Archaeological and Anthropological Sciences (2021) 13: 11
https://doi.org/10.1007/s12520-020-01259-z

ORIGINAL PAPER

Cutting down on the grog: the crystallisation of Neolithic ceramic traditions at Cova d'En Pardo (Alicante, Spain) and cultural change in the western Mediterranean basin (mid-6th and 5th millennia cal. BC)

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Received: 28 August 2020 / Accepted: 7 December 2020 / Published online: 6 January 2021

Abstract
This paper presents the characterisation of 48 ceramic samples from Cova d'En Pardo (Alicante, Spain). Provenance and technology analysis are carried out on materials dated back to different Early and Middle Neolithic cultural phases, including pioneer and Epicardial levels, poorly known in the area. The techniques employed are optical petrography and scanning electron microscope. Two main fabrics were identified, characterised by the heavy presence of temper (grog and calcite), along with five minor petrographic classes, including two imports, one of them probably from southern Iberia. The comparison among occupational phases within the site reveals changes along the stratigraphic series, especially during the transition from the 6th to 5th millennia cal. BC, which is reflected in temper choice. Evidence from the earliest occupation of the site also agrees with the picture of discontinuity previously observed on nearby contexts between pioneer and traditional Cardial ceramic technology, which might be connected to neolithization routes. Firing technology is characterised by the occurrence of microstructure gradients and signs of fast heating rates.

Keywords Neolithic · Pottery · Provenance · Technology · Optical petrography · Scanning electron microscopy

Introduction

The adoption of pottery is of fundamental interest in the study of early farming communities, as it fulfilled needs as varied as the storage of staples, food preparation and consumption (Rice 1987; Barnett and Hoopes 1995; Jordan et al. 2016), not to mention its expression of social values through the variety of designs made possible by its malleable nature or by its gifting and exchange accompanied by biographical stories (Tomkins and Day 2001). Often seen as a leap forward in terms of technology, the almost limitless variations in style have permitted the definition of both chronological sequences and cultural boundaries (Adams and Adams 2008, pp. 97–154). While such variability has often been defined in terms of

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morphology and decoration, other approaches to material culture and ethnographic studies have demonstrated that understandings of technology are equally powerful as a guide to the transmission of knowledge, skilled practice and the expression of identity, accessible through the detailed analysis of the production of ceramic objects (Gosselain 1998; Tite 1999; Lindahl and Pikirayi 2010; Gandon et al. 2014). According to this latter perspective, archaeological ceramics are better seen as the result of a series of actions which enable the transformation of raw materials to final goods, these processes being studied through the *chaîne opératoire* approach, which takes into account both material and cultural constraints (Lechtman 1977; Roux 2017).

Although we now know that pottery vessels occur in hunter-gather societies (Hommel et al. 2016; Jordan et al. 2016, etc.), in many areas its general introduction comes as part of daily life of farming communities (Arnold 1985, pp. 109–126; Halstead 2011). In the North Western Mediterranean, the introduction of pottery occurred mainly as part of the neolithization process, during the first half of the 6th millennium cal. BC (García-Martínez de Lagrán 2015; García-Puchol et al. 2017; Manen et al. 2019). Ceramic studies of this period have fuelled debates over processes of transmission, diffusion and cultural definition at a regional scale (Bernabeu Auban et al. 2009; Gomart et al. 2017; Rigaud et al. 2018). According to those works, the landscape was characterised by communities settled in coastal areas from the Tyrrhenian Sea to the Atlantic, associated with a relatively consistent style characterised by decorative patterns based on *Cardium* sp. shell impression (Cardial ware). The stylistic homogeneity of these groups is generally attributed to a rapid maritime expansion and the maintenance of inter-community networks, which aided the movement of people, goods and ideas (Zilhao 2001; Isern et al. 2017; Gabriele et al. 2019). It was thought that this pattern subsequently broke down, leaving a number of geographically delimited stylistic traditions during the last centuries of the 6th millennium cal. BC, and especially during the subsequent 5th millennium. In turn, these traditions are seen as indicative of varied historical trajectories during the Epicardial and Postcardial cultural horizons (Bernabeu Auban 1999; Malone 2015; van Willigen 2018).

While the traditional model of maritime expansion continues its dominance, recent research has added a new layer of complexity to the study of the neolithization process, as systematic radiocarbon dating has demonstrated that some settlements *predate* those assigned to the traditional Cardial contexts (García-Puchol et al. 2017; Manen et al. 2019). This seems to testify to the sporadic arrival of pioneer communities in Southern France and Iberia from the Western and Central Mediterranean (Manen et al. 2007; Guilaine 2018). The typological variability observed in the ceramic record of these early contexts may represent the varied source areas of such migration, and this raises a range of questions regarding the local development of ceramic traditions (García Atiénzar 2010; Manen et al. 2019).

However, these traditions vary throughout the Neolithic not only in terms of style but also in terms of their whole production sequences. Diachronic studies, often based on optical petrography (Barnett 2000; Convertini 2010), suggest that new technological traditions formed as farming communities spread, and that these ways of doing were constantly reformulated. Such studies have emphasised local variability in ceramic material culture, with compositional variation in ceramic pastes often linked to local raw material resources (Convertini 2010). Yet it is not just a matter of raw material choice, as forming techniques (Gomart et al. 2017) and symbolic systems (Rigaud et al. 2018) equally attest to this diversity in production practice. Clearly, then, this localised pattern of composition and craft practice demands our attention, and yet existing technological studies are somewhat inconsistent in their level of detail, especially when compared with typological research.

One of the areas characterised by this increasingly rich but patchy situation is Eastern Iberia (Bernabeu Auban et al. 2009; García Atiénzar 2009; García-Puchol and Salazar-García 2017) (Fig. 1). Here, typological analysis has a long tradition (Bernabeu Aubán 1989; Bernabeu Aubán and Molina Balaguer 2009; García Borja et al. 2011; García Borja 2017), and the changes in morphology and decoration have been shown to be accompanied by those in production sequences, especially tempering practice (McClure 2011; Clop García 2012), which differs between neighbouring communities (Convertini 2010). However, information on provenance and technology remains relatively sparse, although general evolutionary models have been proposed to explain the patterns (McClure 2011; Clop et al. 2013). Overall, the relationship between ceramic technology, mobilities, technological transmission and local communities' internal development is still poorly understood. Such problem is evident for contexts predating signs of consolidated farming economies (5600–5500 cal. BC), as well as for the period of territorial expansion that occurred during the transition from the 6th to the 5th millennia cal. BC.

This paper, therefore, reports and interprets new data on ceramic traditions of the Neolithic in Eastern Iberia, especially during those periods least represented in existing provenance and technological studies. It argues that, despite a growing tendency to develop general narratives focused on a continental scale, small scale models based on both stylistic and technological traits continue to be key to understanding the social significance of material culture, and the diverse conditions in which past communities lived (Dietler and Herbich 1998, p. 236; Ard 2013; del Pino Curbelo et al. 2019). While it is appreciated that such studies need to be multi-scalar, it is argued that the localised, diachronic technological understandings developed over recent decades need to be integrated into broader models (Clop et al. 2013; Convertini 2010). The methodology employed in the present study is based on the instrumental characterisation of ceramics recovered at Cova d'En Pardo (Alicante, Spain), one of the most complete stratigraphic series for the Neolithic in the area. Pottery production sequences are studied by means of thin section petrography and microstructural observation (scanning electron microscopy, SEM). The resulting data on technology and provenance are then compared with decorative techniques. The patterns revealed at Cova d'En Pardo are then discussed in the light of contemporaneous ceramic evidence from surrounding regions.

Cova d'En Pardo

Cova d'En Pardo forms part of the karst system of the Albureca range, located at the southern limit of the Serpis basin, at an altitude of 680 m facing the Gallinera valley (DMS coordinates: 38° 48′ 52.8″ N; 0° 17′ 53.9″ W,[1] Fig. 1). Its human occupation began in the Upper Palaeolithic, with the Early and Middle Neolithic levels testifying to more intense and continuous occupation (Soler Díaz 2012; Soler Díaz et al. 2013) and it is these which form the focus of the present study.

During the Early Neolithic (levels VIIIb, VIII and VII), the cave was visited only sporadically, with important changes in the activities it hosted. The series starts with an initial occupation interpreted as a hunter camp (level VIIIb, 6660 ± 40 BP -5653-5483 cal. BC)[2] (Soler Díaz et al. 2013). Sedimentological, faunal and micromorphological analyses of subsequent levels testify to sporadic use as an animal pen (level VIII, 6610 ± 40 BP -5621-5480 cal. BC; and level VII, 6240 ± 40 BP -5309-5061 cal. BC). Later, the cave became a livestock enclosure that seems to have been in heavy use at several times of the year (levels VI-IV, ca. 5810–5170 BP, 4800-4000 cal. BC). This picture is enhanced by the presence of silos, storage vessels and human burial remains in the cave, which suggests that it functioned in a complementary fashion to open-space settlements and other shelters (i.e. Soler Díaz and Roca de Togores Muñoz 2008; Ferrer García 2012; García Atiénzar 2012).

The Early and Middle Neolithic pottery assemblage from Cova d'En Pardo can be considered representative of the area. Despite some potential post-depositional vertical and horizontal movement typical of cave deposits, typological studies indicate that sherds ascribed to different wares cluster in a coherent stratigraphic order, following the general model posed for neighbouring sites (Bernabeu Aubán 1989, p. 110; Gómez Pérez 2012). Specifically, appliqué and impressed ceramics are present in levels VIIIb and VIII, and in lower proportion in level VII. Contrary, combed wares were chiefly recovered from levels VII and VI, while the presence of sgraffito is rather limited and restricted to the uppermost occupations (levels V and IV). Initial study suggests that other typical traits of each period are present at the site: simple closed-shaped vessels with frequent cardium shell impression and polished surfaces are dominant in level VIII, while burnished decorated vessels are less frequent in upper layers (i.e. levels VI and IV), where sgraffito ware is present, characterised by high-quality surface treatment and the application of post-firing decoration.

[1] On-site coordinates (Soler Díaz 2012, p. 24).

[2] Radiocarbon dates calibrated with Oxcal 4.2.2 software against the IntCal20 calibration curve (Reimer et al. 2020).

Materials and methods

The sherd material from the cave was classified macroscopically and samples selected according to both decorative technique (Rye 1981, pp. 89–95) and variability in fabric and technology (Fig. 2). The 48 selected samples are presented in Table 1, according to stratigraphic context.

Thin sections were prepared by standard methods, examined on the polarising microscope, grouped and described according to their compositional and textural characteristics (modified from Whitbread 1995, pp. 368–396). Textural traits, including orientation patterns and frequency estimates of the main components (groundmass, voids and coarse fraction), were assessed through visual comparator charts (Bullock et al. 1985; Matthew et al. 1997). Argillaceous inclusions were classified and described according to a previously stablished system (Whitbread 1986). Similarly, the relative amount of primary micrite in the groundmass was used to identify calcareous clay matrices (Quinn 2013, p.44).

Where possible, representative individuals of each petrographic fabric were chosen for SEM examination on fresh fractures in order to assess firing ($n = 20$), with redox conditions determined macroscopically from the colour of the body (Rye 1981, p. 116; Shaw et al. 2001). SEM-EDX sample preparation followed typical SEM mounting and coating protocols, and resulting microstructural observations were labelled attending to the vitrification stages defined in Maniatis and Tite (1981) and Tite (1995). Processes of amorphous fraction formation are also influenced by paste composition, mainly by the presence of calcium carbonate in the groundmass. While this may be partially evident in petrographic analysis and resulting in distinctive micro-porosity observable by SEM-EDX, microanalyses were run on flat areas of the groundmass (avoiding coarse inclusions) to obtain

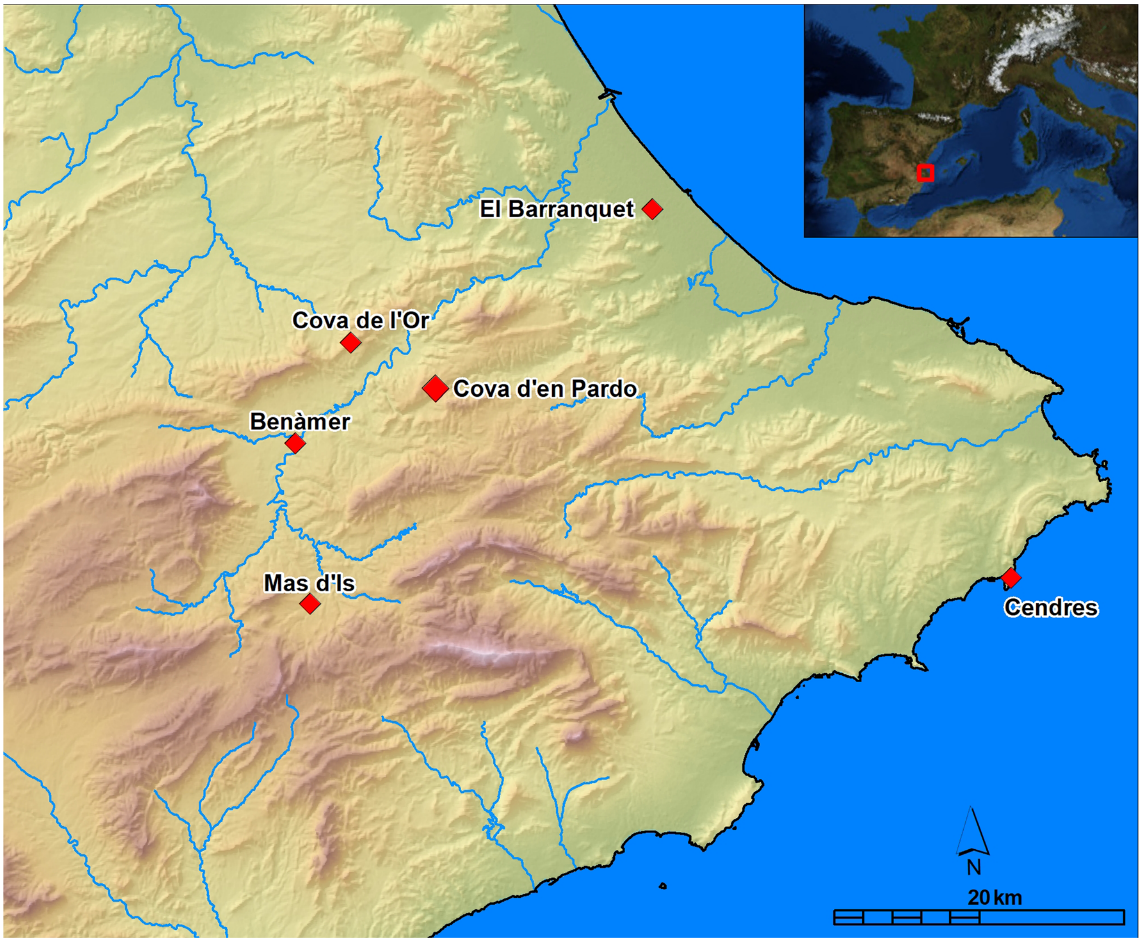


Fig. 1 Location map indicating main archaeological sites cited in the text

a qualitative indication of Ca content in order to be compared with petrographic and microstructural observations.

Results

Optical petrography

Seven petrographic fabrics have been defined (Fig. 3), two of which contain the majority of samples analysed here (ENP-F1 and F2), with a further five classes formed by a limited number of individuals with distinct compositional and textural traits (ENP-F3 to F7). Most of the samples are characterised by the predominance of carbonate inclusions embedded in a micrite-rich groundmass, and by the presence of temper. Only two individuals are poor in Ca-rich materials, characterised by frequent metamorphic and igneous inclusions, in contrast to the rest of the assemblage (ENP-F5 and F6 respectively).

ENP-F1, angular calcite (c:f:$v_{10\mu}$: 15:75:10 to 25:70:5) This group is formed by samples with an orange brown and yellow brown to black (in PPL and XP, × 40) heterogeneous matrix, with firing horizons present indicating incomplete oxidation. Porosity is chiefly formed by macro- and meso-planar voids, and less commonly mega- to macro-vughs. There are some differences within the group probably resulting from forming methods: elongate voids appear strongly orientated parallel to the vessel surface in samples ENP-03, ENP-04, ENP-06, ENP-17, ENP-23, ENP-29, ENP-32 and ENP-39 (Fig. 4a), while in the rest of the sections voids appear locally to be randomly orientated. One sample (ENP-36) exhibits characteristic curved elongate pores (Fig. 4b). The inclusions are unevenly distributed across the section, mainly comprising angular, discrete calcite crystals (≤ 2.5 mm, Mo: 0.3 mm), sometimes exhibiting banding and geometric pattern, and affected by firing, with subordinate quartz (≤ 0.5 mm, Mo: 0.1 mm), limestone fragments (≤ 4.2 mm, Mo: 0.5 mm) and opaques (≤ 0.8 mm, Mo: 0.1 mm).

ENP-F2, fossiliferous limestone and grog (c:f:$v_{10\mu}$: 10:80:10 to 25:70:5) These samples present a yellow brown to dark brown (PPL and XP) heterogeneous matrix, with dark core. Microstructure characterised by macro- to meso-planar voids and less commonly mega- to macro-vughs, locally orientated

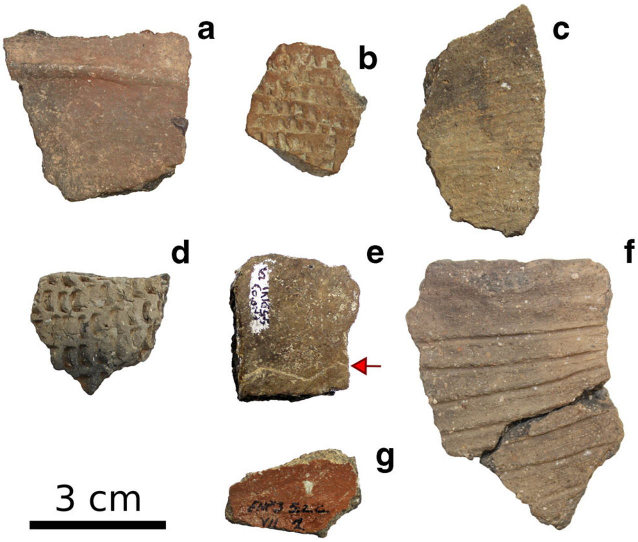


Fig. 2 Main decorative techniques mentioned in the text. **a** Appliqué. **b** Cardial impression. **c** Combing. **d** Non-Cardial impression. **e** Sgraffito (zig-zag line indicated by red arrow). **f** Incision. **g** Red slip

in some sections. Internal variability is mainly due to differences in inclusion composition. Most contain fossiliferous limestone fragments (≤ 3.8 mm, Mo: 0.5 mm), grog (≤ 2.5 mm, Mo: 0.4 mm) and quartz grains (≤ 0.9 mm, Mo: 0.1 mm) in similar proportions, along with subordinate bioclasts (≤ 1.4 mm, Mo: 0.3 mm), calcite (≤ 0.7 mm, Mo: 0.3 mm) and rare quartz-rich metamorphic rock fragments (ca. 0.6 mm). A limited number of individuals exhibit well-rounded quartz crystals (≤ 0.8 mm, Mo: 0.1 mm) and bioclastic limestone fragments (≤ 2.8, Mo: 0.3 mm), and the latter are similar to those previously described, with subordinate grog (≤ 1.3 mm, Mo: 0.5 mm) and calcite (≤ 0.4 mm, Mo: 0.2 mm). Grog characteristics are similar to the fabric in which they are embedded, containing quartz, limestone and microfossils as main inclusions. They are also angular to subrounded in shape, exhibit sharp to clear boundaries and show neutral to high optical density.

ENP-F3, fossiliferous limestone in fine calcareous matrix (c:f:$v_{10\mu}$: ca. 20:75:5) Two sections with a yellow brown to dark brown (PPL and XP) heterogeneous matrix, showing incomplete oxidation. The microstructure of the sections is characterised by abundant mega- to meso-planar and channels, less commonly by mega- to meso-vughs, generally connected to vughs, and rare meso-vesicles, strongly orientated parallel to the vessel surface. Inclusions are mainly bioclastic limestone (≤ 1.3 mm, Mo: 0.5 mm), quartz (mono and polycrystalline) (≤ 1.5 mm, Mo: 0.6 mm) and subordinate quartz-rich metamorphic rock fragments (≤ 1 mm, Mo: 0.4 mm) and opaques (ca. 0.1 mm).

ENP-F4, limestone and mudstone (c:f:$v_{10\mu}$: ca. 10:85:5) Individual with a yellow brown to orange brown (PPL and XP) heterogeneous matrix, and with microstructure characterised by macro- to meso-vesicles and vughs and rare mega-planar voids, generally randomly orientated. Mainly limestone fragments (≤ 2.9 mm, Mo: 0.7 mm) and discrete calcite crystals (≤ 0.4 mm, Mo: 0.1 mm), with subordinate mudstone (≤ 8.2 mm, Mo: 0.8 mm), quartz (≤ 0.5 mm, Mo: 0.1 mm) and bioclasts (ca. 0.4 mm).

ENP-F5, metamorphic rocks (c:f:$v_{10\mu}$: ca. 25:70:5) The matrix in this case is equally heterogeneous and low calcareous, orange brown (PPL) and red brown (XP) in colour. The microstructure exhibits characteristic macro- to meso-vughs, less commonly meso-vesicles and rare macro- to meso-channels, locally orientated. Inclusions include quartz (≤ 0.6 mm, Mo: 0.1 mm), metamorphic rock fragments (quartz, white mica and garnet sometimes partially altered to opaques) (≤ 1.9 mm, Mo: 0.9 mm) and pelitic fragments (≤ 1.3 mm, Mo: 0.6 mm) in similar proportions, and subordinate white mica (≤ 0.6 mm, Mo: 0.2 mm), brown mica (≤ 1 mm, Mo: 0.3 mm), epidote-zoisite (ca. 0.1 mm), opaques (ca. 0.1 mm) and garnet (ca. 0.7 mm).

ENP-F6, plutonic rocks (c:f:$v_{10\mu}$: ca. 25:70:5) Similar to the previous, this individual exhibits a low calcareous heterogeneous matrix, orange brown to black (PPL and XP) in colour, with dark core. Its microstructure is characterised by macro- and meso-channels and planar voids, strongly orientated parallel to the vessel wall. Recorded inclusions are comprised of granitic rock fragments (≤ 2.3 mm, Mo: 0.8 mm), subordinate quartz (≤ 1.3, Mo: 0.3 mm), altered feldspar (≤ 1.5 mm, Mo: 0.3 mm) and brown mica (ca. 0.5 mm).

ENP-F7, fossiliferous limestone in marly matrix (c:f:$v_{10\mu}$: ca. 20:75:5) One sample with brown (PPL and XP) homogeneous marly matrix and incomplete oxidation (dark core). Its microstructure if defined by characteristic mega- to meso-vughs, less commonly macro- to meso-planar vughs and rare meso-channels and meso-vesicles, moderately orientated. Inclusions comprise bioclasts (≤ 0.3 mm, Mo: 0.1 mm) and limestone fragments, mainly bioclastic (≤ 4.1 mm, Mo: 0.8 mm), along with subordinate quartz (ca. 0.1 mm), calcite (≤ 0.7 mm, Mo: 0.1 mm) and opaques (ca. 0.2 mm).

Scanning electron microscopy

SEM observations were undertaken on twenty samples. In most cases, the groundmass either retains the original lattice structure of the phyllosilicate minerals, chiefly unaltered (no vitrification, NV), or contains isolated smooth areas or filaments of amorphous material (initial vitrification, IV) (Table 1; Fig. 5a, b). Nevertheless, some individuals exhibit extensive smooth areas, showing a characteristic cellular structure (extensive vitrification, V), as part of a gradient of

Table 1 Samples information summary. *Abbreviations*: *Var*, variable redox conditions; *R*, reduced; *O*, oxidised; *NV*, no vitrification state; *IV*, initial vitrification state; *FHR*, fast heating rate. Asterisk: SEM observations available

P. Fabric	Sample	Decoration	Level	Redox	Vitrification
ENP-F1	ENP-02	Plain	VII	Var	
ENP-F1	ENP-03	Sgraffito	V	Var	
ENP-F1	ENP-04	Plain	IV	Var	
ENP-F1	ENP-06*	Plain	VI	Var	NV
ENP-F1	ENP-07	Combed	VII	R	
ENP-F1	ENP-09*	Combed	VI	O	NV
ENP-F1	ENP-12*	Plain	VI	Var	FHR
ENP-F1	ENP-14	Combed	VII	Var	
ENP-F1	ENP-15	Appliqué	VI	Var	
ENP-F1	ENP-17	Plain	VII	Var	
ENP-F1	ENP-23*	Impression	VI	Var	NV/V
ENP-F1	ENP-24	Incision	VII	Var	
ENP-F1	ENP-25	Plain	VII	Var	
ENP-F1	ENP-29*	Plain	VII	Var	NV
ENP-F1	ENP-30*	Slip	VII	Var	IV
ENP-F1	ENP-32	Plain	V	Var	
ENP-F1	ENP-33	Plain	VII	Var	
ENP-F1	ENP-34	Appliqué	VII	Var	
ENP-F1	ENP-36	Plain	V	Var	
ENP-F1	ENP-39	Sgraffito	VI	Var	
ENP-F1	ENP-41	Combed	VI	Var	
ENP-F1	ENP-43	Impression	VII	Var	
ENP-F1	ENP-44	Plain	V	Var	
ENP-F1	ENP-46	Incision	VI	Var	
ENP-F1	ENP-47*	Combed	VI	Var	NV
ENP-F1	ENP-48	Incision	VI	Var	
ENP-F2	ENP-01	Appliqué	VII	Var	
ENP-F2	ENP-05	Appliqué	VIII	Var	
ENP-F2	ENP-08	Cardial	VII	Var	
ENP-F2	ENP-10	Plain	VIII	R	
ENP-F2	ENP-13*	Cardial	VII	Var	NV/V
ENP-F2	ENP-16*	Appliqué	VIII	Var	IV
ENP-F2	ENP-20*	Plain	VII	Var	NV
ENP-F2	ENP-21*	Cardial	VII	Var	IV/V
ENP-F2	ENP-22	Plain	VII	Var	
ENP-F2	ENP-27*	Cardial	Sediment screening	Var	IV
ENP-F2	ENP-28	Cardial	VIII	Var	
ENP-F2	ENP-31*	Cardial	VII	O	NV/V
ENP-F2	ENP-35*	Cardial	VIII	Var	NV
ENP-F2	ENP-38	Cardial	VI	O	
ENP-F2	ENP-42	Incision	VII	O	
ENP-F2	ENP-45*	Impression	VII	Var	IV/V
ENP-F3	ENP-18*	Plain	VII	Var	NV/V
ENP-F3	ENP-40*	Appliqué	VII	Var	NV
ENP-F4	ENP-37*	Plain	VI	R	NV
ENP-F5	ENP-19*	Impression	VII	Var	NV
ENP-F6	ENP-26*	Incision	VII	Var	IV
ENP-F7	ENP-11	Impression	VIIIb	O	

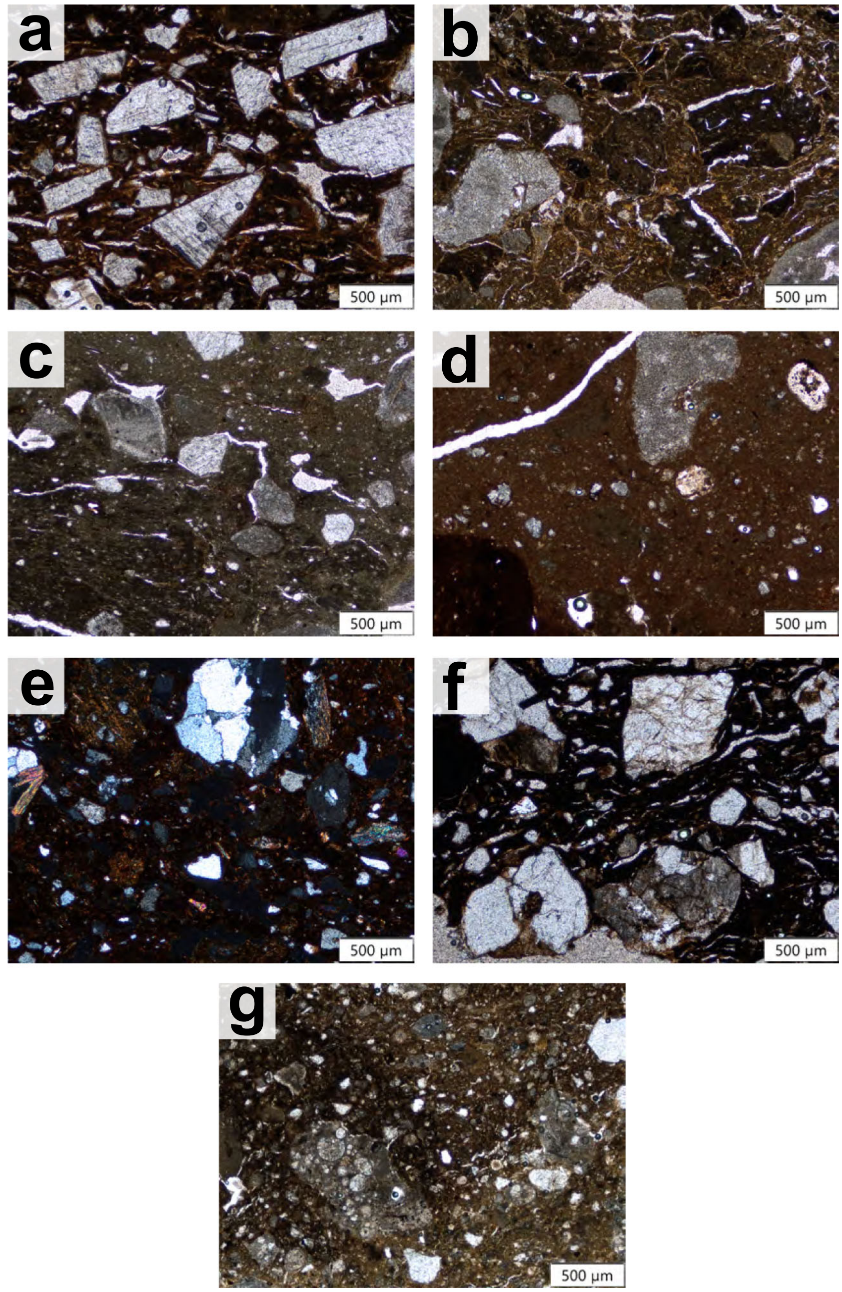


Fig. 3 Optical microscopy micrographs of individuals assigned to petrographic fabrics in plain polarised light (PPL) and crossed polars (XP). **a** ENP-F1 (PPL). **b** ENP-F2 (PPL). **c** ENP-F3 (PPL). **d** ENP-F4 (PPL). **e** ENP-F5 (XP). **f** ENP-F6 (PPL). **g** ENP-F7 (PPL)

microstructure (ENP-12, ENP-13, ENP-21, ENP-23, ENP-31 and ENP-45) where higher vitrification stages (sensu Maniatis and Tite 1981) are located close to the vessel surfaces. In one case, groundmass transformation is accompanied by bloating pores, suggesting fast heating rates (Fig. 5c, d). Fast heating rates could be connected to the presence of thermal gradients (Thér et al. 2018).

Qualitative SEM-EDX results show intense calcium peaks for most sherds, their spectra probably indicate the use of Ca-rich clayey materials, an observation in agreement with the abundant presence of micrite in the matrix in thin section, and the characteristic microstructure developed in most samples with signs of extensive modification. Quantitative or semiquantitative chemical analyses will be required in order to confirm this interpretation, but our observations agree with chemical composition reported for archaeological ceramics and raw materials available in the area (McClure et al. 2006). Indeed, only individuals assigned to ENP-F5 and ENP-F6 exhibit different spectra, in keeping with their different petrology.

Therefore, EFTs can be considered generally low (below 850 °C), at least for those samples showing homogeneous transformation stages (NV and IV) (Buxeda i Garrigos et al. 2003; Maniatis and Tite 1981). In addition, microstructure variation within the sections is a common trait throughout

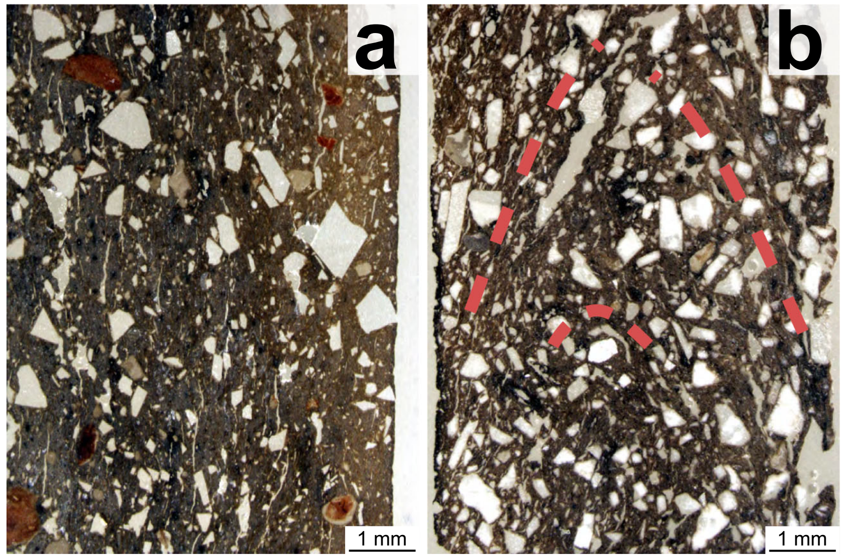


Fig. 4 Micrographs of void orientation patterns. **a** Strongly orientated voids parallel to the vessel surface (ENP-32). **b** Characteristic curved elongate pores in ENP-36. Dashed lines show trends

the assemblage, being present in a high number of samples for which firing temperature estimations can be problematic (Thér et al. 2018). Finally, differences in ceramic paste composition do not correlate with firing conditions.

Production sequences and provenance

Raw material procurement strategies at Cova d'En Pardo were primarily focused on the use of deposits which contained poorly sorted carbonate rock fragments and component mineral inclusions, showing traits of transportation (i.e. ENP-F2, ENP-F3, ENP-4, ENP-F7). Such compositions are compatible with the local geological surroundings, which chiefly comprise Mesozoic and Tertiary autochthonous materials (Almela et al. 1973, 1975), as well as with alluvial deposits from the Serpis valley (Clop García 2011). The spathic calcite which is the main component of the most common fabric, ENP-F1, is typical of the massive Cretaceous ranges that dominate the local landscape (Almela et al. 1973, 1975).

In contrast, the two markedly different minor fabrics are incompatible with the study area. ENP-F5 and ENP-F6, both

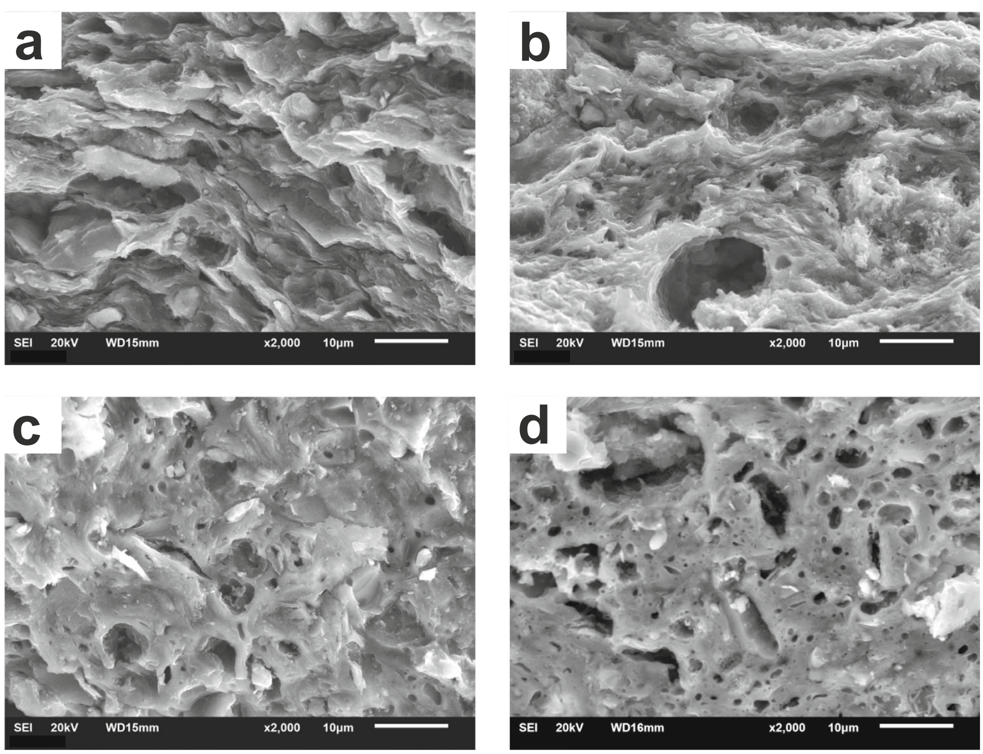


Fig. 5 SEM micrographs showing different vitrification states and typical fast heating rates fine porosity. **a** No vitrification. **b** Initial vitrification. **c** Extensive vitrification. **d** Glassy matrix with bloating porosity

related to level VII—Epicardial—, are instead related to plutonic and metamorphic formations, respectively. Metamorphic sources are especially rare in the region, comprising Palaeozoic slate and quartzite outcrops located to the North, in the provinces of Castellón and Valencia, while to the South, it is possible to find Tertiary phyllite and quartzite in the Alpujarride Complex, on Tabarca island (ca. 70 km from Cova d'En Pardo) and close to the city of Orihuela at the lower Segura valley (ca. 100 km). Regarding the plutonic inclusions of ENP-F6, it should be noted that dispersed outcrops of Mesozoic and Pliocene-Quaternary igneous bodies occur in Eastern Iberia, although these are still scarce in comparison to sedimentary materials. The Mesozoic rocks include mainly dolerite, sometimes exhibiting ophitic texture. Quartz dolerite and diorite are present to the South, in the Crevillente and Abanilla ranges, and on the island of Tabarca, in a similar distribution to that of the Tertiary metamorphic outcrops (Estévez et al. 2004).

Along these lines, the exchange of foreign goods has been previously attested for Neolithic communities in Eastern Iberia, mainly regarding lithic material. Marble bracelets were present in Cardial contexts, increasing their occurrence in the Epicardial and Postcardial phases. Amphibolite and sillimanite adzes were also part of local material culture during the period. However, the most likely sources for the raw materials employed in the production of any of those goods are quite distant, as part of the Baetic range (ca. 300 km), the Vera basin (ca. 200 km) or the middle Segura valley (ca. 100 km). Known workshops connected to these kinds of goods are equally far away, located close to the source areas, i.e. Cabecicos Negros and Cerro Virtud (Vera Basin, Almería), or the cueva-sima de la Serreta (Cieza, Murcia). Those contexts are characterised by ceramics decorated by incision and impression, like in level VII at Cova d'En Pardo (Orozco-Köhler 2000; Martínez-Sevilla 2019), which along with the composition of ENP-F5 and the similitude between ceramic styles from both regions in the transition from the 6th to the 5th millennia cal. BC (Martínez Amorós 2018) suggests the circulation of pots from Southern territories to the study area. Among the data supporting this hypothesis could be the intensive use of metamorphic material in local pastes, along a lower incidence of temper, attested in Andalusian ceramic technology during the Neolithic (Echallier 1999, 2004).

Turning to technology, the observed differences in void shape and distribution may indicate more than one forming technique. Strongly oriented elongate voids such as those detected in samples from ENP-F1, ENP-F3 and ENP-F6 are normally developed when pressure is applied to the vessel wall while the paste is still plastic (Rye 1981, pp. 55–88; Whitbread 1996; Quinn 2013, pp. 174–187). This has been interpreted at other Neolithic sites at Iberia as a sign of slab building (Cubas et al. 2014). Void orientation also suggests that at least one sample in fabric ENP-F1 (ENP-36) was built by coiling (Lindahl and Pikirayi 2010; Quinn 2013, pp. 177–179). The coincidence of microstructural traits associated to both coil and slab building within samples ascribed to ENP-F1 hints at the lack of a clear connection between forming techniques and fabrics.

As noted above, groundmass modification undergone during firing was rather variable and, importantly, linked to dark cores. Inconsistent redox conditions and thermal gradients across the wall section are coherent with firing events employing fast heating rates, short soaking times and an uneven heat distribution (Maggetti et al. 2011; Thér et al. 2018). Those are typical traits of simple firing structures with little insulation, such as open firing episodes, along with low temperature control (Gosselain 1992; Livingstone Smith 2001). Such conditions produce variations in microstructure and the incomplete combustion of organic material, along with the occasional occurrence of high firing (Maritan et al. 2006; Thér et al. 2018), as also attested at the sites of Mendandia (Ortega et al. 2010) and El Congosto (Díaz-del-Río et al. 2011) in northern and central Iberia, which can be indicative of common problems among early potters in Iberia rather than specificities of local practice. Additionally, the vessels have not suffered failure by lime spalling, probably because the fast heating rates and short soaking times extend the stability of coarse calcite inclusions up to ca. 900 °C (Fabbri et al. 2014), which is in agreement with microstructural observations for most of the samples.

Ceramic traditions: technology and style

Summarising these results, it is clear that the Cova d'En Pardo assemblage was chiefly produced either locally or in near proximity to the site, with a limited presence of foreign fabrics (Convertini 2010). Further subdivision among local fabrics is difficult due to the homogeneity of regional geology. However, the assemblage is technologically diverse, notably in terms of composition and tempering practice. For example, imported fabrics ENP-F5 and F6 lack the intentional addition of non-plastics as temper (such as grog or limestone). Even within those fabrics compatible with an origin in the local area, there are indications of marked changes in ceramic technology within local communities. These important patterns of variability in the pottery of Cova d'En Pardo are worthy of further consideration, focusing on stratigraphic positions, possible correlations between stylistic and compositional/technological traits and placing these in relation to contemporaneous contexts in Iberia and the Mediterranean basin.

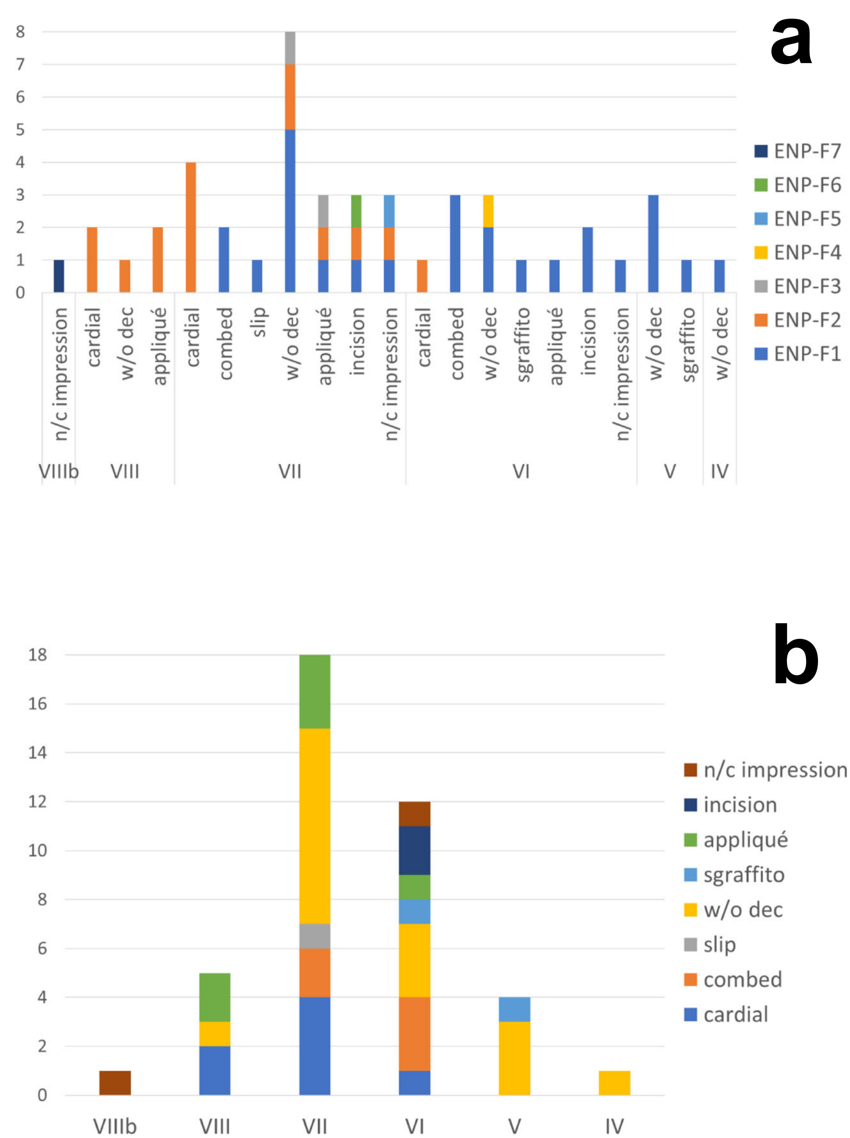
The diachronic view

One of the main questions tackled here refers to the relationship between local practices and the construction of shared technological traditions, which has an important diachronic component. In the case of Cova d'En Pardo, pottery technology is marked by the extensive use of temper, as the two main petrographic fabrics are characterised by the addition of grog (ENP-F2) and angular calcite (ENP-F1), respectively. These distinct fabrics correlate with chronology (Fig. 6): grog appears in levels from VIII to VI, decreasing in frequency over time, while spathic calcite occurs from level VII to the end of the series, being almost the only fabric present in levels V and IV. Outliers and minor fabrics are spread over levels VIIIb, VII and VI, especially in VII.

At the same time, the correlation between macroscopic groups and petrographic fabrics is striking. For example, Fig. 6a shows a distinctive Early Neolithic group (levels VIII and VII), comprised of vessels decorated with Cardial impression, consistently in Fabric ENP-F2. This contrasts with combed and sgraffito categories assigned to upper occupation levels, which are invariably produced with calcite-tempered pastes (ENP-F1). The correlation of fabrics with appliqué, incision and non-Cardial impressions is less consistent, but still seems to follow a chronological pattern: individuals from levels VIII and VI are produced with the most common paste recipe in each phase, while level VII pottery is equally diverse. Plain pottery follows a similar trend.

In general terms, the picture from Cova d'En Pardo is consistent with that at other sites in Eastern Iberia (Clop García 2011; McClure 2011). It is also coincident with Cova de l'Or, the reference ceramic sequence for the basin, where the first extensive use of angular calcite occurred in levels V and VI, dated to the transition from the 6th to 5th millennium cal. BC (Gallart Martí 1980, p. 80). Similarly, angular calcite-bearing samples from those levels exhibited non-Cardial impression, incision, sgraffito and appliqué as decoration, along with a significant amount of plain ware. More specifically, the shift to extensive calcite use seems contemporaneous in both caves, perhaps reflecting a general pattern in the

Fig. 6 Stacked bar graphs. **a** Petrographic fabrics distribution according to decorative techniques along the stratigraphic series. **b** Decorative techniques distribution along the stratigraphic series



Alicante area, since spathic calcite is virtually the only inclusion attested also at Cova de La Falguera, Cova de Santa Maira, Mas d'Is, Niuet and Colata in those levels dating from mid-5th millennium cal. BC onwards. In the latter (and more recent) two contexts calcite-tempered pastes appear connected to assemblages dominated by combed and plain wares (McClure 2011).

There and back again: local choices and the regional picture

Clearly, the local pottery at Cova d'En Pardo exhibits the most characteristic traits of Neolithic Eastern Iberian pottery production: the addition of temper, almost exclusively grog and calcite (not in combination), and a close correlation between temper choice, decoration and chronology (Clop et al. 2013). With very few exceptions (e.g. El Barranquet, Clop García 2011), this sets its region apart from other areas of Iberia and the Western Mediterranean (Convertini 2010). Petrographic characterisation at Cova d'En Pardo provides useful information on the occurrence of local traditions and their change along the time in Eastern Iberia.

Pottery from level VIII at Cova d'En Pardo is the earliest displaying the whole set of vernacular choices, which is also characterised by distinctive typological traits that have served in the definition of the *Valencian Cardial Group*, present in the area roughly between the Serpis and Algar river valleys (McClure and Molina 2008; McClure 2011; Clop et al. 2013). This group is characterised by the combination of unique pottery shapes (handle-spout, barrels, double cups and cylindrical flat bases) with the use of ornate decorative patterns and figurative motifs (Martí Oliver and Hernández Pérez 1988; van Willigen 2004). Interestingly, stylistic dissimilarities are echoed by paste composition across Iberia, as communities within parts of Catalonia and SW Portugal seldom used temper (Clop et al. 2013; Masucci and Carvalho 2016), while it was commonly added in the rest of the peninsula, though following different traditions: including discrete crystalline inclusions, various rock fragments, organic fibres and bone (Echallier 2004; Ortega et al. 2010; Díaz-del-Río et al. 2011; Cubas et al. 2012, 2014; Jorge et al. 2013; Masucci and Carvalho 2016).

On that note, the Valencian Cardial Group may reflect the process of fragmentation of a common technological heritage, where differences in production along the NW Mediterranean shore may testify to the formation of new ceramic traditions in other territories throughout the 6th millennium cal. BC. In that group, temper choice may be fundamental to technological practice from early on, being common in the territory of the Franco-Iberian Cardial, which extended from Provence to the Iberian coast (Binder et al. 2010). The Valencian Cardial Group and the broader Franco-Iberian Cardial groups are characterised by relative stylistic regularity, with preference for round-based vessels decorated with horizontal and vertical shell-impressed bands. This contrasts with the heterogeneity observed in *central Mediterranean* contexts, where morphologically and decoratively distinct vessels are rarely tempered (Guilaine 2018). Such patterns over a variety of scales fit the perception of early farming communities as highly adaptive to local circumstances, in which technological practice varies not only spatially but also over time (Guilaine and Manen 2007).

Focusing on the context addressed in this paper, current explanatory models of ceramic change in Eastern Iberia are based on ideas of diffusion and functionality. It has been suggested elsewhere that the adoption of calcite tempering was due to the horizontal transmission of the practice to the West, in a similar fashion to that suggested for the tradition of grog tempering (Clop García 2012), and that this shift to calcite was concomitant with transformations in pottery function during the Middle Neolithic (Ortega et al. 2010; McClure 2011). According to the latter view, calcite-tempered pastes would improve pottery performance, especially in terms of thermal shock resistance, beneficial as pottery was increasingly used for cooking (McClure 2011, p. 116). However, cases such as the mentioned evidence from Cova d'En Pardo and Cova de l'Or challenge the connection between extensive calcite use and the idea of the desire for more durable ceramics. This is because calcite tempering appears during the Epicardial occupation associated with a wide stylistic range of vessels, and not only in the plain or combed wares, which are most commonly taken as signs of change in pottery functionality.

The decline in ceramic decoration and appearance of new forms later in the 5th millennium cal. BC may indeed indicate a turn towards the use of pottery in cooking activities (García Borja et al. 2011; McClure 2011), though use-wear and contents analysis would be required to reinforce such arguments. However, our results join others from earlier contexts in Eastern Iberia in testifying to a variability in the conditions of adoption of grog and calcite tempering observed across other NW Mediterranean groups (Convertini 2010), in which temper choice does not necessarily seem to follow technical or functional parameters (Binder et al. 2010). Furthermore, it is important to stress that suggestions of the link between compositional change and vessel use have their roots in functional approaches to ceramic paste preparation, and specifically the contention that calcite-tempered pottery is more resistant to thermal stresses than those dominated by grog or quartz inclusions (Hoard et al. 1995).

Such line of argument has been repeated countless times in the literature, despite its basis being challenged in technical and experimental work (Kilikoglou et al. 1998). Cooking pot technology is a complex matter, with a range of factors affecting performance. Recent work has suggested that, on balance, calcite inclusions may have little measurable effect on the suitability of low-fired pottery vessels, even were we to accept this as a major factor in material choices (Bebber 2017). In fact, some ethnographic studies suggest that potters' choices are rarely influenced by a desire for some *optimisation of technical performance* (Day 2004, 2020). This does not mean that the choice and manipulation of raw materials lacks significance; quite the opposite. The point here is that technological systems appear always embedded in social processes and relations, which can be overlooked when the emphasis is put on technical aspects (Dietler and Herbich 1998). Spatial diversity of technological choices during the Neolithic also makes it clear that local communities were central in the definition of production practice, and that we need to contextualise technology more than providing cross-cultural views of functionality that fall far from the reality of such practice (DeMarrais 2013).

Contextualising this picture from pottery, Eastern Iberia exhibits important peculiarities in material culture at least since the mid-6th millennium cal. BC and inter-community networks seem to have played an active role in the configuration and reproduction of the Valencian Cardial Group (García Atiénzar and Jover Maestre 2011; Jover Maestre et al. 2019). Technological and stylistic features of its ceramics correlate with those observed in rock-art, delimiting the territory occupied by Cardial communities (Torregrosa Giménez 2000), encompassing gathering sites such as Cova de la Sarsa, Cova de l'Or or Pla de Petrarcos (Hernández Pérez et al. 2002; García Atiénzar 2009), as well as with the use of nearby caves for funerary purposes (Bernabeu Aubán et al. 2012). Nevertheless, this early situation did not last long, and significant changes coincide with transformations detected in the ceramic assemblage at Cova d'En Pardo.

The transition from the 6th to 5th millennia cal. BC, the period in which main change in paste compositions occur, is characterised in the study area by population growth, community fission and territorial expansion (García Atiénzar 2009). New settlements are founded to the West, as far as the Villena basin, and to the South, along the Vinalopó and Segura river valleys (but see Jover-Maestre et al. 2018). Pollen analysis from cave and open-air settlements confirms an increasingly marked human impact on the environment (Dupré Ollivier 1988; López Sáez et al. 2011; Martí Oliver 2011). Rising demographic pressure may equally underlie the denser occupation of Cova d'En Pardo in levels VII and VI, along emerging shepherding routes (García Atiénzar 2006; Badal et al. 2012). At the same time, changes in the management and distribution of staples, with greater reliance on local storage, characterises marked changes in the daily life of local communities (Pérez Jordà and Peña Chocarro 2013), also visible in the reduced engagement of groups in inter-community life and an emerging diversity of the material record (Ibáñez-Estévez et al. 2017). The latter can be also connected to the mentioned goods' mobility from the South.

If population growth and concomitant expansion of settlements produced a greater number of the household units familiar to us from the open-air site of Mas d'Is (houses 1 and 2; McClure 2011) and Benàmer (Torregrosa Giménez et al. 2011), this may have affected the assumed basic unit of craft production and perhaps on the diversity of learning patterns and technological practice (McClure 2011). Such changes may have been echoed in pottery style (Bernabeu Aubán 1989; Bernabeu Aubán and Molina Balaguer 2009), but perhaps also by the change from decorated grog-tempered vessels to calcite-tempered combed ware. Indeed at Cova d'En Pardo and Cova de l'Or, grog fabrics and calcite-tempered groups comprise the two end members of a more complex transitional sequence, although our knowledge of ceramic technology from the 6th to 5th millennia cal. BC is still too scarce to provide a clear picture of the change.

Alternative beginnings and pioneer potters

In addition to the previous, the results from level VIIIb at Cova d'En Pardo suggest that traits considered characteristic of the Valencian Cardial Group may have been absent in earlier Neolithization stages in the same territory. From that level, sample ENP-11 is a petrographic outlier and, while only one sample, its singularity somehow echoes the change observed at other sites between Cardial levels and earlier occupation. Pottery from pioneer occupation at El Barranquet and Mas d'Is is different, in terms of grain-size, surface treatment and firing atmosphere, from later vessels at Mas d'Is, Cova de l'Or, Cova de la Falguera or Cova de la Sarsa (McClure and Bernabeu Aubán 2011). If anything, this is a picture of discontinuity.

In Eastern Iberia, the apparent differences between pioneer and traditional Cardial levels involve variation in shape and decoration, including Cardial and tool impression, grooving, appliqué and the so-called Arene Candide style, all traits with connections to the central and Western Mediterranean (García Atiénzar 2010; García Borja et al. 2014). Among these, vertical impressions made with maritime shells, a style found at Cova d'En Pardo (Fig. 2 D, ENP-11), have been found to exhibit similarities with assemblages from Arene Candide and Grotta Pollera, in Liguria (Soler Díaz et al. 2013), as well as with other contexts located along the southern European Mediterranean coast, especially in southern Italy (Guilaine 2018). The same decorative pattern was employed by pioneer dwellers of Cova del Montgó, Cova de Les Cendres (Bernabeu Aubán and Molina Balaguer 2009), Mas d'Is and El Barranquet (Bernabeu Auban et al. 2009), which indicates that first occupation of Cova d'En Pardo was not an isolated case.

Indeed, the identification of pioneer contexts predating the traditional Cardial horizon alters our perception of the Neolithization process. The idea of the Cardial horizon as an indicator of pioneering early farming communities in the Western Mediterranean, involved in a progressive and regular process, producing gradual occupation of the nearest available territories is thus being challenged. Instead, the earliest pottery using levels appear to be a product of long-distance maritime migration, resulting in a heterogeneous record (Manen et al. 2019). In contrast to the technological and stylistic coherence of Cardial assemblages, research at Peiro Signado and Pont de Roque-Haute, in southern France, suggests only low-level transformation of earlier technical and economic traditions, as pioneers maintained the technological traditions of their home regions, including in the production of pottery (Manen and Convertini 2012). Thus, the apparent technological and stylistic diversity at Cova d'En Pardo and other early farming contexts in Eastern Iberia may be related to the craft traditions of their pioneer groups. Could the initial assemblage from Cova d'En Pardo be linked to production practices where temper addition was rare?

This question may be challenging, especially given that differences in composition and tempering practices are equally detectable in later occupational phases of the cave. Nevertheless, further evidence supporting a distinctive long-distance relationship of the study area can be found in early levels at Cova de les Cendres, in the presence of painted vessels, something rare in the NW Mediterranean (Bernabeu Aubán and Molina Balaguer 2009, p. 82). It is also worth noting that the coiling and slab-building forming techniques proposed for Cova d'En Pardo are typical of central Mediterranean pottery and *not* of other Western Mediterranean traditions (Gomart et al. 2017). This may help to explain the internal variability observed in the territory of the Valencian Cardial Group, especially at El Barranquet. While further data may be needed to argue for a specific origin for pioneer communities arriving in Eastern Iberia, the suggestion of alternative migration trajectories (García Borja et al. 2014; Jover-Maestre et al. 2018; Manen et al. 2019) opens new and promising lines of research.

Conclusions

As sociotechnical systems (Pfaffenberger 1992), ceramic traditions were reproduced within complex intra- and inter-community relational frameworks, something often overlooked by popular explanatory models which often suggest monocausal explanations such as population migration, functional approaches and simplified ideas of *influence*. Cova d'En Pardo provides an example of a ceramic sequence that challenges existing generalised accounts of the adoption of pottery-making and its development in Iberia.

While our analyses corroborate the importance of the Cardial horizon in the configuration of NW Mediterranean ceramic traditions, with technological and stylistic conventions shared by communities located across the region, Cova d'En Pardo still shows a marked *local* character. At the same time, the lower levels at Cova d'En Pardo, representing episodes of pioneer occupation, join other contemporary contexts in suggesting that ceramic traits characteristic of the Eastern Iberian Neolithic were not necessarily present in these earlier cultural stages. This indicates that this is not simply a matter of the faithful transmission of *ways of doing* in pottery production ab initio, but rather that the crystallisation of local pottery traditions occurred only once farming economies were consolidated in the area.

An atomised production structure, along with important changes in the settlement system, may have contributed to changes in existing production sequences, coinciding with an increased diversity of decorative patterns in the area during the last centuries of the 6th millennium cal. BC. Even if we accept that performance may have been a contributing factor in promoting technological change, at least in the late Middle Neolithic, when new shapes and a decrease in decoration suggest shifts in pottery function, this model is difficult to apply to previous contexts, when calcite-tempered pastes appear in use within a wide stylistic range of ceramics, most of them still showing a great deal of similarity with vessels of the earlier cultural phases.

While we clearly need further data on pioneer contexts and on the interface between the Early and Middle Neolithic to be confident of detailed interpretation, the important new correlation between fabrics and decorative techniques observed at Cova d'En Pardo highlights the influence of social factors on production practice. The interplay between the diversity seen in the earliest contexts of pottery use and the localised reaction to changes at the time of the Cardial horizon suggest diversity of daily life among early farming communities, often subsequently eclipsed by apparent stylistic and cultural homogeneities.

Funding Sample preparation and analyses were funded by the projects NEOMEDPOT (Marie Skłodowska-Curie program, European Commission, grant number 659466) and Espacios sociales y espacios de frontera durante el calcolítico y la Edad del Bronce en el Levante de la península Ibérica (HAR2016-76586-P, Ministerio de Economía y Competitividad and FEDER).

Miguel del Pino is a postdoctoral researcher within the Viera y Clavijo program, funded by the Universidad de Las Palmas de Gran Canaria (Spain). The initial draft of the paper was finished while a postdoctoral researcher within the APOSTD program funded by the Generalitat Valenciana and FEDER funds (Spain).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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