectra and the highest mean values among A (148.3933), C (176.42) and H (327.64). This last group, mainly of reduction type, includes the vessels bearing Bell Beaker decors and sun-shaped motifs.

Finally, the composition of the raw materials (Gámiz et al. 2013; Velde and Druc 1999) allow establishing a first group consisting of the largest proportion of smoothed and decorated ware (ID 52, 53, 54, 56). These vessels, characterised by both reducing and oxidising atmospheres, at times contain highly spherical tempers with rounded or sub-rounded edges of quartz, calcium carbonates and mica, as well as small pellets, charcoal and microfossils. The proportions of temper fall into four subgroups: 1.A, vessels with temper not exceeding 5%; 1.B, vessels revealing a high percentage between 10 and 20% (this is the most common group) (Fig. 8); and 1.C, vessels with temper exceeding 30%, (Fig. 9) and 1.D vessels (exclusively pots and platters) with a high proportion (50%). On the other hand, the study differentiated a second technological group, represented by only three vessels, two of which bear Bell Beaker decors (51, 55), bearing a low percentage of quartz, calcium carbonate, mica, plant matter and small clay pellets (c. 5–10%). These very fine elements tend to be spherical with

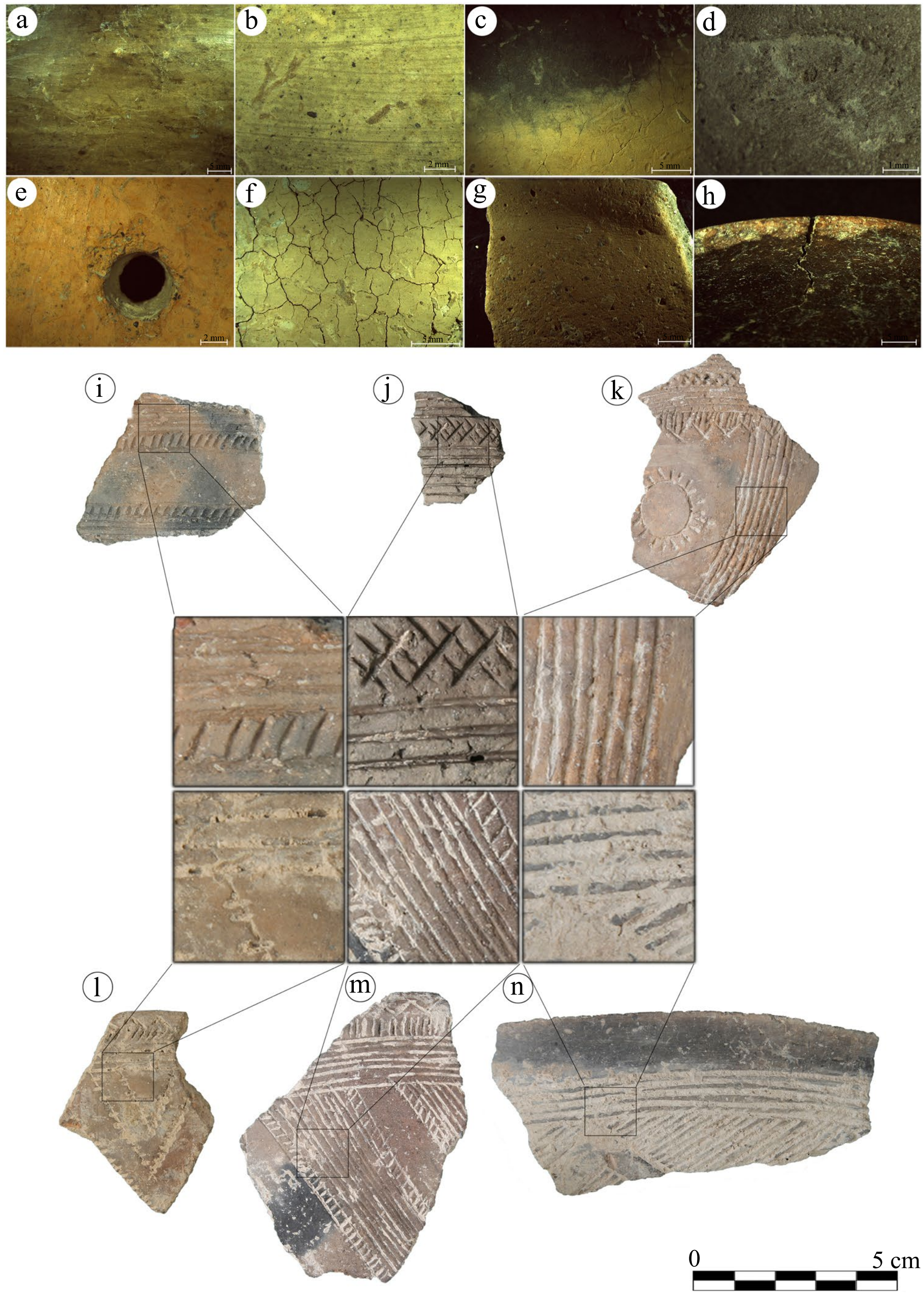

Fig. 5 Pottery surface treatments: **a** burnishing, **b** spatula, **c** smoothing. Technological traces: **d** fingerprint; **e** perforation. Firing: **f** crackling, **g** lip deformation, **h** overfiring crack. Bell Beaker decorations: **i** (ID 51); **j** (ID 56); **k** (ID 54); l (ID 53); **m** (ID 55); **n** (ID 52)

subangular edges with medium compact matrices with black, greyish and dark brown hues (Fig. 10).

Thin section petrography

The results of the petrographic study of 10 samples allow delving deeper into the characterisation of the corpus (Table 2) leading to distinguishing three petrofabric types.

Petrofabric 1: Ca-rich clay with heterometric limestone rock fragments (c:f:v 10μ = 20:70:10 to 30:55:15)

This group, made up of four samples, notably a platter, pot, a deep bowl and a bowl (ID 3, 24, 27, 56), is characterised by an abundance of quartz, dolomite, limestone rock fragments and FeO granules, and to a lesser extent micas (muscovites) (Fig. 11a–d). The forms of the coarse fraction range between sub-rounded and sub-angular. The proportions of the group vary between 20 and 30% for the coarse fraction, 55–70% for the fine fraction and 10–15% for the pores and striations. The temper, often in high relief, reveals intense levels of pleochroism. Its elements are usually distributed homogeneously throughout the matrices and

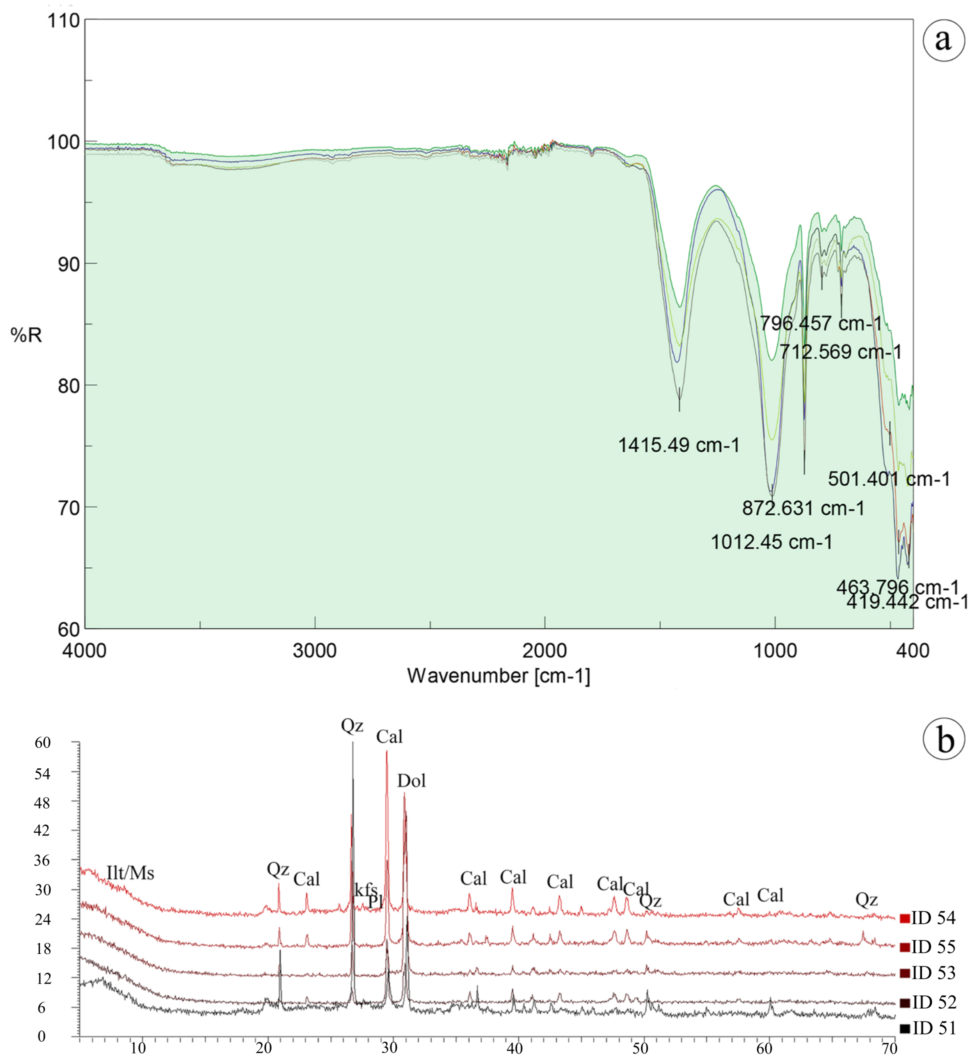

Fig. 6 **a** Graph depicting the infrared spectra with the characteristic bands of CaCO3 and SiO2; **b** white paste diffractograms (ID 51, 52, 53, 54, 55)

marked by parallel and oblique orientations with respect to the vessel walls. Plane polarised light likewise revealed a low-medium percentage of sub-rounded, fine-medium sized opaque elements appearing to be FeO. A fine fraction with low anisotropy was likewise observed in all the samples that, in general, share the same chromatic scheme of dark brown nuclei with grey, beige, red and orange surface hues, and progressive zones of contact between the different areas of those of fine fraction. The observations point to two main types of clay pellets, respectively those with greyish hues bearing diffuse limits and neutral optical density and dark brown elements with limits defined by high optical density. The pores and striations, in turn, are elongated, small-medium in size and usually distributed homogeneously, tending towards parallel or oblique orientations resulting from clay contraction during the drying and firing phases (Echallier 1984). Observations under crossed nicols often reveal micrite depositions along the inner rim of the pores stemming from the recrystallisation of calcium carbonate during postdepositional alterations.

Petrofabric 2: Ca-rich clay with heterometric limestone rock fragments with microfossils (c:f:v 10μ = 40:45:15)

The group comprises four samples: two platters, a pot and a bowl (ID 37, 52, 39, 35). As the previous group, it is characterised by quartz, dolomite and limestone fragments and FeO granules (Fig. 11e–h). Minerals such as micas (muscovites) appear to a lesser degree. The forms of the coarser fractions are sub-rounded to sub-angular. Their percentages can be broken down into 40% for the coarse fraction, 45% for the fine fraction and around 15% for the pores and striations. Moreover, apart from the common minerals, this group features the particularity of containing numerous microfossils (gastropods, sponges, oolites, red algae). Plane polarised light likewise renders it possible to detect a low-medium percentage of certain opaque

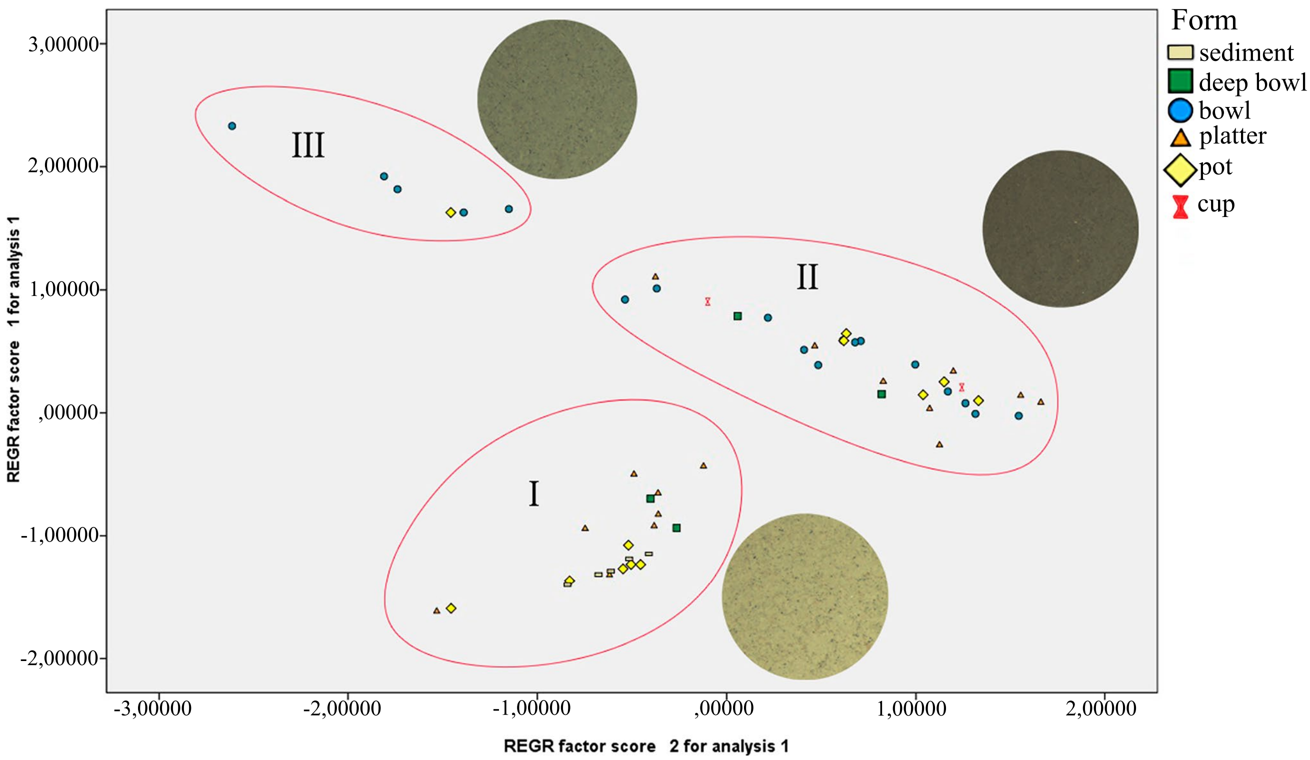

Fig. 7 Graph of the Principal Component Analysis (PCA) depicting the chromatic variability of the pottery assemblage based on colourimetric data

elements of fine-medium size of sub-rounded shape identified as FeO granules. The temper, in great relief and revealing an intense level of pleochroism, is distributed most often in a homogeneous manner throughout the matrix and oriented parallel and oblique with respect to the walls of the vessel. The finer fraction is usually characterised by low anisotropy and a colour scheme of dark brown nuclei with grey, beige, reddish or orange margins and progressive contacts between the different areas among the samples of fine fraction. The group has grey-toned clay inclusions, diffuse limits and neutral optical density, as well as dark brown clay inclusions, defined limits and high optical density. Lastly, numerous pores and striae in the form of vacuoles and/or elongated voids are commonly observed among the fine fraction. They are of small-medium size, homogeneously distributed tending towards being parallel or oblique. Observations with the crossed nicols technique suggest the deposition of micrites along the inner rim to be linked to postdepositional alterations (Quinn 2013).

Petrofabric 3: Ca-rich clay with bimodal limestone rock fragments and FeO inclusions (c:f:v 10μ = 20:70:10)

This group consists only of two bowls bearing Bell Beaker decors (ID 54, 55) that stand out due to the limestone fragments included among the fine fraction of the Ca-rich clay (Fig. 12). Although their fabric bears characteristics similar to that of the previous group, it reveals certain variations in its proportions: 20% for the coarse fraction, 70% for the fine fraction and circa 10% for the pores and striations. The phenocrysts mainly consist of dolomites. Many FeO inclusions are also distributed chaotically in the fine fraction while fragments of muscovite micas are present to a lesser extent. Worth highlighting is that this fabric bears a different, more compact structure and contains quadrangular tempers with sub-rounded edges as well as numerous brownish clay inclusions (pellets) bearing clear, sharp boundaries and a high optical density. The voids are vesicular and elongated with minute sub-rounded chambers (vughs) distributed homogeneously and oriented for the most part obliquely. These hollows, as in the case of the previous examples, reveal micrites albeit in smaller proportions.

X-ray diffraction (XRD)

The XRD mineralogical analysis identified the main crystalline phases of all the samples (Table 3). This allowed delving deeper into the petrographical compositions and confirm that there are no substantial variations between the different pottery forms (Fig. 13) and only changes among the quantities of crystalline phases. In this sense, the relationship between the sediment and sherd samples is evident from the standpoint of type and proportion. Hence, the main crystalline phases are,

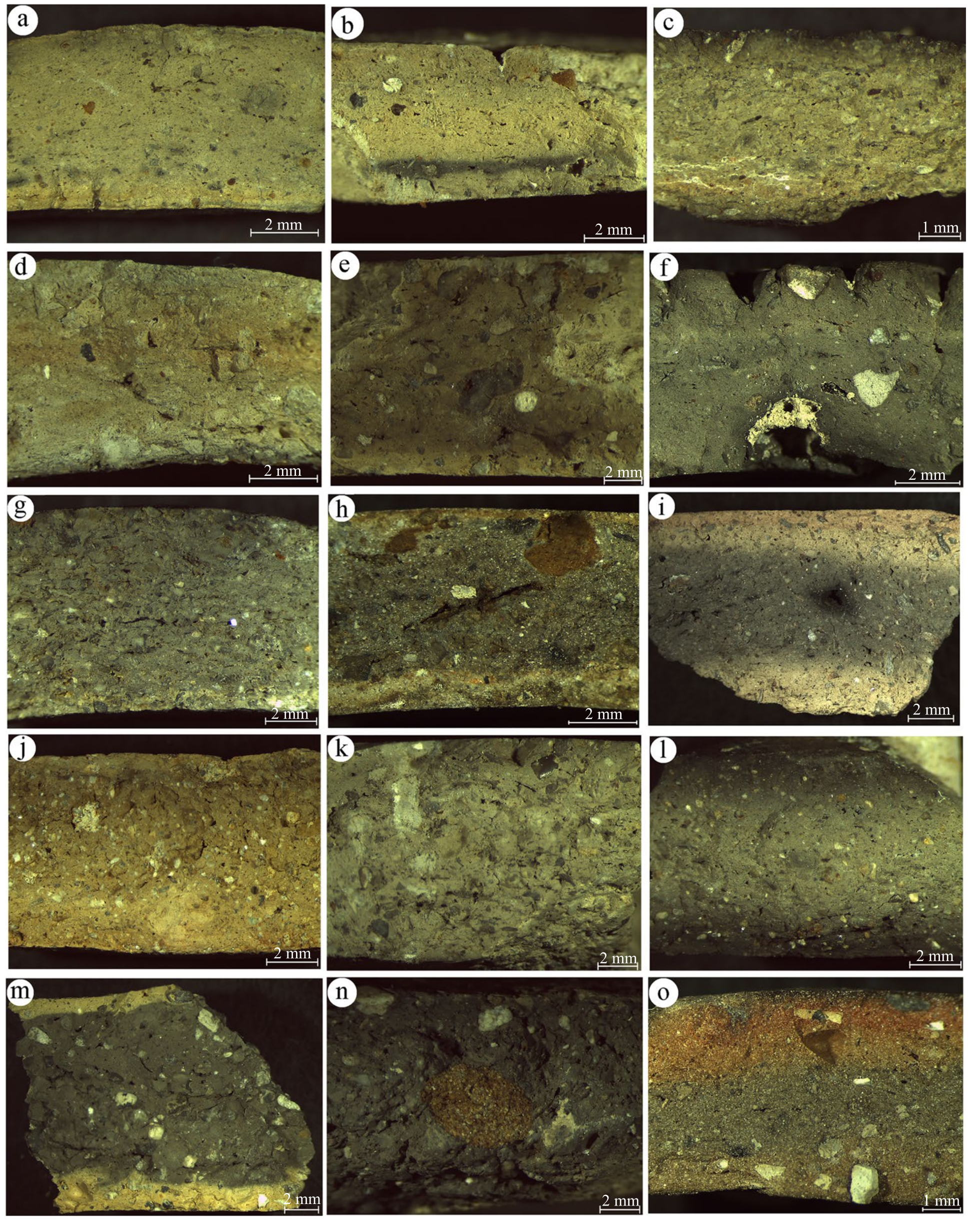

Fig. 8 Microphotographs of the technological subgroups: 1A (**a**–**f**); 1B (**g**–**o**)

respectively, calcite (29%) stemming in part from the micrite formed along the pores and thus of secondary origin (based on the petrographic observations), quartz (22%), dolomite (19%) and calcite (29%) which demonstrate its greatly calcitic characteristics. Phyllosilicates in the form of illite/muscovite micas appear in smaller proportions (5%). Finally, the feldspars can be broken down into potassium feldspar (3%) and plagioclase (3%).

Thus, the analysis evidences low quantities of clay minerals throughout the sampling, elements which disappear at temperatures between 350 and 700/750 °C (Peters and Iberg 1978). Moreover, the existence (although modest) of a number of illite/muscovite micas that vanish starting at 950/850 °C respectively (Peters and Iberg 1978; Buxeda and Tsantini 2009) thus offers very well-defined caloric ceilings. The presence of calcium carbonate and dolomites among the samples, in turn, suggests that that temperature was not exceeded so as to not induce alterations in the structures and avoid fractures throughout the firing processes as they remain stable up to 850 °C, in the first case, and 750 °C in the second (Peters and Iberg 1978; Fanlo and Perez 2011). Finally, the absence of neoformed phases linked to the destruction of phyllosilicates and calcium carbonate such as diopside, wollastonite and gehlenite (Capel 1986) is consistent with these caloric ceilings of the remaining minerals. The findings thus indicate the vessels were fired at temperatures oscillating between 550 and 750 °C.

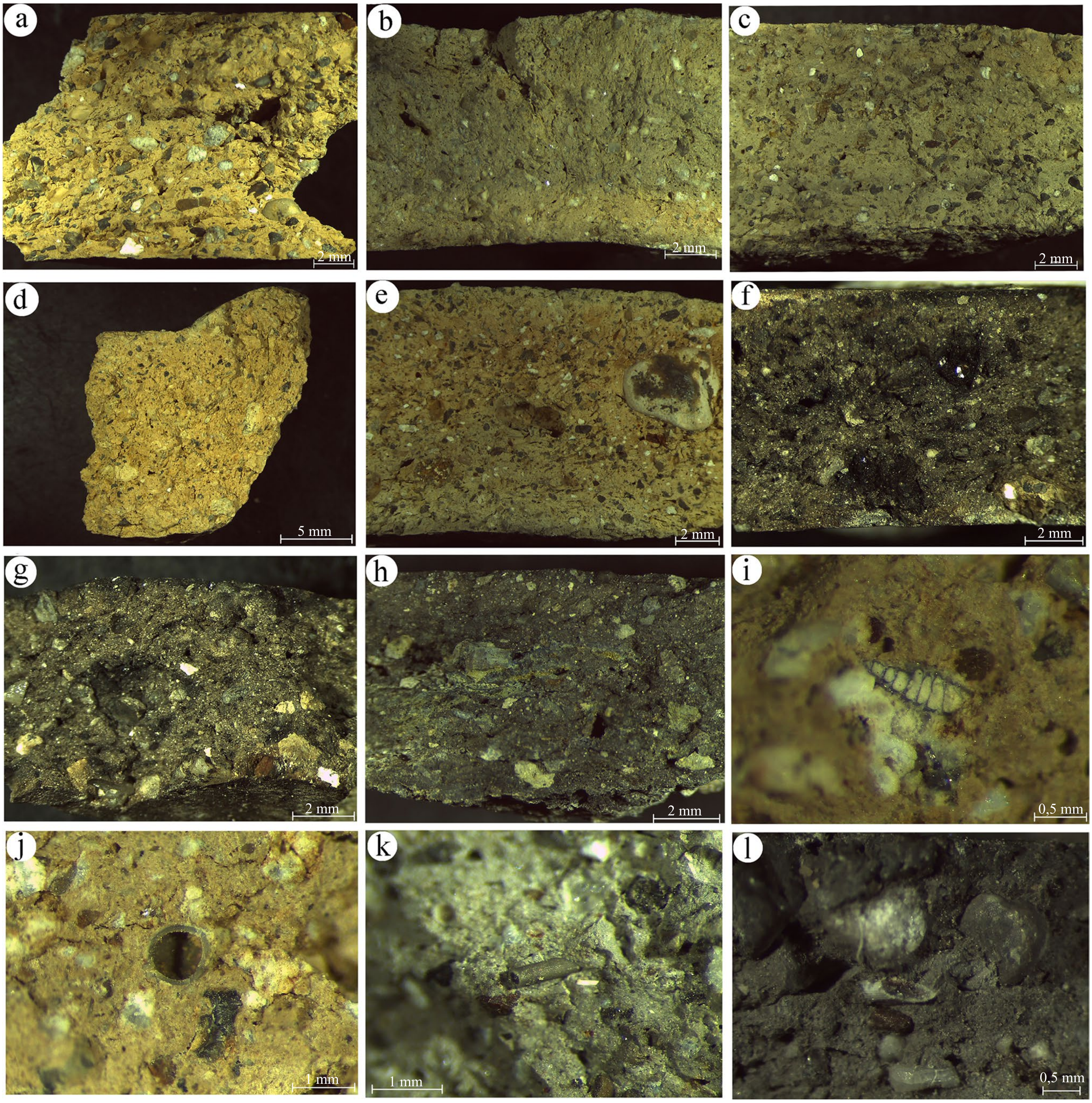

Fig. 9 Microphotographs of the technological subgroups: 1B (**a**–**g**); 1C (**h**–**o**)

Scanning electron microscope (SEM)

The SEM analyses reveal the lack of vitrification or sintering of the matrix of a calcitic nature, visible in the thin section petrography and the XRD and SEM–EDS microanalyses (Fig. 14, Supplement II). These observations thus indicate that the clays did not undergo sinterization/vitrification stemming from exposure below a temperature 700/750 °C.

Although the colourimetric study reveals a diversity of hues stemming from different firing atmospheres and, therefore, from the variations of the temperatures of the kilns of the period, the SEM analysis suggests a certain regularity in the distribution of the pores and striations of the matrix liked to the phases of drying and firing. The natural inclusions previously defined by the other techniques are perfectly integrated into the matrix reflecting a thorough kneading of the clays by the ancient potters.

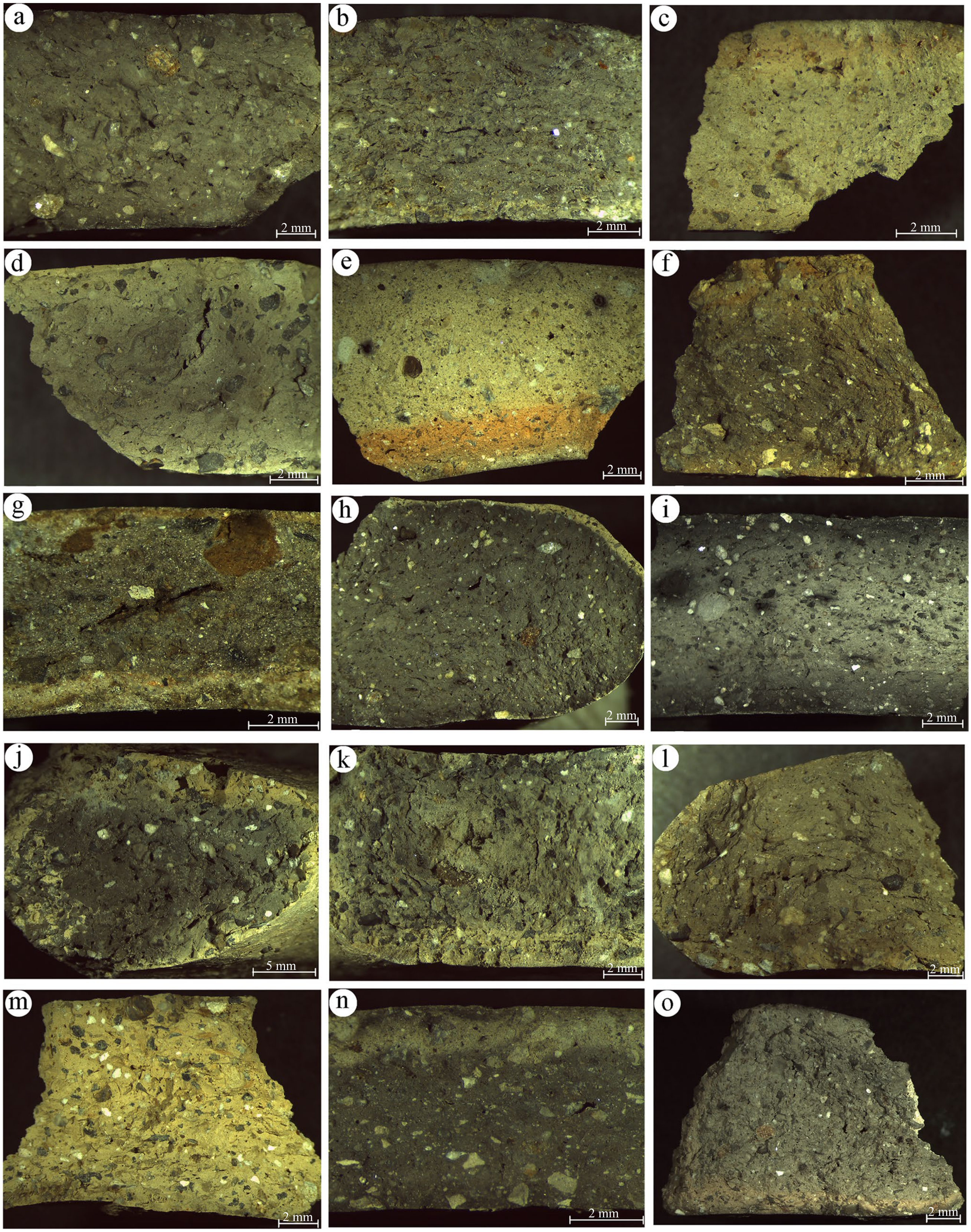

Fig. 10 Microphotographs of the technological subgroups: 1D (**a**–**e**); 2A (**f**–**h**)

Table 2 Microscopic features of the three petrographic fabric types identified among the ceramic samples of the site El Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén)

Samples	Porosity	Matrix	Inclusions	
Fabric 1: dark brown clay with heterometric limestone rock fragments (c:f:v 10μ = 20:70:10 to 35:55:10)				
ID 3, 24, 27, 56	Common: vacuoles, elongated pores and striae of small/medium size	Dark brown, colour optical activity	Fine to very fine, Sand-sized, subrounded and subangular, parallel and oblique orientation	Dominant: heterometric limestone rock fragments Common: quartz, dolomite, limestone rock fragments, FeO Rare: micas (muscovites), micrites
Fabric 2: dark brown clay with heterometric limestone rock fragments with microfossils (c:f:v 10μ = 40:45:15)				
ID 37, 52, 39, 35	Common: vacuoles, elongated pores and striae of small/medium size	Dark brown, colour optical activity	Sand-sized fine-very fine, subrounded and subangular, oriented parallel or obliquely	Dominant: heterometric limestone rock fragments Common: microfossils, quartz, dolomites, limestone rock fragments, FeO Rare: micas (muscovites), micrites
Fabric 3: dark brown clay with bimodal limestone rock fragments and FeO inclusions (c:f:v 10μ = 20:70:10)				
ID 54, 55	Common: vacuoles that are elongated and vesicular, small subrounded chambers (vughs)	FeO, dark brown, colour optical activity	Sand-sized fine-very fine, sub-rounded to sub-angular, oriented obliquely	Dominant: smaller limestone rock fragments and FeO Common: quartz, dolomites, limestone rock fragments Rare: micas (muscovites), micrites

Portable X-ray fluorescence (pXRF)

Geochemical studies were carried out on all the pottery samples and on the five sediment samples (Table 4). The multivariate statistical analysis clearly identifies the geochemical relationships of the assemblage allowing it to be divided into two large groups which are visible in both the cluster dendrogram (Fig. 15a) and in the PCA dispersion diagram (Fig. 15b–c). Thus, geochemical group IA represents almost all of the sherd and sediment samples with CaO (194,523) as the most abundant element followed by smaller proportions of Fe (24,607) and K (12,885). The minor elements are ordered as follows: Ti (1471), Mn (783), Sr (706), S (455), Sc (404), Zr (118), W (85), Cu (69), Zn (68), V (58), Rb (53), Cr (35), Mo (11), Pb (11), As (10), U (6) and Th (5). Group IB reveals variations among three of the pottery samples. These are specifically two bowls (ID 15, 34) and a platter with a bevelled rim (ID 33) devoid of Bell Beaker decor whose values differ slightly from those of both the geological sediments and the main pottery assemblage (group IA). This stems from a geochemical composition with higher values of Fe (71,702) and lower percentages of Ca (134,584) and K (12,072).

Geochemical group II (ID 30, 50, 51, 54, 55) which consists of five vessels bearing Bell Beaker decors and a bowl from a funerary context is characterised by a higher proportion of the mean value of Ca (63,070), practically double that of Fe (41,049) with respect to the IA group and practically identical in K values (12,559). For its part, the mean values of the minority elements of the samples are as follows: Sr (491), S (441), Mn (260), Sc (221), Zr (209), V (103), Cu (92), Cr (75), Rb (68), Mo (8), W (45), Zn (29), As (18), Pb (14), U (6) and Th (6).

These different elements thus confirm the close ties between the characteristics of the samples of geological sediments collected from surroundings of the site and those of the mineralogical, petrographic and geochemical groups of the vessels. These elements thus indicate that the raw materials procured to produce the pottery were located in a geographical and geological proximity to the archaeological site in spite of the fact that certain samples reveal their own peculiarities.

The operational sequence of Late Copper Age pottery manufacture in the Upper Guadalquivir Valley

Pottery is one of the least studied aspects of the Copper Age in the south of the Iberian Peninsula (Cordero et al. 2006: 22). Research on this question in recent years has nonetheless increased with the publication of several papers focusing on methods of provenancing (Odriozola, et al. 2009; Inácio

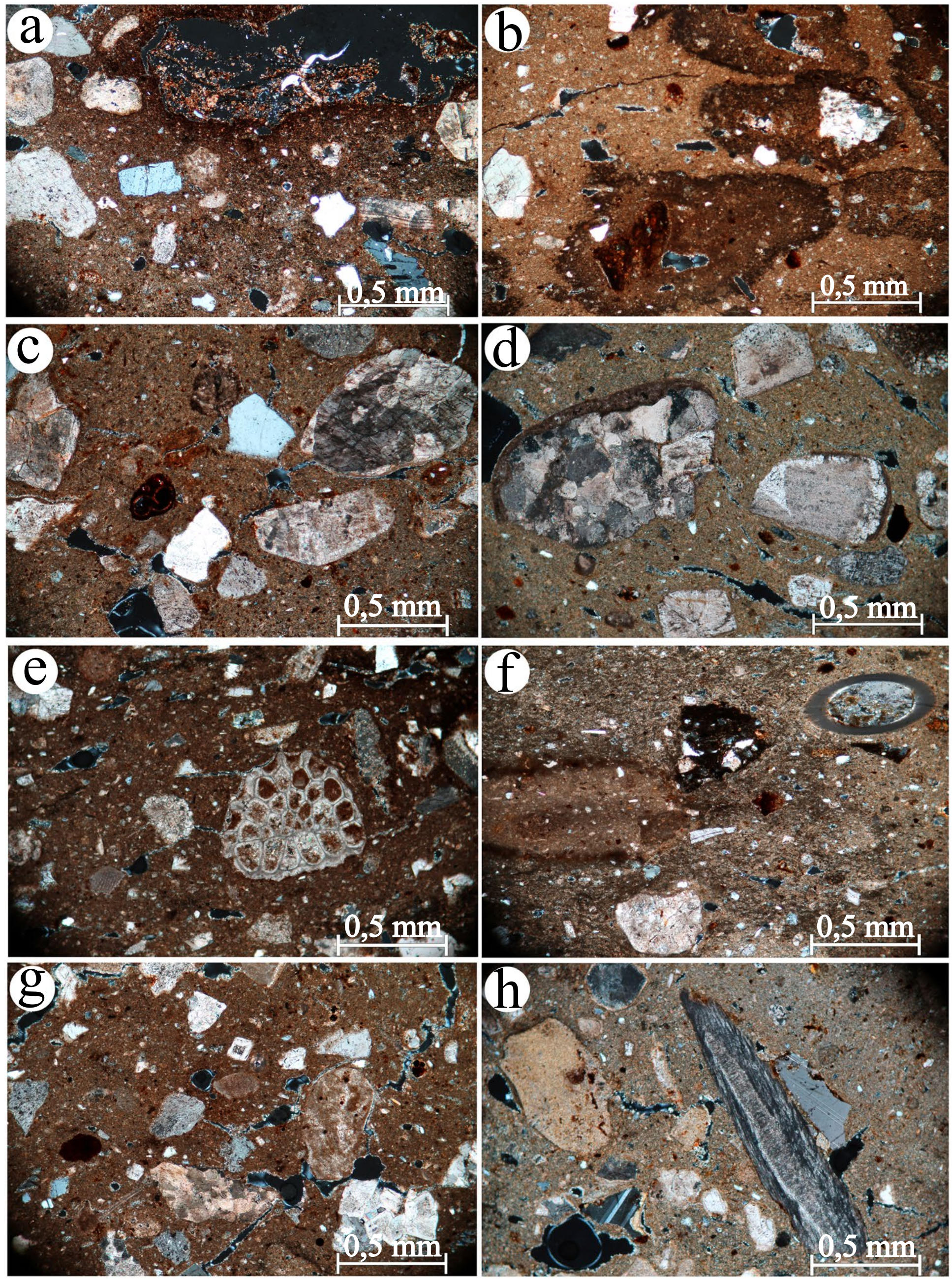

Fig. 11 Examples of potsherds corresponding to petrofabric 1 (**a**–d, ID 27, ID, 56, ID 24 and ID 3 respectively) and petrofabric 2 (**e**–**f**, ID 37, ID 35, ID 52 and ID 39, respectively). Photographs with a 5×/0.10 magnified under polarised crossed nicols

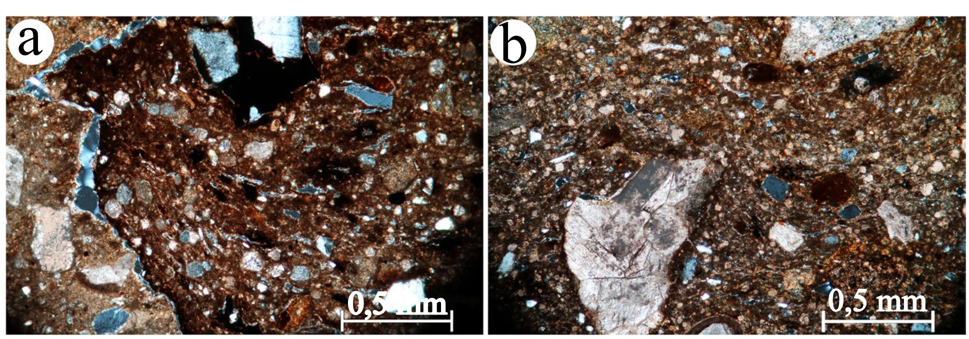

Fig. 12 Examples of potsherds corresponding to petrofabric 3 (**a**–**b**, ID 55 and ID 54 respectively). Photographs with a 5×/0.10 magnified under polarised crossed nicols

Table 3 Quantitative results of the XRD analysis of the pottery and geological sediment samples of the site of Cortijo de Montiel Bajo (Santo Tomé de la Vega, Jaén) (abbreviations according to Whitney and Evans 2010)

ID	Ms/Ilt	Qz	Kfs	Pl	Cal	Dol	Amorph
3	4	15	3	2	26	40	11
4	3	14	2	2	19	51	9
5	8	26	3	3	28	15	17
6	6	20	3	2	34	21	14
7	8	29	5	3	24	12	18
8	6	18	3	2	40	17	13
9	7	24	4	4	28	12	21
10	6	18	3	3	30	24	17
13	5	19	2	2	25	30	15
14	5	29	3	3	33	14	13
15	6	30	4	4	26	11	18
16	6	14	2	2	35	30	11
17	5	16	2	3	31	28	14
18	7	18	3	2	37	18	15
19	6	25	4	3	33	11	19
20	6	33	4	3	32	7	16
21	5	20	3	3	25	26	17
22	6	16	4	4	53	4	13
23	6	19	3	3	34	19	16
24	4	20	4	3	41	13	14
25	7	23	3	3	32	12	19
26	6	17	3	3	35	22	14
27	5	17	3	2	29	29	15
28	6	22	7	3	32	14	15
29	5	22	3	2	19	31	16
30	4	25	3	2	7	47	11
31	6	18	3	2	29	26	16
32	5	15	2	2	25	37	13
33	7	21	5	4	29	18	17
34	6	26	4	3	25	14	21
35	8	30	5	6	23	6	23
36	7	24	4	4	30	12	19
37	4	13	3	2	44	23	10
38	8	26	4	3	36	7	16
39	1	16	4	2	38	20	14
40	5	36	3	3	21	18	13
41	5	18	2	2	28	31	13
42	5	18	5	2	29	25	16
43	4	19	4	3	30	25	14
44	6	30	5	3	26	14	16
45	6	25	3	3	37	11	15
46	5	22	3	3	37	16	14
47	6	15	2	2	41	22	11
48	5	19	3	3	32	22	16
49	7	28	3	4	31	10	17
50	7	43	7	6	11	6	20
51*	6	38	5	5	9	18	19
52	5	18	3	3	32	24	15
52*	14	8	2	3	27	20	25
53	7	31	5	5	22	6	23
53*	10	11	2	2	10	52	13

Table 3 (continued)

ID	Ms/Ilt	Qz	Kfs	Pl	Cal	Dol	Amorph
54	8	42	5	4	15	8	18
54*	6	18	4	3	29	20	19
55	5	25	7	4	8	28	22
55*	7	18	2	2	19	35	17
56	6	23	3	4	40	9	15
SV-SED-001	4	29	6	2	26	21	12
SV-SED-002	10	24	4	4	36	5	17
SV-SED-003	3	30	3	2	18	31	11
SV-SED-004	5	30	4	2	22	24	13
SV-SED-005	9	22	3	4	35	11	16
Pottery [$\bar{x}$ (σ)]	5 (1)	22 (6)	3 (1)	3 (1)	29 (8)	19 (10)	15 (3)
Sed [$\bar{x}$ (σ)]	8 (3)	18 (11)	3 (1)	3 (1)	18 (9)	29 (14)	18 (4)
White paste [$\bar{x}$ (σ)]	6 (3)	27 (3)	4 (1)	2 (1,09)	27 (7)	18 (10)	13 (2)

et al. 2015), operational sequences (Inácio 2015; Dorado et al. 2017, 2021; Inácio et al. 2017, 2019; Vico et al. 2018; Del Pino et al. 2019; Pinillos 2019) and ornamental elements such as white paste inlays (Odriozola et al. 2007, 2012; Molina et al. 2017). Hence, following the different technical actions characteristic of a manual pottery manufacture (Orton et al. 1993; Calvo et al. 2004; Forte 2013–14; Roux 2019), this study offers an interpretation of the results garnered from the different analytical techniques which can be summarised as follows: procurement and preparation of the raw materials, modelling, surface treatment, decorating, drying and firing.

The macroscopic analysis of the source of the raw materials of the pottery of El Cortijo de Montiel Bajo, which equates with the first phase in the operational sequence of its manufacture (Rye 1981; Livingstone-Smith 2007), has differentiated two technological groups that reveal close links to the geological surroundings of the site. The clay procured to manufacture the pottery is thus presumably associated with Quaternary deposits of the De la Vega River and, more rarely, with deposits linked to the Guadalquivir. This is reflected through petrographic analyses that, besides suggesting that the raw materials were poorly prepared, reveal the presence of a coarse fraction bearing in its matrix a high percentage of rounded sand and iron oxides. It is noteworthy that the iron oxides reveal a higher percentage among petrographic group III and geochemical group II, an aspect that is consistent with the geographical location of the fluvisol soils characteristic of environments with abundant organic matter such as cultivated fields and alluvial deposits (Gallardo 2015).

Following this line, the pFRX analysis clearly places the main raw material catchment area in the proximity of the De la Vega River. This technique also evidences how geochemical group I (the largest of the assemblage) is clearly associated with sediment samples SV-Sed 001 and SV-Sed-002 dominated by silts and clays from the banks of the De la Vega River. Furthermore, the analysis indicates that SV-Sed 003, abundant in gravel, grey loams, calcareous sandstones and reddish silts, and SV-Sed-005, mainly fine gravels, silts and clays, originate in fields having served to cultivate olive trees. Sample SV-Sed-004, in turn, rich in silt and clay originating from the banks of the Guadalquivir is linked to geochemical group II and represented by a more modest number of ceramic samples. Therefore, the close relationship between the ceramic samples and the sediments collected in the site's surrounding forebear identifying raw material catchment areas in geographical and geological areas removed from the surroundings of El Cortijo de Montiel Bajo.

Vessel modelling equates with a phase of the operational sequence that serves as a true value of identity (Roux 2019) as the way vessels are conceived, reproduced and decorated (Gosselain 2011) incarnate stylistic canons of a society (Lemmonier 1992). It is in fact possible in this case to confirm a predilection for certain construction strategies as approximately 65% of the samples (generally platters, pots and deep bowls) applied the basketry technique, at times combined with coiling. These means of building medium- and large-sized vessels are common to assemblages from numerous sites in the south of Iberia such as Almizaraque (Cuevas de Almanzora, Almería), Los Millares (Santa Fe de Mondújar, Almería), Terrera Ventura (Tabernas, Almería), El Malagón (Cúllar-Baza, Granada) and Las Angosturas (Gor, Granada) (Rovira 2006). However, vessels bearing traces of moulds in the SE of Iberia are more common compared to those with more carefully finished surfaces characteristic of the Guadalquivir Valley (Vico et al. 2018). Furthermore, the use of moulds in these areas appears nonetheless to relate to functional needs, that is, to a rapid making of vessels without prioritising aesthetic or

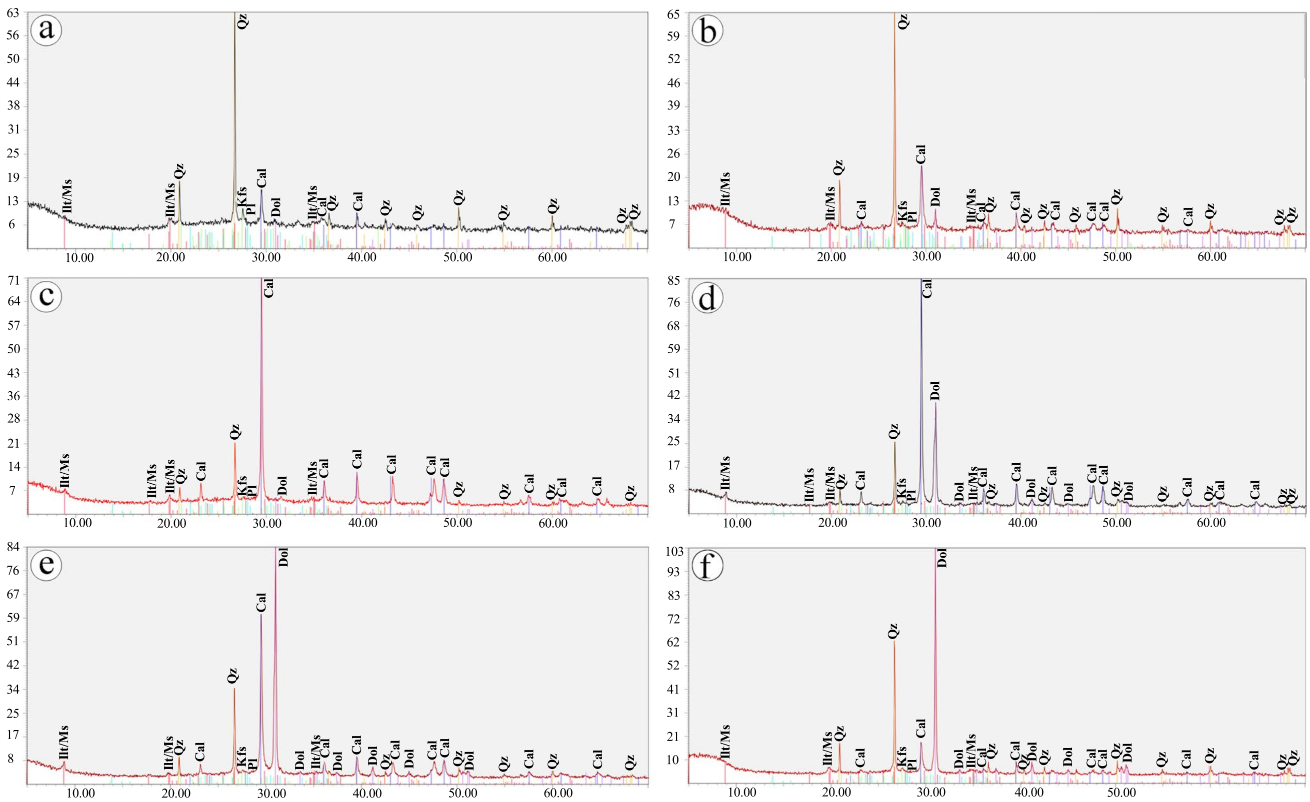

Fig. 13 Representative diffractograms of the groups of the study according to a greater presence of quartz (**a–b**, ID 2 and ID 3), calcite (**c–d**, ID 48 and ID 6) and dolomite (**e–f**, ID 33 and ID 39) (abbreviations according to Whitney and Evans 2010)

other criteria. The remaining samples, representing around 35% of the assemblage (mainly bowls), were fashioned by pinching or hollowing, techniques evidenced by fingerprints and irregular rims.

The study of vessel compactness, a quality also demonstrated by the petrographic analyses, is commonly based on the appearance of more or less regular matrices marked by pores and striations stemming from the drying and firing phases. These different elements suggest that the strategies of pottery construction yielded vessels with relatively compact bodies (Gámiz 2018), an aspect that is common to fine ware bearing decorative motifs (petrographic group III) and low proportions of pores and striae.

Among the surface treatments stands out is the smoothing technique, mostly by hand. It is most often visible on bowls, platters and deep bowls. Burnishing, in turn, is linked mainly on pots, bowls and platters. This second technique is characterised by metallic- or polychrome-type surfaces stemming from rubbing with smooth object (Gámiz et al. 2013). A lesser observed technique is that of the spatula identified by surface striations and furrows on pots, deep bowls and a cup. The burnishing technique not only resists the loss of moisture of the foodstuffs contained in the vessels as evidenced of its application only to the interiors but likewise yields a shiny lustre that in certain cases offers aesthetic connotations during consumption, especially in case of Bell Beaker ware (Dorado et al. 2017). This treatment among the current samples is usually associated with medium and large vessels that on occasion bear a coarse exterior finish. This is the case of the technological subgroup 1D consisting of platters and pots with a high proportion of temper. These vessels hardly depreciated over time as evidenced by perforations to repair them and prolong their life. It is compelling to highlight that certain samples reveal polychrome burnishing, a technique typical of the productions of the Upper Guadalquivir Basin (Nocete 1994). It probably derives from a specific and intentional strategy linked to how the vessels were arranged inside the kilns during the firing.

Bell Beaker ware production not only comprised surface treatments, but another series of decorative features. Their proportion among the current assemblage of El Cortijo de Montiel Bajo is nonetheless a very low compared to the undecorated ware. Motifs of this type produced by incision and impression (Cuomo di Caprio 2007) are visible on one platter and five bowls. The incisions are represented by continuous oblique, vertical or horizontal lines, whereas impressions were carried out with a punch yielding hemispherical motifs or a spatula leaving thicker oblique lines. The two techniques were combined to produce the 'sun-shaped' and zig-zag motifs. Common to these vessels

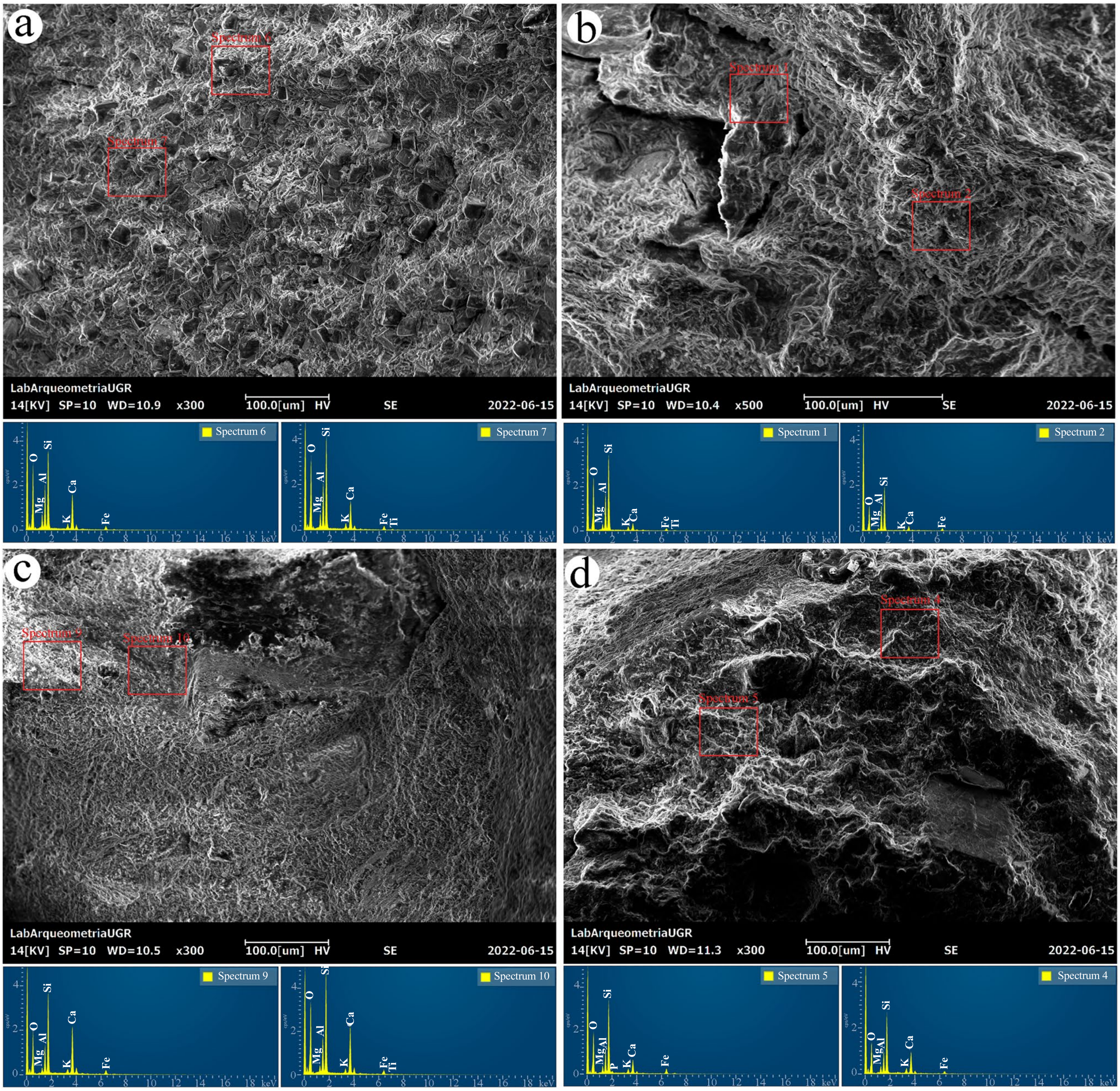

Fig. 14 Scanning electron microscope (SEM) results of potsherds with a calcareous matrix: **a** ID 53, **b** ID 50, **c** ID 52 and **d** ID 54

are also decorations arranged in friezes grouped in horizontal and parallel bands separated by smooth empty spaces of varying size.

These elements are common to the manufacture of pottery of the Lower Guadalquivir Valley (Muñoz 1983) and to other areas of the south of the Iberian Peninsula in Late Bell Beaker phases when comb impressions practically disappeared giving place to 'symbolic' motifs on vessel interiors (Molina et al. 2017). The links through natural passes from the High Plains of Granada to the SE of Iberia could explain the similarities between certain political oppositions with respect to the western rolling slopes of the vast territory known as the Campiñas del Alto Guadalquivir (Nocete 1994). On the other hand, certain features such as surface finishings on platters or polychrome burnishing suggest closer ties with the Guadalquivir Valley than with those from the SE of Iberia.

There are specific parallels among the patterns of Bell Beaker decors of El Cortijo de Montiel Bajo with vessels from the site of El Manzanil (Loja, Granada) (Fresneda 1980: plates XI-XII). However, the presence of point-based lines reveals major differences. There are likewise no clear

Table 4 Results of the XRF analysis of the pottery and geological sediments from surroundings of the site (expressed in ppm)

Sample	Form	Mo	Zr	Sr	U	Rb	Th	Pb	As	Zn	W
3	Platter	6	88	645	7	41	4	10	5	43	41
4	Vessel	12	161	347	6	22	4	12	8	13	41
5	Platter	17	138	755	9	78	4	15	7	129	70
6	Storage vessel	12	66	596	6	41	4	6	7	94	149
7	Pot	9	124	856	6	79	4	14	6	84	112
8	Platter	8	109	749	6	47	4	9	7	57	41
9	Bowl	18	97	969	6	65	8	10	14	118	153
10	Pot	11	98	867	6	54	5	10	7	70	41
13	Platter	18	77	678	6	51	4	9	9	116	145
14	Platter	16	158	651	6	62	7	11	10	81	109
15	Bowl	18	163	1055	14	84	4	22	5	162	331
16	Pot	5	77	515	6	37	4	7	5	47	41
17	Pot	9	89	627	7	44	4	6	5	49	42
18	Vessel	10	73	652	6	38	4	8	6	69	41
19	Platter	14	105	833	6	67	4	15	8	112	70
20	Storage vessel	15	84	787	6	48	4	6	9	85	94
21	Pot	17	84	704	16	53	4	8	5	93	80
22	Platter	14	144	760	11	74	9	14	24	73	41
23	Bowl	12	103	874	6	58	4	10	9	73	64
24	Pot	18	87	907	14	49	4	6	15	48	77
25	Platter	9	81	573	6	41	4	9	6	45	41
26	Bowl	12	86	719	6	45	4	15	30	52	48
27	Storage vessel	12	80	731	9	45	4	6	47	66	41
28	Platter	7	89	736	6	49	4	8	11	35	41
30	Platter	8	195	408	6	68	8	6	14	14	41
31	Bowl	14	87	654	6	47	4	7	19	52	41
32	Platter	10	95	660	7	48	4	13	13	37	41
33	Platter	26	138	839	6	84	11	6	49	146	347
34	Bowl	21	137	1088	6	97	4	6	41	193	744
35	Bowl	13	91	767	6	65	7	26	11	104	105
36	Platter	11	101	814	6	58	4	17	8	75	41
37	Platter	9	82	608	6	41	4	14	5	44	41
38	Pot	13	118	798	6	60	4	30	7	80	71
39	Pot	6	85	824	6	35	4	9	5	35	41
40	Bowl	14	108	806	6	60	6	14	5	74	41
41	Pot	11	77	666	8	42	4	6	6	40	41
42	Storage vessel	5	95	706	6.05	44	4	9	5	41	41
43	Platter	7	84	612	6	39	4	10	5	36	41
44	Bowl	19	129	752	6	67	4	14	10	168	194
45	Pot	8	92	758	6	52	4	11	5	46	45
46	Pot	7	95	898	6	54	4	9	5	47	51
47	Pot	7	80	610	6	38	4	6	5	61	41
48	Bowl	7	98	654	6	53	4	13	5	52	41
49	Bowl	13	107	1025	6	60	4	14	5	70	53
50	Bowl	6	246	369	6	72	9	25	25	49	41
51	Bowl	9	219	582	8	74	5	11	8	47	65
52	Platter	12	85	482	6	37	4	8	5	58	46
53	Bowl	7	157	556	6	60	5	6	7	30	42
55	Bowl	9	200	517	6	67	8	12	5	23	41
56	Bowl	8	88	666	6	45	4	17	5	53	41

Table 4 (continued)

Sample	Form	Mo	Zr	Sr	U	Rb	Th	Pb	As	Zn	W
29	Bowl	5	74	564	6	39	4	8	6	22	41
SV-SED-001		16	166	483	6	57	7	15	6	35	72
SV-SED-002		8	111	705	6	72	4	11	5	42	41
SV-SED-003		17	227	262	9	42	11	6	8	24	100
SV-SED-004		7	793	366	7	42	28	17	6	28	41
SV-SED-005		5	114	527	6	65	4	16	5	52	41
Sample	Form	Cu	Fe	Mn	Cr	V	Ti	Sc	Ca	K	S
3	Platter	34	16,938	337	23	40	1260	486	240,571	14,181	1215
4	Vessel	35	33,710	87	70	75	2626	394	154,981	6419	495
5	Platter	82	31,240	1085	33	69	1749	343	143,372	13,468	338
6	Storage vessel	97	28,826	1059	89	46	1208	271	189,227	11,201	338
7	Pot	59	27,445	837	39	73	2239	340	167,633	21,497	522
8	Platter	38	18,150	715	18	54	1387	485	250,322	13,538	338
9	Bowl	90	34,402	1214	56	58	1274	410	173,780	11,874	524
10	Pot	30	21,069	1159	18	72	1662	385	214,508	13,765	338
13	Platter	108	29,759	1052	55	51	1127	331	182,511	11,321	383
14	Platter	100	27,038	1185	31	69	1389	404	163,864	1111	338
15	Bowl	192	56,140	2160	94	69	1543	280	136,381	13,169	338
16	Pot	49	13,153	348	18	59	1298	423	246,671	13,265	822
17	Pot	46	16,811	476	18	47	1248	542	237,622	12,983	338
18	Vessel	43	14,639	405	18	40	1037	640	245,508	14,947	995
19	Platter	64	24,819	1031	18	62	1442	561	211,087	15,615	338
20	Storage vessel	82	28,293	807	45	50	1113	388	169,252	11,738	647
21	Pot	119	26,576	954	31	48	1242	384	152,319	12,022	338
22	Platter	67	34,535	155	30	56	1631	472	182,116	12,232	338
23	Bowl	61	23,031	806	18	70	1704	472	222,470	14,454	338
24	Pot	55	22,059	984	18	49	1046	419	201,000	11,517	457
25	Platter	39	19,784	702	18	63	1593	504	209,164	12,542	552
26	Bowl	50	18,028	825	18	66	1282	522	247,719	11,524	338
27	Storage vessel	112	25,222	1179	42	69	1069	479	182,762	9491	338
28	Platter	53	15,135	464	18	62	1326	391	232,955	13,913	934
30	Platter	35	29,173	406	45	65	2467	262	88,012	14,984	338
31	Bowl	105	18,538	487	18	63	1188	441	244,137	11,629	586
32	Platter	46	16,370	545	18	54	1476	454	229,116	11,438	338
33	Platter	226	70,762	1913	129	87	1569	294	150,248	11,381	491
34	Bowl	322	88,207	3152	162	73	1682	157	117,123	11,667	51
35	Bowl	71	34,340	1198	64	66	1784	260	127,199	15,077	533
36	Platter	38	20,838	677	18	57	1434	291	158,162	13,076	451
37	Platter	40	17,189	431	18	59	1287	545	251,660	12,710	338
38	Pot	60	22,409	628	33	59	1418	430	20,842	16,223	736
39	Pot	30	15,772	615	18	39	1168	377	273,472	11,993	338
40	Bowl	104	22,648	746	25	58	1528	376	150,263	11,868	347
41	Pot	43	17,037	376	18	45	1063	461	204,021	10,514	338
42	Storage vessel	32	15,188	414	18	53	1253	420	183,391	12,911	338
43	Platter	80	14,248	426	18	38	992	442	201,037	11,431	522
44	Bowl	126	35,747	952	56	68	1366	322	160,993	12,472	338
45	Pot	22	17,372	685	18	56	1127	381	201,863	12,192	550
46	Pot	30	19,820	861	18	57	1411	447	211,647	15,291	443
47	Pot	43	14,348	392	18	59	1172	511	257,748	11,575	338

Table 4 (continued)

Sample	Form	Cu	Fe	Mn	Cr	V	Ti	Sc	Ca	K	S
48	Bowl	33	16,670	623	18	66	1543	535	209,890	13,994	338
49	Bowl	71	21,953	643	18	66	1763	443	189,977	14,523	440
50	Bowl	56	52,256	106	131	151	5307	131	51,271	11,065	338
51	Bowl	49	43,992	194	83	103	3904	249	64,595	14,000	338
52	Platter	51	17,863	628	23	44	1145	331	196,440	10,023	338
53	Bowl	36	32,404	318	65	89	2946	335	132,360	16,668	338
55	Bowl	20	41,367	73	80	102	3612	158	49,097	12,629	338
56	Bowl	45	17,447	423	18	52	1388	539	218,811	14,427	338
29	Bowl	19	13,253	400	18	46	1455	306	170,917	11,517	338
SV-SED-001		61	17,443	592	36	31	992	324	184,309	9924	409
SV-SED-002		31	22,435	751	27	87	2381	296	177,601	18,483	338
SV-SED-003		71	17,140	379	37	28	810	279	193,279	10,357	338
SV-SED-004		30	15,705	555	18	69	2786	371	205,284	13,935	684
SV-SED-005		34	19,641	885	33	70	1881	361	148,056	14,988	338

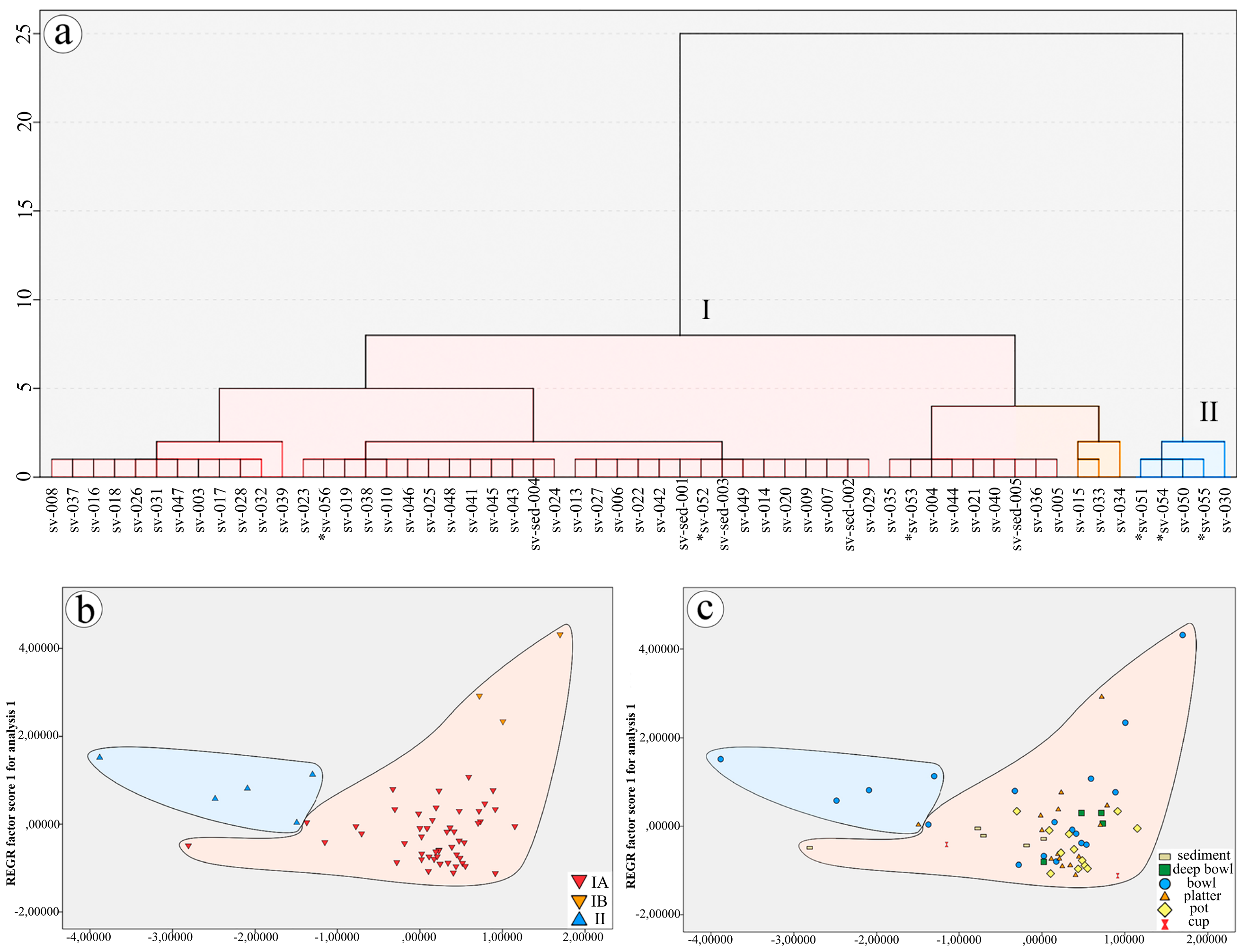

Fig. 15 Dendrogram and simple dispersion graphs of the principal component analysis (PCA). They represent the results the X-ray fluorescence (XRF) analysis of the geochemical groups (*vessels with Bell Beaker decors)

similarities with sites in the west of the Province of Granada, notably the most recent phases of Los Castillejos (Las Peñas de los Gitanos, Montefrío, Granada) or Cerro de la Encina (Monachil, Granada) (Carrilero 1991; Vico 2016; Dorado et al. 2017). There are however ties with vessels from phase II.3 of the Cerro de la Virgen (Orce, Granada) (2250–2150 BC) dominated by incised and interior decors. This last site also reveals decors of symbolic nature such as 'sun-shaped' motifs, a type that is likewise frequent at the eponymous site of Los Millares (Molina et al. 2017; Cámara et al. in press).

The similarities and differences of decorative techniques may have chronological connotations, notably the absence of comb impressions and complex patterns and the presence of decors on vessel interiors. There may be, however, other explanations of contextual character (such as the absence of decors on large vessels) or what is of even greater interest, of ethnic nature.

It is therefore possible to suppose a greater relationship, as in later times (Molina et al. 2002), between areas of the Upper Guadalquivir and those of southeastern Iberia, and a lesser connection, between the westernmost sectors of the Province of Jaén indicated by the proliferation of decors on the interior of vessels. However, there is also evidence, as noted above, of certain smooth undecorated traditions suggesting a disconnection with other areas of the southeastern of Iberia.

Another compelling aspect is the use of decorative white CaCO3 and SiO2 inlay in other territories (Odriozola et al. 2012). The results garnered so far in Iberia's southeastern quadrant suggest that these materials, as in the case of the clays, were local materials. The inlayed white paste of Cerro de la Virgen, as opposed to that of El Cortijo de Montiel Bajo, suggests a preference for gypsum (Molina et al. 2017). The fact that these decorative elements are found on a platter with a bevelled rim and several bowls suggests these vessels served for consumption, most often liquid, possibly in the framework of exceptional events (Garrido 1999; Guerra and Delibes 2019). This idea is bolstered by their association with human remains and with the ditch delimiting the settlement's perimeter.

The study also indicates that 48% of the vessels of the assemblage, in particular the bowls, where subjected to an irregular reduction firing process. Furthermore, the colourimetric analyses suggest that group II, the largest of the lot, is marked by the highest percentage of reduced firings. Colouration, in any case, is an aspect that can respond to variations in temperature and a lower or higher presence of oxygen. It is also linked to greater or lesser quantities of organic matter (roots, fibres, humus, manure) in the clay itself. Another 35% of the assemblage reveal oxidising firings while 15% indicate mixed conditions. The mixed firings, most commonly associated with platters and bowls, suggest an absence or lack of control of the flow of oxygen. The colourimetric results likewise signal that group I incorporates all the geological sediment samples, as well as a greater number of vessels linked to oxidation atmospheres. However, the hue most commonly associated with oxidising conditions can in fact relate to clay composition (Shepard 1956; García and Calvo 2006; Cuomo di Caprio 2007), which in this case, based on the different analyses, is of calcareous origin. Therefore, as evidenced by the analyses of the sediments of this group, the firings concord with productions that oscillate between yielding hues of beige in the case of oxidising atmospheres and only grey tones in the case of reductions (Cultrone et al. 2011).

Lastly, the colourimetric analyses also highlight that the two bowls bearing Bell Beaker motifs that form group III, despite being the smallest group, differ from the decorated vessels of group II as they are the only cases bearing 'sun-shaped' motifs combined with oxidising and mixed firings. In spite of the chromatic heterogeneity of their fabrics, they could betray an intentional search for different shades as well as other technical choices either related to the control of the flow of oxygen in the kilns or to the types of clays (Rye and Evans 1976; May and Tuckson 1982; Gosselain 1995; Livingstone 2007; Calvo et al. 2004). However, the lack of possibility of adding fuel to these types of kilns, led to firing temperatures rarely exceeding 700/750 °C. This thermal range is in line with the findings of the XRD analyses revealing an absence of diopside or wollastonite as well as by the microstructural results evidencing no vitrification or sintering of their clay structures. This notion is likewise bolstered by the macroscopic analyses of the surfaces which identified networks of thermal cracks, modifications of the original form and the appearance of vertical fractures which are wider at the edge than at the base (García and Calvo 2006, 2013).

Conclusions

The archaeometric study of the ceramic assemblage of the settlement of El Cortijo de Montiel Bajo thus sheds new light on technological characteristics of pottery from the Late Chalcolithic. A key aspect is that the ware unearthed at the site bears Bell Beaker decors that, although devoid of the typical comb patterns, do reveal symbolic motifs along their interiors that resemble those of other sites in the SE of the Iberian Peninsula (Molina et al. 2017; Cámara et al. in press). Their chronological timeframe is corroborated by a radiocarbon dating and by comparisons with finds from other settlements in southern Iberia (Vico et al. 2018; Pinillos 2019; Dorado et al. 2017, 2021; Molina et al. 2017; Del Pino et al. 2019).

Although the total number of samples is rather modest, it does allow exploring a series of technological characteristics that are key to grasping the tradition of pottery making of the Chalcolithic in the Upper Guadalquivir Valley. In this sense, it is relevant to point out that clays from the surroundings of the site were collected to manufacture both the undecorated and decorated vessels. Moreover, the analyses signal that a small number of vases bearing Bell Beaker decors and a bowl unearthed in a funerary structure contain greater amounts of FeO suggesting that certain specific raw materials were procured to fashion vessels of symbolic nature. Beyond this assessment, the findings undoubtedly highlight general variations in the geochemical composition of the clays from the surroundings of the site, disparities that are likewise evidenced by the proportions of quartz, dolomite and limestone (at times bioclastic microfossils) garnered through the petrographic analyses of the fabrics.

Thus, although the presence of Bell Beaker ware implies that the settlement of El Cortijo de Montiel Bajo formed part of a network stretching across a vast explatterse of Europe at the time, and the characteristics of the techniques and style allow affiliating the site with concrete cultural entities and chronological frameworks (Soares and Silva 1974–77; Harrison 1987) of the SE of Iberia in the final phases of the 3rd millennium BC, the local character of the raw materials and production processes (including the other vessels, notably from phase 1) places the site clearly in the tradition of the south of the Iberian Peninsula. This therefore suggests a continuity of the population and contrasts with recent proposals stemming from genetic research (Olalde et al. 2018).

Finally, the study of this pottery assemblage suggests it to be the fruit of a domestic manufacture carried out by potters who were aware of contemporary formal and technological standards (Bate 1998). Their intention was to produce vessels destined mainly to the daily necessities of storing, processing and consuming foodstuffs (Colomer 1995) while simultaneously, at times, desiring to reproduce elements of a social system and of power mechanisms characteristic of the Late Chalcolithic (Inácio et al. 2019). To conclude, it is noteworthy that the dating of the decorated Bell Beaker ware from El Cortijo de Montiel Bajo coincides with transformations taking place elsewhere at the end of the 3rd millennium BC during the transition between the Chalcolithic and the Bronze Age (Lull et al. 2010, 2015, 2020; Molina et al. 2014, 2016, 2020a, b; Jover et al. 2019, 2020).

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Author contribution Conceptualisation, data collection, investigation, development and edition of manuscript (P.P. and A.D); investigation, writing (original draft), development and edition of manuscript, conceptualisation, methodology (reviewing and editing) (A.D and JA.C); data collection (C.P).

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Declarations

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Consent for publication Not applicable.

Consent of interest The authors declare no competing interests.

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