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REVIEW

Natural "megalithic art" at Valencina (Seville): a geoarchaeological approach to stone, architecture, and cultural choice in Copper Age Iberia

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Abstract
Valencina (Seville, Spain) is one of the most important megalithic sites of the third millennium BCE in Western Europe. Among its most celebrated monuments are the *tholoi* of Montelirio, La Pastora, Matarrubilla, and Structure 10.042-10.049. Although sharing the same architectural tradition, these monuments were raised at different times of Valencina's history and present important formal differences. In particular, the *tholoi* of La Pastora and Matarrubilla contrast with that of Montelirio in that they are devoid of artistic ornamentation such as paintings and engravings, showing instead an inordinate number of natural geological features. This study, focusing on La Pastora and Matarrubilla, offers an innovative approach to the notion of "megalithic art." Firstly, these elements are characterized and classified and their natural origin established. Thus, the calcareous sandstone blocks dated from the Tertiary reveal structures on their surfaces generated by biological (bioturbation) and physical (by currents) processes during the Neogene. The surfaces of certain slabs of identical lithology at La Pastora experienced more recent intense marine bioerosion and bioconstructions in the form of *Ostrea* preserved to this date. Secondly, we emphasize the choice of different rock types following a certain pattern or serving to highlight a particular constructive element. In sum, all the natural elements bear highly aesthetic qualities and appear to have been deliberately chosen to highlight specific decorative or symbolic aspects. As a result, we suggest that future research on "megalithic art" should include analogous geological examinations in order to discern the origin and nature of the different elements.

Keywords Megalithic art · Third millennium BCE · Valencina de la Concepción · La Pastora · Matarrubilla · Sedimentary structure

Introduction

Ornamental and artistic motifs on Iberian megalithic architecture have been recorded since the late nineteenth century (Alburquerque e Castro et al. 1957; Beltrán 1983; Bosch 1965; Breuil 1935, 1940; Coelho 1931; Jorge 1983; López Cuevillas 1943; de Pinto 1929; Vasconcelos 1907; etc.). They range from paintings and engravings (Bueno et al. 2009) to figurines, idols, and *stelae* that often feature among the offerings that accompanied the rituals associated with these monuments (Almagro 1966; Almagro and Arribas 1963; Bueno 1995; Bueno et al. 2016b; Díaz-Guardamino 2010; etc.). Currently, the study of "megalithic art" focuses on interpreting the worldview of their creators, their perception of certain daily activities, and their social structure (Bueno and Balbín-Behrmann 2000).

In the last two decades, the deployment of scientific methods to characterize and date painted motifs has led to

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substantial advances in the interpretation of "megalithic art." Since the 1980s, for example, absolute dates have been obtained on the organic components of pigments by AMS dating (Carrera and Fábregas 2008; Evin 1996; Hyman and Rowe 1997). Furthermore, application of Bayesian statistical models (Buck et al. 1991) has led to greater statistical precision in interpreting the data (Bueno et al. 2016a).

To date, however, few studies have applied geological techniques to explore the question of megalithic ornamentation in Iberian Late Prehistory. In this context, geology has essentially served to identify the nature and source of megalithic materials (Aranda et al. 2017; Boaventura 2000; Carrión et al. 2009, 2010; Kalb 1996; Lozano et al. 2014; etc.). Yet, research has revealed that specific lithologies may respond to various functions including decoration. Stonehenge is probably the most celebrated case, comprising two main types of rocks, sandstone (sarsen) serving for the outer circle and rhyolite and dacite (bluestones) for the inner one (Bevins and Ixer 2013; Green 1997; Parker Pearson et al. 2011; Thorpe et al. 1991).

This paper focuses on the Copper Age mega-site of Valencina de la Concepción-Castilleja de Guzmán (henceforth Valencina) located in Seville, south-western Spain (Fig. 1). Valencina is one of the most significant sites of this period due both to its vast extension of 468.8 ha (Vargas 2004a, 2004b) and the complexity of the society that frequented or inhabited it throughout the third millennium BCE (García-Sanjuán 2013; García-Sanjuán et al. 2017, 2018; etc.). Valencina includes major megalithic monuments, some of which have been studied recently: Montelirio (Fernández et al. 2016), La Pastora (Cáceres et al. 2014; Hunt et al. 2012; Ruiz 2013; Vargas et al. 2012), Matarrubilla (Cáceres et al. 2016; Odriozola and García-Sanjuán 2013; Schuhmacher et al. 2013), and Structure 10.042-10.049 (García-Sanjuán et al. 2019). Previous research has centered on various aspects of the "megalithic art" present at some of Valencina's monuments, especially at Montelirio (Bueno et al. 2016b), and on the nature of the mineral pigments such as cinnabar powder (Hunt and Hurtado 2010; Hunt et al. 2011; Rogerio-Candelera et al. 2013).

To date, however, no systematic analysis of the geological structures observed on constructive elements has been undertaken. The main aim of this paper is to highlight, through a geological description and characterization, the existence of many "natural" features on the stones at La Pastora and Matarrubilla (Fig. 1) and explore their potential role as ornamentations.

Our approach to "megalithic art" is therefore fairly innovative. Many of these elements respond to different physical and biological processes that took place during or after the formation of the rocks that were later used as building materials. These natural elements form structures of great plastic beauty that, in all probability, did not go unnoticed by the *tholoi* builders. In other cases, the choice of different rock types resulted in ornamental effects bearing potential symbolism. Hence, we propose that those elements were culturally selected and consciously used as ornamentation, opening up new questions for the study of communities that built and used

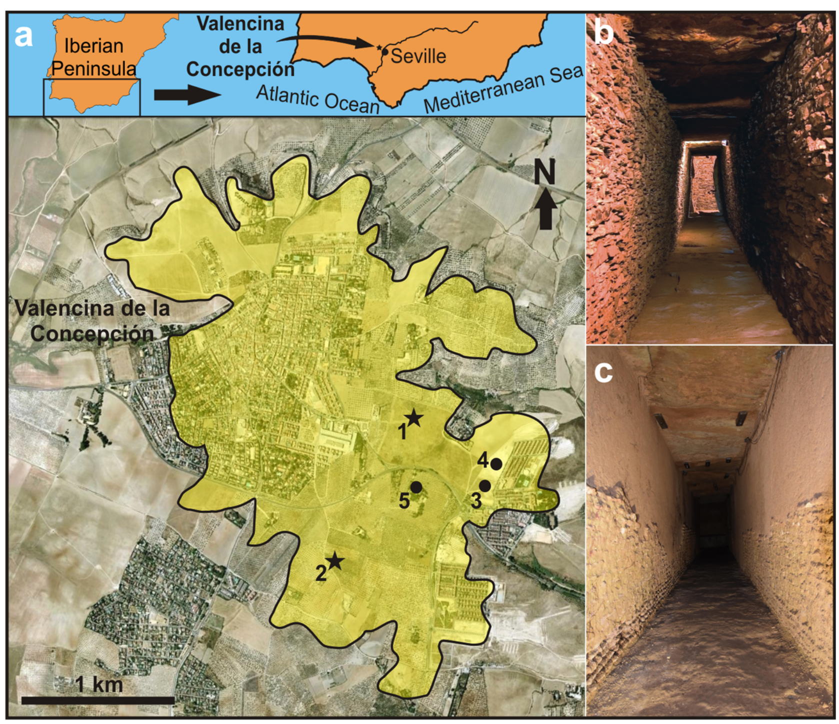

Fig. 1 **a** Location and extension of the archaeological site of Valencina, and position of the main megalithic monuments: 1 La Pastora, 2 Matarrubilla, 3 Montelirio, 4 Structure 10.042-10.049, and 5 Ontiveros. **b** General views of the La Pastora's passage, facing the chamber. **c** Identical view in Matarrubilla

these monuments. We also consider essential that future "megalithic art" research include geological analyses to discriminate the natural and anthropic structures in order to obtain more precise interpretations as to their design and meaning.

The *tholoi* of La Pastora and Matarrubilla

Although burial features are found throughout the whole expanse of Valencina, most of the megaliths are concentrated in its southeastern sector. These constructions are of various sizes and forms, but include mostly tholos-type monuments featuring a small circular chamber rarely exceeding 3 m in diameter accessed by a passage measuring between a few meters and several dozen meters in monumental cases. The *tholoi* of La Pastora, Matarrubilla, Ontíveros, Montelirio, and Structure 10.042-10.049 are the largest known to date at the site. Of them, only La Pastora and Matarrubilla are currently accessible and are therefore the main focus of this paper (Fig. 1).

Recent work has upgraded and corrected the measurements available for La Pastora. Thus, according to the new data, this monument has a total length of 43.06 m, of which 28.10 m are roofed. The maximum-minimum width and height of its passage range between 1.04–0.76 m and 1.81–1.38 m while its circular chamber measures 2.6 m in diameter with a maximum height of 2.42 m. The monument's orientation is toward sunset, contrary to that of most Iberian megaliths, which face sunrise (Hoskin 2002). La Pastora was built with three types of rocks: Palaeozoic quartz arenite, Palaeozoic granite, and Tertiary calcareous sandstone (Cáceres et al. 2014, 2016). The dry masonry walls of the monument uses small quartz arenite slabs with colors ranging from brown to greyish. The passage, of trapezoidal section, is divided into three segments separated by calcareous sandstone door jambs, lintels, and a threshold marking the entrance to the chamber. The chamber's walls are corbeled, with the two upper rows consisting of larger calcareous sandstones. The same lithology was used for the capstones (20 of which are preserved) and floor slabs (Fig. 2). The surface of these sandstones presents a natural variable coloration, even within the same block, which can range from yellowish to orange and reddish tones. Large capstones made of yellowish white granite roof both the passage (five preserved) and the chamber. The whole construction was covered by an earthen *tumulus*. At the moment of the megalith's discovery more than 150 years ago, the mound covering the chamber was more than 2 m thick (Tubino 1868). Today, however, it is hardly preserved.

The *tholos* of Matarrubilla was subject to several restorations throughout the twentieth century that altered its original appearance. The monument comprises a 29.6-m-long passage (22.5 m with the original roofing) and a circular chamber with a maximum diameter of 2.80 m. The average width and height of the passage is respectively 1.30 and 2 m, while the chamber is 2.18 m high. Its northward orientation (N20E) is also discordant with megalithic norms. The walls of the passage and the chamber were originally of narrow, flattened slabs of cream-colored oncolithic limestone (2–4 cm) secured by layers of clay. The chamber is covered by a granite capstone. The monument's passage includes one capstone of the same rock (Fig. 2) plus 15 others made of calcareous sandstone. In spite of the monument's modern restorations, it is worth noting that the capstones preserved today are laid in their original positions. This can be deduced from the descriptions published by Obermaier (1919) concerning the capstones closest to the chamber, as well as the comments made by Collantes de Terán (1969) regarding the 1955 restoration. Finally, the floor of this monument does not present slabs, but compact clay-silt (Obermaier 1919).

A highly idiosyncratic element at Matarrubilla is a quadrangular carved gypsum monolith (1.72 × 1.25 × 0.50 m) that takes up most of the space of the chamber (Cáceres et al. 2016). It is a massive and compact gypsum with intercalations of white centimetric layers, with others dark greenish and some reddish-brownish very folded. Although this monolith resembles a "basin," its function remains largely unknown. In any case, given its size, it must have been placed in the chamber before or during its construction, suggesting that it must have served as the chamber's main feature.

Natural elements and structures

Sedimentary rocks are formed by the accumulation and precipitation of sediments that when subject to physical and chemical processes (diagenesis) yield more or less compact materials (rocks). During deposit, the sediments undergo different biological and physical processes (Collinson et al. 2006) that can leave traces in the form of sedimentary structures (Allen 1970) that reflect environmental conditions.

Biological processes result from the activity of living organisms that interact with a soft or consolidated substrate when in search of dwelling, a place of rest or food (e.g., de Gibert et al. 2004). The traces take on fossilized forms (Fig. 3) either in sediment layers (full-relief) or on the surfaces between strata, that is, either on the top of the lower layer (positive structure or concave/convex epirelief) or on the bottom of the upper layer (negative structure or concave/convex hyporelief) (Gámez and Liñán 1996; Seilacher 1964). These types of fossilized biogenic structures called ichnofossils are the subject of the discipline of ichnology (Bromley 1990). It is nonetheless necessary to differentiate between biogenic interactions carried out during sediment deposition (soft substrate of loose sediments) and those produced on hard substrates. The first give rise to bioturbation structures and involve the distortion and/or destruction of the unhardened substrate (fluid, soft, non-firm). The second, in turn, yield bioerosion

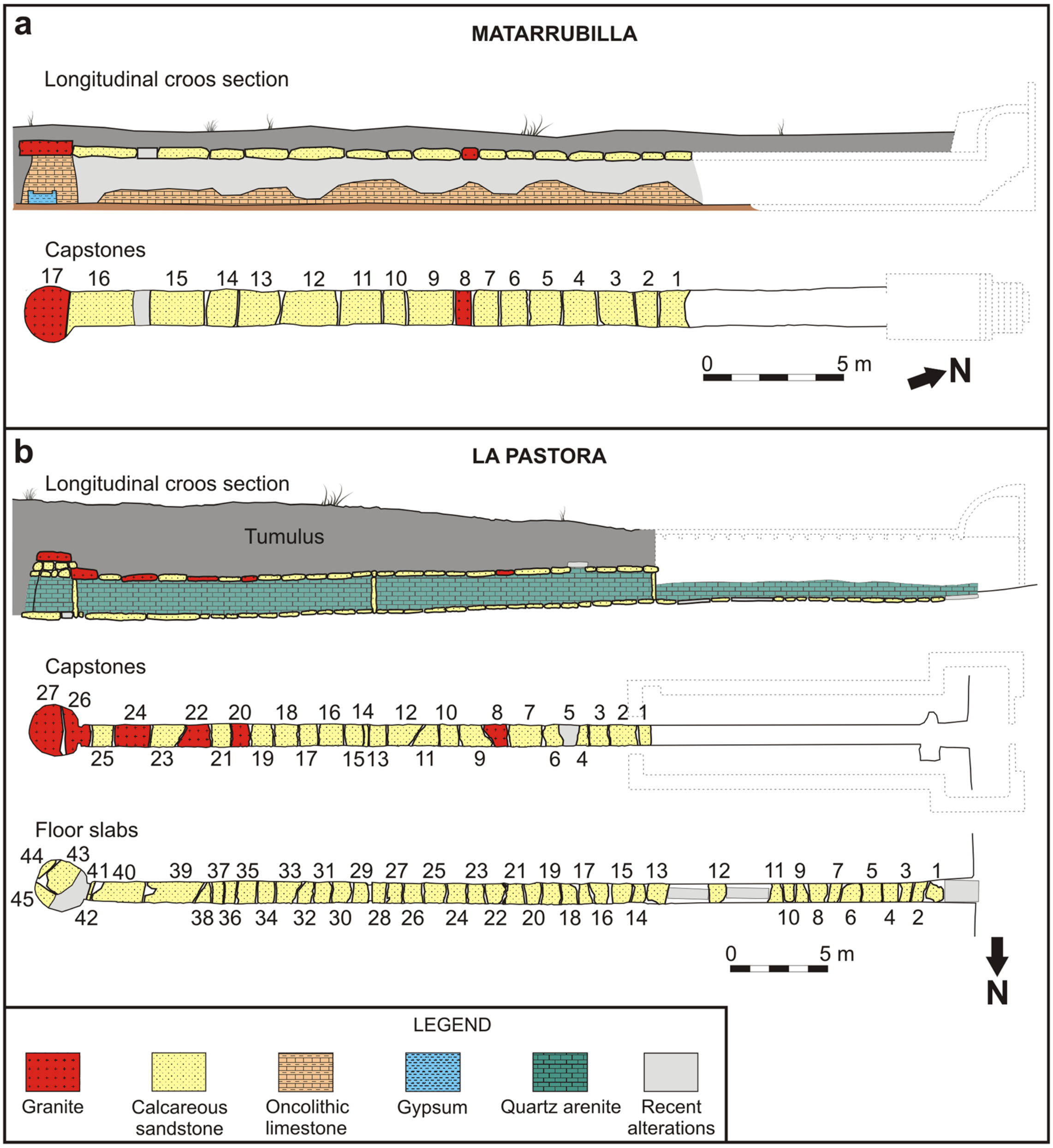

Fig. 2 Longitudinal cross sections and plans of the tholoi of Matarrubilla (**a**) and La Pastora (**b**), indicating the lithology of their constructive elements and numbering of capstones and floor slabs of the monuments. The dashed line draws the current buildings of access to monuments

structures that involve the destruction of the consolidated substrate, whether biogenic (shells, bones, amber, coprolites) or non-biogenic (rocks) substrate (Bromley 1970; de Gibert et al. 2004; Neumann 1966).

The main physical processes that modify the aspect of sediments are currents. These can provoke an ordering of materials (by grain size or lamination), dig channels leaving surface grooves, generate erosive features or depositions around and behind obstacles, as well as drag larger objects that erode the substrate (Reineck and Singh 1980). These physical structures can subsequently be observed on the original surface of the strata in the form of concave or convex epireliefs as in the case of biogenic structures (Fig. 3). They can also be observed at the bottom of strata above them in the form of casts (equivalent to concave or convex biogenic hyporelief structures).

Furthermore, these sedimentary structures can take on dimensions and concentrations conferring the rock unique textural (“aesthetic”) features. These features do not go unnoticed to profane eyes and even less to those looking for stone materials to build major monuments, as musts have been the case for the inhabitants of the lower Guadalquivir Valley in the third millennium BCE.

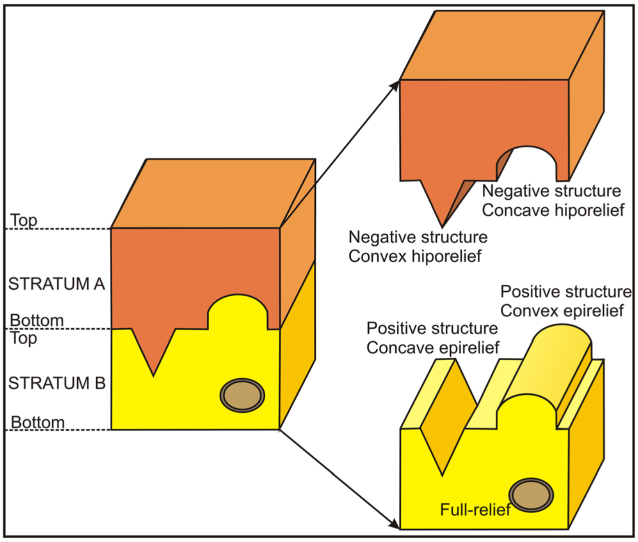

Fig. 3 Scheme of biogenic structures in stratified sedimentary rocks including those produced by currents in or on the surface of strata

Materials and methods

Among the most significant natural structures of the two *tholoi* studied here are those associated with calcareous sandstone blocks. They make up most of the capstones of the Matarrubilla and La Pastora passages, including jambs, lintels, and floor slabs as well as the upper blocks in the chamber of La Pastora. Detailed observations of the potential structures on the surface of its floor slabs, nonetheless, have not been carried out as the monument receives many visitors and the earth covering the floor, although a hindrance to observation, protects it.

This rock belongs to the regional "Transition Facies" geological unit deposited during the Upper Miocene in a marine environment (Mayoral and González 1987). Outcrops of this rock are common in the vicinity of Valencina and stretch several kilometers to the south. Our study reveals the use of specific rocks in remarkable elements of the megalithic architecture, as is the case with the monolithic gypsum basin in the chamber of Matarrubilla, or the use of different rocks following an apparent pattern, as is the case with the capstones of calcareous sandstone and Palaeozoic granite in the roofing of the tholoi.

Observation and description

In this investigation, we have used geological analytical methods from sedimentology, paleontology and petrology. Physical and biological structures in the calcareous sandstones were identified by means of macroscopic observation. Such structures were described, photographed, and measured in their main parameters: length, breadth, and depth/elevation (Table 1). The position of each structure or feature on its slab was recorded and then mapped in the various plans produced for the tholoi (Fig. 2). The inner cartography of each monument was obtained by means of a survey with terrestrial laser scanning (TLS) technology coupled with high-resolution photographs taken with a 24.3Mpx Nikon D750 camera provided with a Nikon AF-S 1.4 Nikkor 50 mm lens and aided by a Canon Ixus 170. TLS data points were edited and processed with the CAD software (Autocad 15) and redrawn with CorelDraw X3.

Identification

Once recorded, all sedimentary features were identified through comparison with examples already published in the specialized literature, such as Allen (1970, 1982), Collinson et al. (2006), Potter and Pettijohn (1963), or Reineck and Singh (1980) for current features, and Bromley (1970, 1990), Buatois and Mangano (2011), Donovan and Hensley C, (2006), and Seilacher (2007) for biogenic ones. Other structures such as those caused by dissolution and water were identified on the basis of the work by Gutiérrez and Ibáñez (1979). Although the methodology used for the lithological characterization of the rocks used in the architecture of both monuments was already described in previous publications (Cáceres et al. 2014, 2016), a complementary study using a Nikon Eclipse LV-100 POL petrographic microscope was in some cases necessary to corroborate each type of rock.

Statistical analysis

Once identified and mapped, the features and structures present in each slab of Neogene sandstone were counted, excluding lithological elements, which have their own peculiarities. Maximum densities were then estimated for the most abundant features and a relative frequency analysis calculated for all three frequency groups: (R) rare (less than 5 structures), (C) common (from 5 to 10), and (A) abundant (more than 10) (Fig. 15). This type of frequency analysis is often used in ichnology studies (e.g., Buatois and Mangano 2011; Muñiz 1998).

Results

Bioturbation structures

The main bioturbation structures present on the surfaces of the calcareous sandstone blocks of the two Valencina *tholoi* studied here (parameters in Table 1) are as follows:

Ophiomorpha nodosa **(Lundgren 1891)** A system of simple or complex burrows with regular or irregular external knobby

Table 1 Inventory of sedimentary structures and their maximum measurements in the rocks of La Pastora and Matarrubilla *tholoi*. The numbers correspond to those of the capstones and floor slabs of Fig. 2

Structure		La Pastora			Matarrubilla	Measurement (cm)		
		Floor	Ceiling	Others	Ceiling	Depth or elevation above the rock surface	Length	Diameter or width
Ophiomorpha	Circular section	1, 4, 5, 6, 10, 22, 24, 25, 28, 33, 38	1, 2, 3, 4, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 21, 23, 25	IJ, CJ	3, 4, 5, 6, 9, 10, 14	1		5
	Longitudinal section	4, 10, 11	1[e], 3[e], 4[e], 7[e], 12, 14[e]	IJ, CJ, SB		0.6	80	
	Funnel-shaped apertures	13, 45				4		9.5
Scolicia–Cardioichnus			16			2–2.8	110	6–8
Groove cast		33	13		4, 6, 7, 11	5	75	8
Bounce casts		5		CJ[N]	4, 6, 7	0.6	18	1.5
Flute cast				CJ[N]	4, 11	0.8	10	5
Obstacle marks	Current shadows or scour remnant ridges	33, 38			3, 5	4 (*Op*) 1.5 (Is)	60 (*Op*) > 100 (Is)	6.5 (*Op*) 10 (Is)
	Current crescents	24, 28				3.8	34	8.6
Gastrochaenolites			6, 9[e], 10, 12[e], 13, 14, 15, 16[e], 17, 19[e], 23[e], 25	CJ, SB		8		1.5
Bioconstructions		21, 24, 30, 31, 39	12, 13, 17	CJ, SB	11, 15			
Physical-chemical erosion marks					1, 13	0.5 (Sg) > 8 (Dh)	> 100 (Sg)	1.5 (Sg) 10 (Dh)

IJ intermediate jambs, *CJ* door chamber jambs (both), *CJ*[N] northern jamb of the chamber, *SB* sandstone blocks of the chamber wall, *Number*[e] structure in transverse faces of the stone measurement (maximum observed), *Op* structure with Ophiomorpha as obstacle, *Is* incomplete structure without head (obstacle), *Sg* sinuous grooves, *Dh* dissolution holes

(pellets) walls caused by decapod crustaceans (e.g., *Callianassid thalassinidean*) (Bromley and Frey 1974). The features take on the form of vertical or sub-vertical cylindrical tubes with circular cross sections and funnel-shaped apertures. The pelletized walls are harder than the encasing layer and were subsequently backfilled with sediment that sets itself apart from the surrounding material by its grain size and color. These are the most common natural structures of the two monuments (Table 1) and appear for the most part in the form of circular transversal sections. On certain slabs, their abundance is striking (Fig. 4a).

On the other hand, *O. nodosa* appear as hollows or cylindrical tubes in certain longitudinal sections transversal to the stratum. This type is less common as most of the visible faces of the slabs correspond to original stratigraphic surfaces. However, they are visible on certain jambs, lintels, and upper slabs of the walls of La Pastora's chamber (Fig. 4b).

It is worth highlighting the special case of *Ophiomorpha* that resemble anthropic cup marks. This is the case of La Pastora's floor slab 13 (Fig. 4c) covered by 26 perfectly conserved concave epireliefs characterized by funnel-shaped apertures on a stratum top. Two identical structures are also on floor slab 45 of the chamber.

Scolicia **(Quatrefages 1849)-*Cardioichnus*** **(Smith and Crimes 1983)** A system of traces resulting from relocations linked to grazing (*Scolicia*) and rest (*Cardioichnus*) of equinoderms echinoids (Belaústegui et al. 2017). The oval shape of *Cardioichnus* coincides approximately with the outline of sea urchins and is usually preserved as a convex hyporelief. *Scolicia* usually appear as bilobed or trilobed meandrical forms conserved in epirelief or concave hyporelief.

This type of structure is present on capstone 16 of La Pastora (Fig. 5) in the form of convex hyporelief (*Scolicia*) extending along most of the stone's surface, parallel to the passage's axis. The end facing the monument's chamber is oval (*Cardioichnus*) and projects slightly above the other parts of the structure.

Sedimentary structures resulting from currents

Groove casts are rectilinear negative top structures (convex hyporelief) ranging from a few millimeters to a few meters in length that correspond to the dragging of larger objects or coarser grains by currents (Kuenen 1957). Their cross sections are semi-cylindrical or irregular with striations or small impact marks of other fragments. They are at times arranged in twisted "corkscrew" patterns (Collinson et al. 2006) resulting from

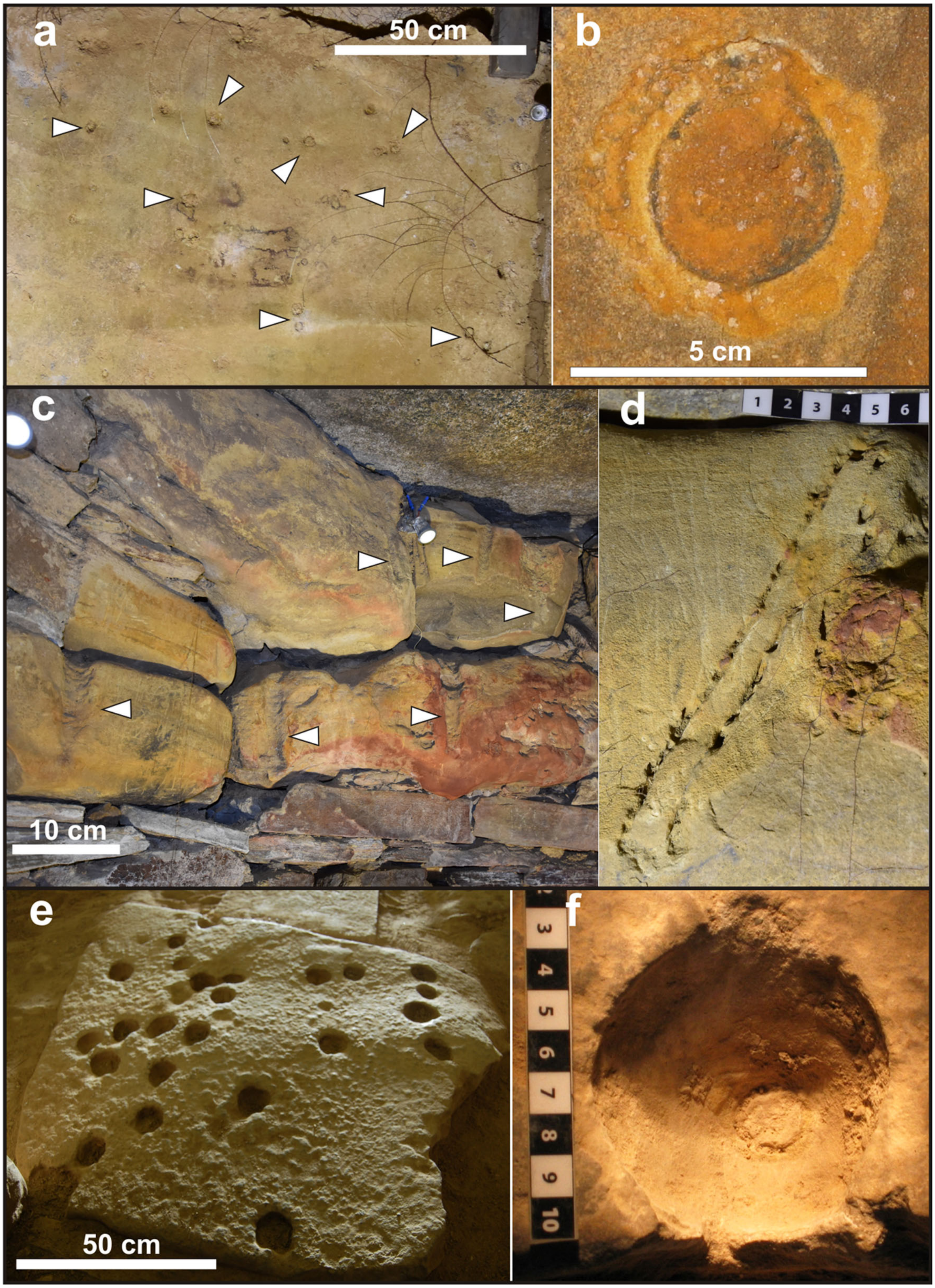

Fig. 4 *Ophiomorpha nodosa* in Matarrubilla and La Pastora. **a** Matarrubilla, view from below of capstone 6 bearing numerous transversal sections. **b** Detail of a cross section. **c** Lateral view of La Pastora chamber with several longitudinal sections on the calcareous sandstones. **d** Detail of a longitudinal section (scale: cm). **e** *O. nodosa* of La Pastora floor slab 13 that resemble cup-shaped. **f** Detail with a central biogenic tube (scale: cm)

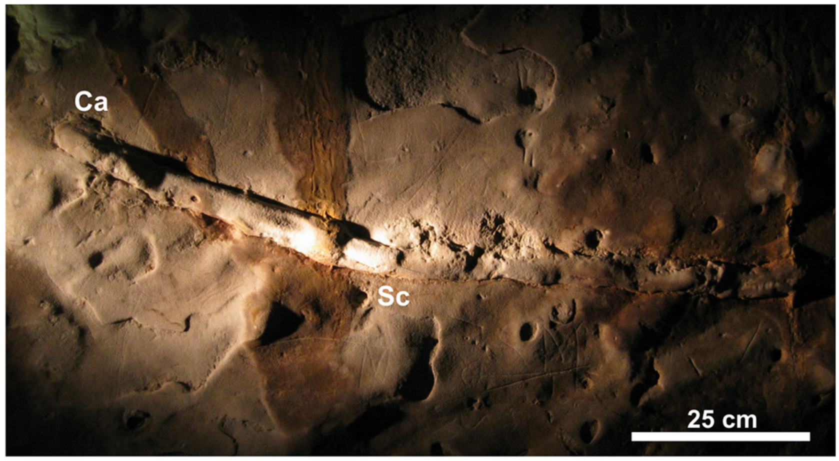

Fig. 5 View from below of La Pastora's capstone 16 with a composite system of *Scolicia* (Sc)-*Cardioichnus* (Ca)

the rotary motion of fragments transported by helicoidal currents. The examples on Matarrubilla's capstone 4 are noteworthy (Fig. 6) as they correspond to two U-section parallel grooves on which other marks in oblique directions are superimposed, conferring them a peculiar corded shape. The oblique marks result from thicker fragments being dragged by helicoidal currents.

Bounce casts are negative top structures corresponding to infills of marks caused by impacts and rebounds of objects dragged and pushed by water currents (Potter and Pettijohn 1963). They are characterized by an elongated (centimetric), narrow, and discontinuous morphology. Matarrubilla's capstone 4 (Fig. 6) bears structures of this type both in the previously described groove and its surroundings. All follow the same direction, slightly oblique as to the main groove, and are the product of helical currents.

Moreover, on the inner face of the northern jamb of La Pastora's chamber is a structure corresponding likely to the impact cast of a heavy object (Fig. 7). This object, about 8 cm

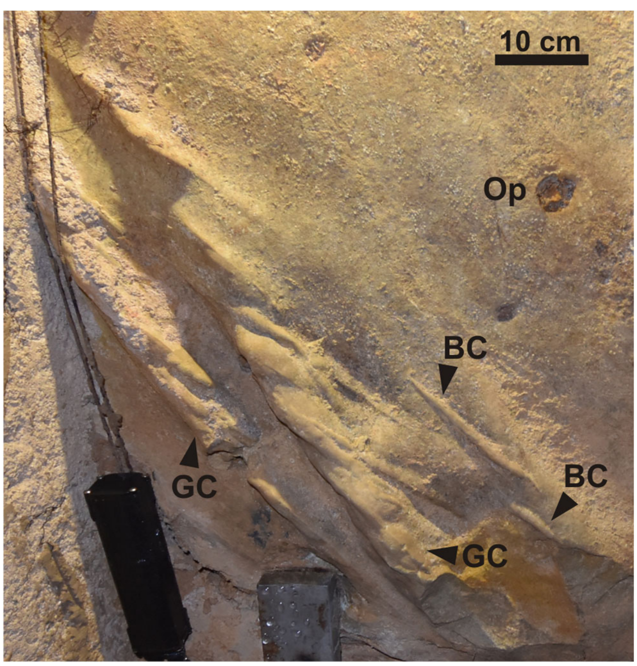

Fig. 6 Slightly oblique view from below of capstone 4 of Matarrubilla with two groove casts (GC) with corded morphology resulting from the impact of objects (bounce casts, BC) generated by helicoidal currents; *Ophiomorpha* (Op)

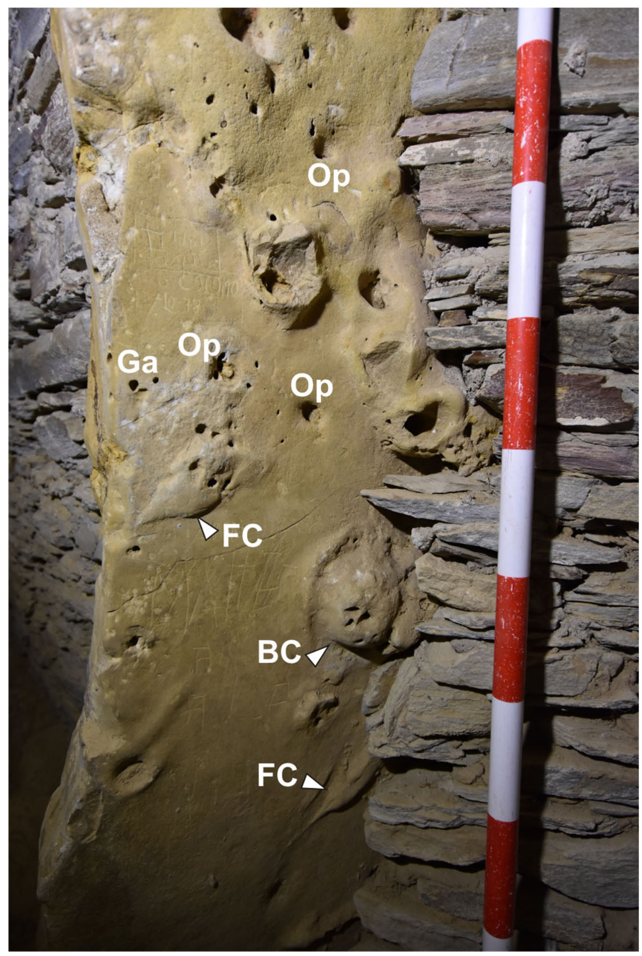

Fig. 7 Internal face of the north jamb of the access to the chamber of La Pastora. Several primary structures are observed such as flute casts (FC), bounce casts (BC), and *Ophiomorpha* (Op). The smallest borings correspond to bioerosion structures (*Gastrochaenolites*, Ga) (scale: dm)

in diameter, may have impacted the soft bottom producing a small crater-like depression before bouncing and being transported away by the current. This feature is the infill of the depression surrounded by slightly elevated edges of the impact.

Flute casts correspond to elongated discontinuous grooves aligned with the flow of the current. Single or in groups, they are characterized by one well-marked extremity and another that progressively attenuates before disappearing downstream (Potter and Pettijohn 1963). They are generated by turbulent currents with strong vortices that remove the underlying sediment before progressively losing force downstream. These currents yield a triangular cast (convex hyporelief) that opens in the direction of the paleocurrent.

Although difficult to distinguish, and masked by other structures, marks of this type appear on the capstones of Matarrubilla (Table 1). They are also present on the northern jamb of La Pastora, on the surface facing the chamber (Fig. 7).

Obstacle marks: current shadows or scour remnant ridges and current crescents They are sediment mounds (convex epirelief) that develop behind an obstacle, according to the flow of the current. They correspond either to accumulations (current shadows) or remnants protected from general erosion by the current (scour remnant ridges) (Allen 1970, 1982). In any case, the morphology of the mound is analogous, with an elongated shape that progressively narrows down and shrinks, ending in a point downcurrent. The obstacles can be single rocks, shells, bones, or structures of biological origin. The latter may correspond to chimneys of *Ophiomorpha* in which the pelletized reinforcement of the walls of the burrows can originate small superficial protrusions that are more resistant to the erosive action of the currents.

Excellent examples can be found on Matarrubilla's capstones 3 and 5 (Table 1). The first of them (Fig. 8) has more than 25 obstacle marks, all with the same orientation and all of the whole examples are in association with Ophiomorpha in their headers, a situation that is exceptional even in the geological domain.

Capstone 5 reveals a group of large-sized structures of this type (Fig. 9). The larger marks do not show their heads, as they are all beyond the limits of the stone, rendering it impossible to identify the obstacles that generated them. On the other hand, there is another positive structure (convex epirelief) that crosses the main group at an angle of about 62°. This gives the impression that the elevation somehow reactivated the crests progressing toward it and that at this point rose again, perhaps forming a new obstacle to the current.

Current crescents (Peabody 1947) are analogous to the previous structures. In this case, besides the ridge on the protected side of the obstacle (convex epirelief), the current produced a U-shape (concave epirelief) excavation around it. The arms of the U are oriented in the sense of the flow, enfolding the obstacle and the ridge (Allen 1982).

Floor slabs 24 and 28 of La Pastora bear a series of small depressions oriented and connected with *Ophiomorpha* (Fig. 10). These structures are similar to those of Matarrubilla but in negative relief (concave hyporelief). They display clear elevated U-shaped borders around their depressions that are more pronounced on slab 24. Hence, they are identified as casts of current crescents around *Ophiomorpha*. Thus, since they are casts, the protruding U-shaped ridges would correspond originally to the hollows dug by the current around the obstacle and the intermediate depression would be the ridge behind it.

Bioerosion structures

Of the two *tholoi* under study, bioerosion structures are only identified on the calcareous sandstones of La Pastora. A detailed description of these structures, defining their marine nature and significance, was made in Cáceres et al. (2014). Here, we will focus exclusively on the most exceptional cases.

***Gastrochaenolites* (Leymerie 1842; Donovan and Hensley 2006)** They are small vertical or slightly inclined clavate borings in the rock by lithophagous bivalves as habitation structures. Their cross sections vary from heart-shaped to circular while their longitudinal sections are teardrop-shaped. Their size at La Pastora varies (Table 1) (Fig. 11) with the greatest concentration (285 boring/m^2) on capstone 6 (Cáceres et al. 2014). It is common to observe these structures on one or two sides of the sandstone blocks, which indicates exposure of more than one side of these blocks during the bioerosion. In general, it is uncommon for the trace maker to be present in the boring. Among La Pastora's sandstones, nonetheless, they are often well-conserved and can be identified as *Petricola lithophaga* Retzius (Cáceres et al. 2014).

All the above, together with other bioerosive features affecting these rocks, suggest that this material was quarried at a rocky coastal environment exposed to tides where the rocks were naturally shaped as blocks (slabs) (Cáceres et al. 2014). C^{14}–AMS dating of some examples of *P. lithophaga* yield ages ranging between 5460 and 4300 cal BP (3510–2350 years BCE) suggesting a post quem date for the quarrying of this material and the construction of the monument. Subsequently, a Bayesian modelling combining these radiocarbon dates with others obtained from samples of human bone (two) and perforated shell bead (one) revealed that the activity within La Pastora began in 2755–2465 cal BCE (95% probability), probably in 2615–2480 cal BCE (68% probability), and ended in 2485–1360 cal BCE (95% probability), probably in 2435–2035 cal BCE (68% probability) (García-Sanjuán et al. 2018).

Fig. 8 Capstone 3 of Matarrubilla with obstacle marks consisting of current shadows or scour remnant ridges. **a** View from below. **b** Oblique view highlighting the relief. **c** Details of the structures with *Ophiomorpha* (Op) as obstacles. **d** Detail of the relief of the marks and interaction between two structures (triangle)

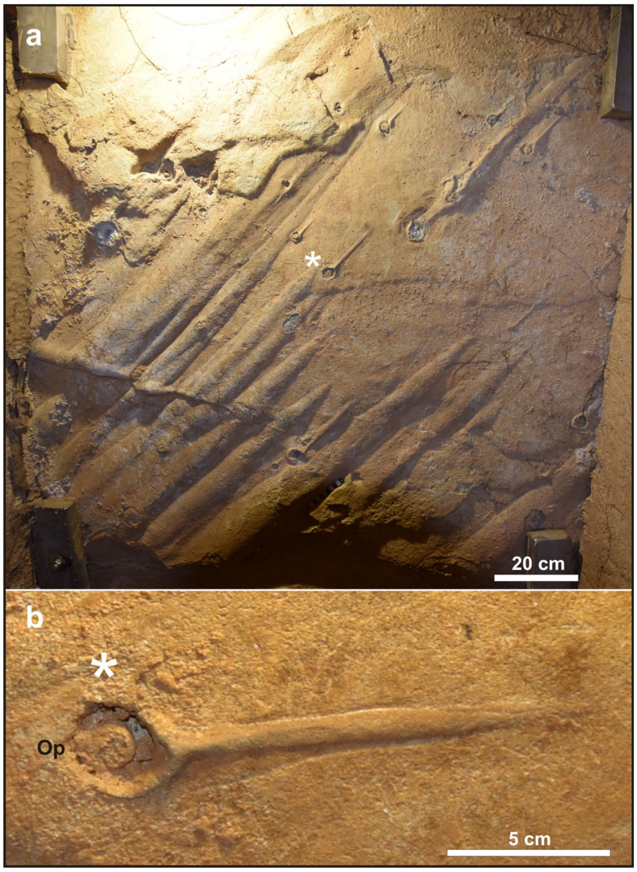

Fig. 9 Capstone 5 of Matarrubilla with large obstacle marks. **a** General view from below of the ceiling with structures produced by currents. **b** Detail of a smaller complete structure

Other elements

Next, we will highlight other natural elements (geological and biological) present at La Pastora and Matarrubilla that may correspond to ornamental elements.

Bioconstructions At La Pastora, there are several calcareous sandstone blocks that bear attached colonies of epilithicbiont organisms (Taylor and Wilson 2003), including the bivalve *Ostrea edulis* Linnaeus. These colonies respond to the same environmental and temporal characteristics as bioerosion (Cáceres et al. 2014). Most bioconstructions are visible on floor slabs 24 and 21 (Fig. 12). The first comprises a colony with 32 individuals cemented between themselves and to the rock that are disarticulated and in life position. Despite their position on the floor, their conservation is good as they occupy the less trodden areas along the monument's wall. Other less dense and less visible bioconstructions are identified elsewhere at La Pastora (Table 1) and at Matarrubilla.

Physical-chemical erosion marks Non-biological erosive marks are not common, at least not on the visible faces of the monuments under study. Thereby, little dissolution cavities are detected on the lower face of Matarrubilla's gypsum "basin" (Fig. 13b). However, capstone 13 bears converging or parallel sinuous grooves that practically cross its entire surface (Fig. 13a). In addition, capstones 1 and 13 of Matarrubilla also present circular-section holes some of which extend irregularly toward the interior of the rock. All of these features result from the dissolution of the sandstone's carbonate cement by running water. Their smoothed edges are characteristic of dissolution under a shallow soil. Thus, these capstones could hail from a small initial and slightly developed karren given the rock's low percentage of carbonate (Gutiérrez and Ibáñez 1979).

Lithological elements The different rock types of the *tholoi* carry out different constructive functions (Cáceres et al. 2016). It is nonetheless important to highlight certain other interesting aspects:

– The lithology of Matarrubilla's 'basin' (Fig. 13b). It is a large and compact block of alabaster type gypsum, as described above. The only other example of this rock at the site is a block currently placed at the entrance of Matarrubilla whose original position and purpose remain unknown. This is therefore an "exotic" lithology within the context of Valencina.
– The use of different rock types for the roofing of the tholoi. In Matarrubilla, all capstones are made of calcareous sandstone except two granite stones: numbers 17 (the large capstone of the chamber) and 8 (Fig. 2). The latter, placed approximately halfway through corridor, is the smallest stone in the monument (57 cm wide) and has rounded edges (Fig. 14a). La Pastora, by contrast, is roofed by six granite capstones and 20 calcareous sandstones. The eight closest to the chamber (numbers 19 to 26) alternate between the two rock types (Fig. 2). Capstones 1 to 19, by contrast, are all sandstones except 5 and 8. Capstone 5, in fact, does not follow the scheme and possibly served to cover the makeshift access used to enter the monument at the time of its discovery in the 1860s (Vargas et al. 2019). Slab 8 is a granite that differs from the other granites in that about 18% of its volume (the extremity toward the exit) is an aplite dike (Fig. 14b) with finer grain and whitish hue. The limit between the aplite and the granite is clear and rectilinear, perpendicular to the monument's passage.

Discussion

Having described the natural elements and structures observed at La Pastora and Matarrubilla, we now turn to the discussion

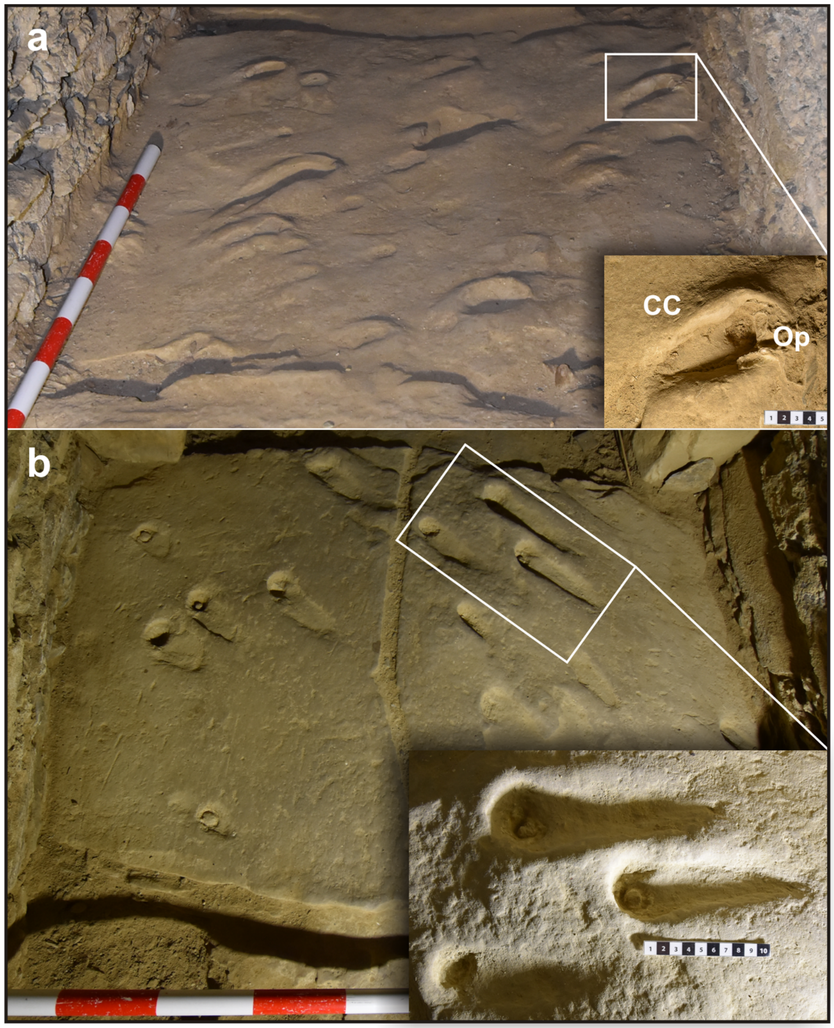

Fig. 10 Floor slabs 24 (**a**) and 28 (**b**) of La Pastora with casts of obstacle marks. Oblique views of the slabs (scale: dm) and details of structure systems *Ophiomorpha* (Op)-Current Crescent cast (CC) (scale: cm)

of their location, relative frequency (Fig. 15) and potential significance.

The most common bioturbation structure corresponds to transversal cross sections of *Ophiomorpha nodosa* "circles" visible on the calcareous sandstones that differentiate themselves by their coloration and texture. Thus, "circular" forms appear constantly in both monuments (Fig. 15).

The sandstones of the upper rows of La Pastora's corbeled chamber are arranged so that up to 14 longitudinal sections of *O. nodosa* are visible in way of vertical "cylindrical hollows" (Fig. 4). Meanwhile, the protruding frontal sides of the chamber's jambs also present "cylindrical" structures in more or less horizontal longitudinal sections. The structures appear in the same manner on both jambs, emphasizing even more, if possible, the framing to the entrance of the *tholos* chamber. This arrangement could well have an aesthetic or symbolic purpose, even more so as the surfaces facing the chamber bear numerous natural structures such as flutes, bounce casts, *Ophiomorpha* and bioerosion (Fig. 15).

Another case of *Ophiomorpha* is found on La Pastora's floor slab 13, with circular depressions densely packed on the surface. These features have usually been interpreted as anthropogenic cup marks (ACAM 2002; Ruiz 2013). Yet, their biogenesis is evident as at the bottom of each cup there is the annular shape corresponding to the entrance of *Ophiomorpha* burrow. Although they cannot be attributed a specific function in the monument, it is unquestionable they held an aesthetic value.

In the remarkable system of traces *Scolicia-Cardioichnus* on La Pastora's capstone 16 (Fig. 5), it is again greatly significant that the face of the stone bearing the traces (in fact the casts of the traces) was placed toward the interior of the monument rendering them visible to its visitors.

A similar situation is that of the imposing current marks (groove and bounce casts) on Matarrubilla's capstone 4. These last marks all point in the same direction forming an angle of (roughly) 40° with the northern wall toward the interior of the monument (Fig. 6). In turn, on capstones 3 and 5, probably the

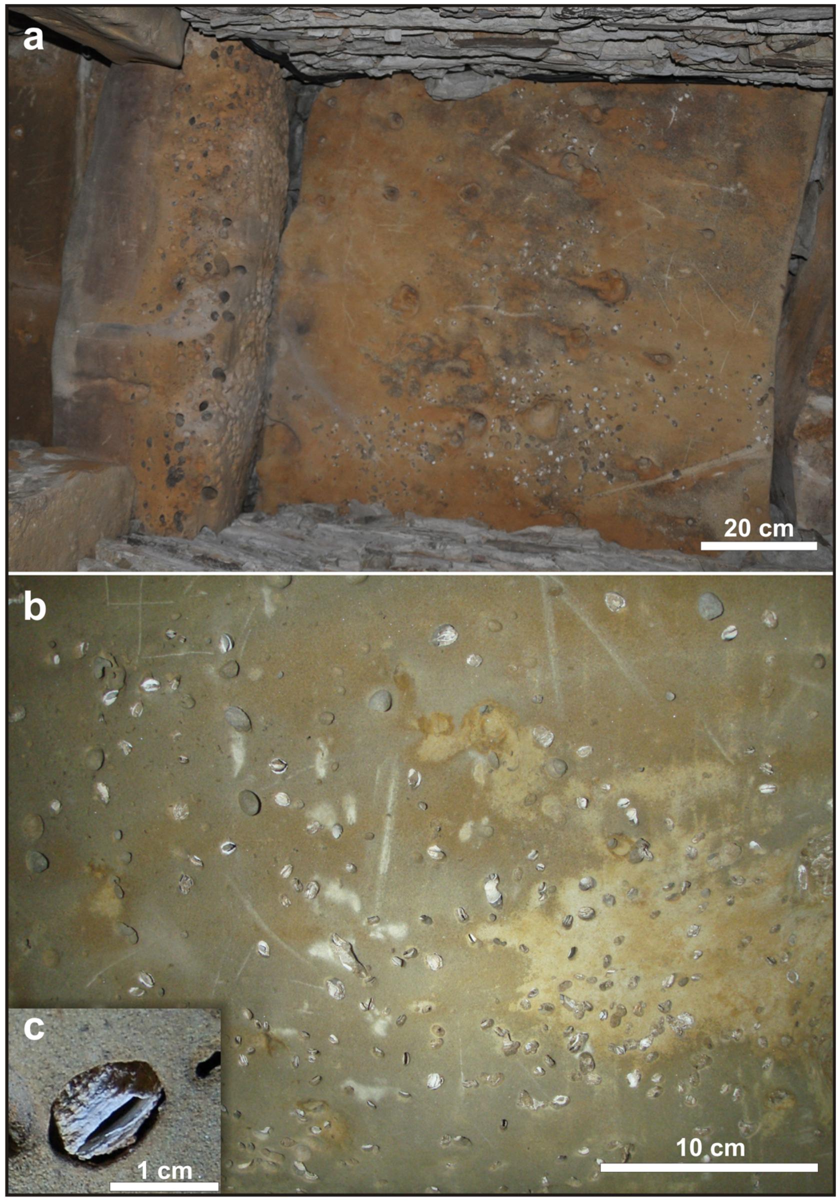

Fig. 11 Bioerosive structures (*Gastrochaenolites*) on calcareous sandstones. **a** View from below of La Pastora lintel 14 and capstone 15. **b** Same view of capstone 17 highlighting the contrast between the color of the rock and the lithophagous bivalves inside the *Gastrochaenolites*. **c** detail of a *Petricola lithophaga* preserved in situ in a *Gastrochaenolites*

most spectacular ones of the whole assemblage (Fig. 8), the numerous obstacle marks (Fig. 15), result in very marked positive reliefs, all of which bear a lanceolate shape (pointed elongations), a shape that leads them to be popularly referred to as "swords." Their orientations differ on both stones. On capstone 3, they point outwards forming an angle of 18° with the southern wall, whereas on capstone 5 they point inwards forming a 35° angle with the northern wall. This suggests, therefore, that orientation is not related to the positioning of the marks on the monument's ceiling. Yet, what is worth highlighting, once again, is that all structures are placed to so that the protruding relief (convex) can be seen from the interior of the monument, in way of bas-relief. This situation implies that, while capstone 4 (casts) is placed like those of the original rocky outcrop, slabs 3 and 5 (not casts) were deliberately turned over from their original position when they were placed in the monument. On the other hand, the current structures observed in the floor of La Pastora (Fig. 10) are mostly casts or negative reliefs (concave hyporeliefs). Therefore, they were also turned over from their natural position.

Another element worth highlighting is the morphology conferred to the bioeroded blocks of La Pastora resulting from the high concentration of small borings (Fig. 15). Those on the lintel of the intermediate portal are the largest and appear on the faces oriented toward the chamber and the floor. Noteworthy are also the capstones characterized by many bivalves in their minute chambers. These bivalves are white, while the encasing rocks are of darker yellow-orange hue. Hence, when observed as a whole, the

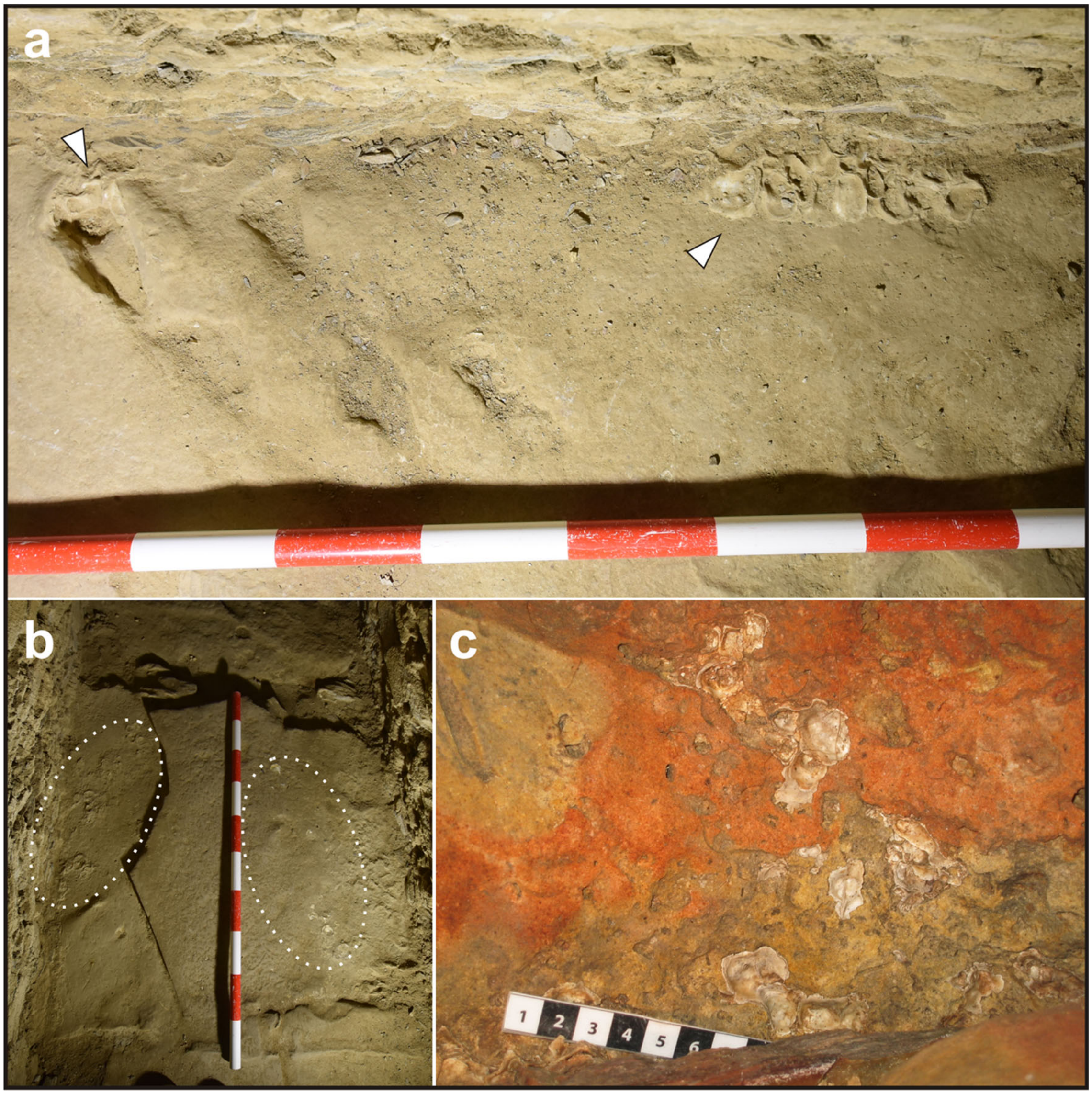

Fig. 12 Ostricide bioconstructions on floor slabs 24 (**a**) and 21 (**b**) of La Pastora (scale: dm). **c** Bioconstruction on the upper blocks of the chamber wall (scale: cm)

bivalves stand out as a broad set assemblage of white points on a darker background. It is tempting to suggest its resemblance to a "starry sky." This arrangement also involved slabs being turned over (Cáceres et al. 2014).

The bioconstructions on the floor slabs are hardly visible due to the passage of time and visitor trampling. Yet, their contrast with the rocky background must have been very obvious during the erection of the monument. It is worth noting that the builders seem to have preserved them deliberately, as their removal would have been a relatively simple task. Perhaps they wanted to leave "samples" on the building materials of these organisms, well-known to the builders and a conspicuous representation of the value they attached to the marine environment. These features could represent a claim to the surrounding territory and its persistence over time connected to the group or individual that raised the monument. In any case, an unambiguous testament to the strong bond of Copper Age communities with the sea are the *Pecten maximus* shells used as grave goods (Liesau et al. 2014) or the tens of thousands of marine shell perforated beads decorating the spectacular attires worn by the women buried in Montelirio's large chamber (Díaz-Guardamino et al. 2016).

The dissolution marks of capstones 1 and 13 of Matarrubilla were generated in an environment with surface running water and are, as in the case of bioerosion, contemporary to the extraction of the slabs for the construction. Once more, it is necessary to emphasize that the slab was deliberately placed in the monument upside down with respect to its original position at the outcrop.

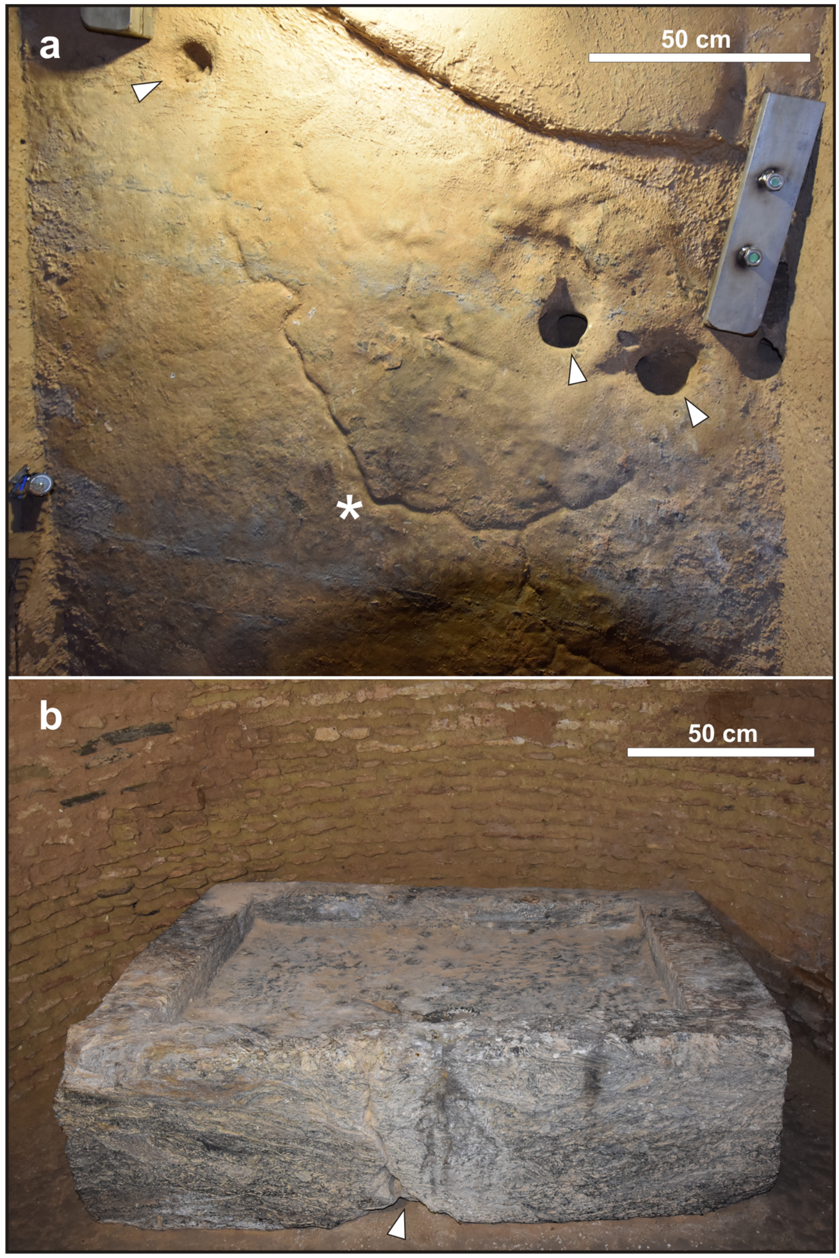

Fig. 13 View from below of capstone 13 (**a**) and "basin" (**b**) of Matarrubilla. Structures resulting from physical-chemical erosion: sinuous grooves (asterisk) and dissolution hollows (triangles)

Figure 15 shows the distribution and relative frequency of all biogenic structures, currents, dissolution, and bioconstructions in the tholoi. Thus, at Matarrubilla, the highest concentration of features appears between capstones 3 and 7. From capstone 8 (the intermediate granite slab) inwards, features become far less abundant and varied. Therefore, it would seem that capstone 8 marks the separation between two discrete segments along the monument's corridor. La Pastora, on the other hand, follows a different pattern. Here, the highest and most diverse concentration of features can be seen in the intermediate segment of the corridor and more specifically on both sides of the lintel. However, it should be noted that the first segment of the roof of La Pastora is not covered and we do not know if it was originally. Furthermore, it is also worth noting that on both jambs to the chamber there is a high concentration of features, especially on the sides facing the chamber, and on the northern jamb. Finally, the arrangement of features on floor slabs appears to be less patterned although, as was mentioned above, their detailed study is problematic under current conditions. It is worth noting the presence of remarkable features in the first segment (slabs 4 to 11), the higher variety on slabs 24 and 33 (placed at the same distance from the intermediate portal), and the roughly coincident use of bioconstructions around said portal here and the roof. Therefore, although the distribution and frequency of features in both monuments seems to

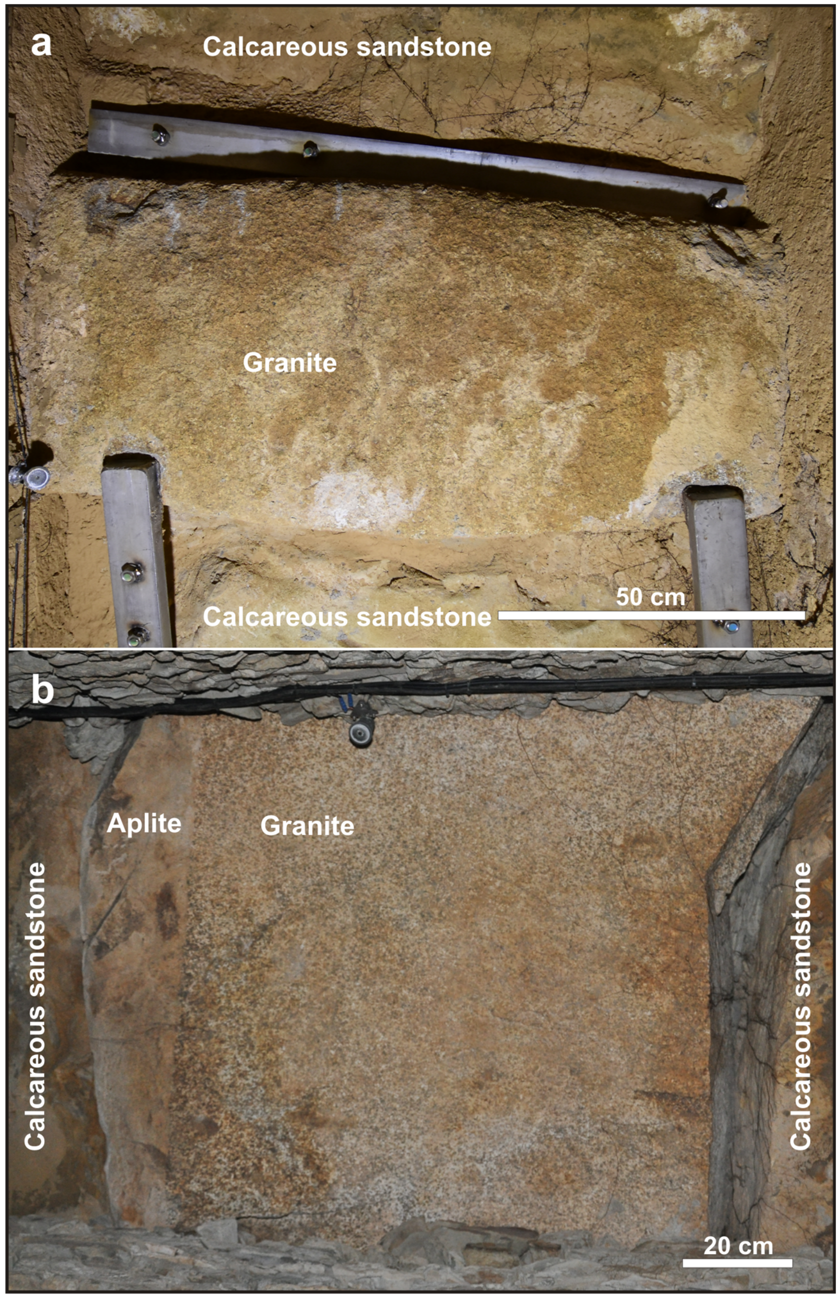

Fig. 14 Views from below of the granite capstone 8 of Matarrubilla (**a**) and La Pastora capstone 8 (**b**). The first is characterized by a regular quadrangular shape with rounded angles while the second reveals the contrast between the granite and aplite dike (left)

suggest some possible patterns, it is unclear to what kind of specific symbolism the may have responded. Therefore, although the distribution and frequency of features in both monuments seems to suggest some possible patterns, it is unclear to what kind of symbolism the may have responded. In our view, however, it is undeniable that these geological features were used consciously by the builders of the megaliths, either as "aesthetic" decoration or because of their symbolic value, or both.

Regarding the different rock types, it is necessary to review some aspects that go beyond simple constructive functions.

The "basin" of Matarrubilla is made of crystalline gypsum, a material not available in Valencina's surroundings. This "exotic" lithology was, therefore, very special. In addition, although it is relatively easy to work, it is worth asking whether that alone justified its transport from at least 50 km to the east, at the other side of the marine gulf that at that time occupied what today is lower Guadalquivir Valley (Cáceres et al. 2016). In consonance with its remarkable architectural position, occupying the whole of the chamber space, as well as its likely ritual use (of which nothing is known), it is a very special rock, very different from all building materials used in the monuments raised up until then.

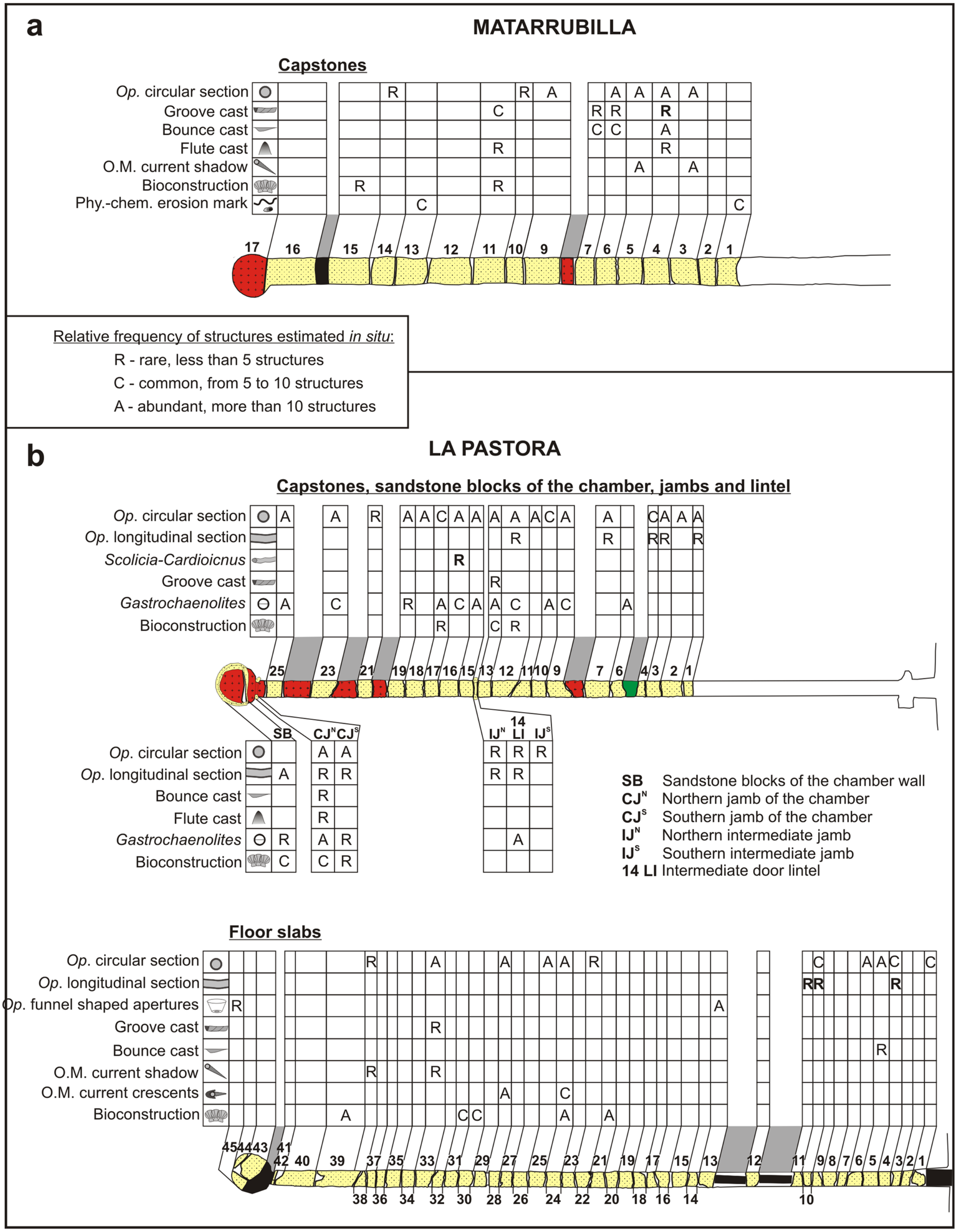

Fig. 15 Distribution and relative frequency of structures in the calcareous sandstones of Matarrubilla (**a**) and La Pastora (**b**). The numbering of the slabs is the same as the one in Fig. 2. Relative frequency in bold are rare (unique) structures but very evident on the slab

Finally, the different rock types chosen for the capstones are not particularly significant if it were not for their apparent order. The choice of granites to cover the chambers of the two monuments is possibly due to its greater constructive stability. Granite is also heavier and more massive than sandstone, and much harder to carve. On the other hand, both *tholoi* comprise sandstone slabs that are sufficiently large and compact as to guarantee a stable cover for the chambers. Therefore, the specific choice of granite for roofing of the chambers could also be due to issues unrelated to architectural function.

This circumstance is even more evident in the passages of the monuments. Matarrubilla has only one granite capstone (Figs. 2 and 14a) placed toward its middle. Its smaller size, homogeneous width, and rounded edges suggest it was reused as is the case of other megalithic sites in southern Spain (Linares and Mora 2015). The reason for its use at that specific point of the monument cannot be linked to purely structural factors, which opens up the possibility of a symbolic use, designating a specific point or segment, which is further suggested by the distribution of geological features as mentioned above.

As has already noted, the last eight capstones leading to the chamber of La Pastora alternate between sandstones and granites (Fig. 2), a feature unprecedented among those southern Iberian megaliths for which lithological characterization of the building materials is available (Carrión et al. 2010; Borja and Borja 2016; Aranda et al. 2017). Although deliberate, the motive of this alternation is not technical. It possibly reflects an intentional aesthetic effect or may have responded to other kinds of choice that could be linked to how the stones converge with the chamber.

A granite capstone also marks the midpoint of La Pastora's inner space, a situation approximately analogous to that of Matarrubilla. This coincidence, worth highlighting, could either be random or respond to similar significance. Yet, this granite block differs from those of the studied megaliths as it features an aplite dike that bestows it with a totally different aspect. This geological feature of contrasting lithologies also undoubted added aesthetic value, as the same block presents two apparently different lithologies. Furthermore, the lithological differentiation is transversal to the passage, with the aplite dike of lighter color oriented toward the monument's entrance while the darker granite is oriented toward the chamber. These features seem to point to the transition from one end to the other of the monument.

Another question to consider is that the illumination technology available in the Copper Age (lamps and torches) would have probably enhanced the symbolic, sensory and even emotional effect of the natural "decorative" motifs on their onlookers.

In light of the above, it is undeniable that the choice of building materials and their position in the *tholoi* resulted from carefully formulated cultural choices taking into account their visual and natural features. This is especially true as certain faces of the blocks bearing natural structures were deliberately placed inwards to be viewed from the passages or chambers. Although not all faces of the blocks were subject to analysis (many of them are hidden under their *tumuli*), the conscious selection of the visible faces by the builders is nonetheless evident from the position of certain bioerosive and biogenic structures, in particular those where the organisms are on one or two perpendicular faces. Deliberate choice is also evidenced by the groove and bounce casts only conserved on one face, specifically at the bottom of the upper layer. Moreover, it is very unlikely that the concentration and magnitude of these forms repeat themselves on the hidden faces of the other blocks.

Conclusions

The discussion presented in the preceding pages lead to a main conclusion, as well as other secondary ones. The main conclusion, as noted above, is that blocks bearing geological structures on their surfaces were deliberately selected and positioned consciously in both of the *tholoi* under study.

The La Pastora and Matarrubilla *tholoi* reveal no evidence of paintings or engravings, elements that are characteristic of Iberian "megalithic art" of the fourth and third millennia BCE, and of which the neighboring Montelirio *tholos*, also part of the Valencina Cooper Age mega-site, is a perfect example (Bueno et al. 2016b). This study provides the first-ever systematic recording and analysis of "natural or geological decorations" in megalithic architecture. Conclusive proof of this are the unusual concentrations of naturally "aesthetic" elements on the surfaces of blocks, for the most part on calcareous sandstones (Tertiary) that served as capstones for both monuments, as well as on floors, jambs, lintels, and upper blocks of La Pastora's corbeled chamber. This analysis classifies these natural structures according to their origin (biological and/or physical) and the moment they were formed, that is, during deposition of the sediment generating the rock or on the rock's surface after its consolidation. The analysis of distribution and frequency of structures in the monuments shows some patterns in this sense, but they are not definitive, especially considering the possible lack of slabs on the roof of both *tholoi* and the difficulties of studying the La Pastora floor.

The use of different lithologies in the *tholoi* appears to go beyond the merely functional and practical. This is evidenced by the choice of "exotic" rocks for singular features such as the gypsum "basin" of Matarrubilla's chamber or the combination of a deliberate alternation of calcareous sandstone and granite capstones at La Pastora. In this sense, careful and specific choices in the selection of lithic resources are also clear when portable stone technology is considered. (García-Sanjuán et al. 2016).

In sum, the different natural structures described above appear to have been intentionally positioned so as to appear on the visible faces of the capstones of both *tholoi* and on the floor slabs of La Pastora. The use of the different rocks does not only follow constructive constraints, but opens the possibility of an aesthetic or decorative use to convey a symbolic message.

The indirect findings of this study are the following:

- There are notable differences between the two *tholoi* studied here and other monuments at Valencina (e.g., Montelirio) along the lines of architectonics and use of "megalithic art" (Fernández et al. 2016) also suggesting of their lack of contemporaneity. The formal differences between these major monuments were probably the result of changing social and ideological environments at different times (García-Sanjuán et al. 2018). Thus, the particular characteristics of these rocks deliberately served to confer the two *tholoi* with more ornate or symbolic features and, perhaps, to differentiate them from those built several generations before, possibly in different social circumstances.
- The observations carried out in this study point clearly to the existence of a pattern of cultural selection of rocks bearing elements linked to marine environments. This link appears to be more intense at La Pastora with the largest concentrations of ostreas and where certain capstones show evidence of bioerosion by lithophagous bivalves. A link with the sea appears to be common at Valencina, as suggested by the importance of marine elements among the worldview of the Copper Age communities that lived across the lower Guadalquivir River Valley.

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Compliance with ethical standards

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

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